IMPROVING WORKING MEMORY IN LEARNING AND INTELLECTUAL DISABILITIES

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IMPROVING WORKING MEMORY IN LEARNING AND INTELLECTUAL DISABILITIES

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The last forty years of research have demonstrated that working memory (WM) is a key concept for understanding higher-order cognition. To give an example, WM is involved in reading comprehension, problem solving and reasoning, but also in a number of everyday life activities. It has a clear role in the case of atypical development too. For instance, numerous studies have shown an impairment in WM in individuals with learning disabilities (LD) or intellectual disabilities (ID); and several researchers have hypothesized that this can be linked to their difficulties in learning, cognition and everyday life.

The latest challenge in the field concerns the trainability of WM. If it is a construct central to our understanding of cognition in typical and atypical development, then specific intervention to sustain WM performance might also promote changes in cognitive processes associated with WM. The idea that WM can be modified is debated, however, partly because of the theoretical implications of this view, and partly due to the generally contradictory results obtained so far. In fact, most studies converge in demonstrating specific effects of WM training, i.e. improvements in the trained tasks, but few transfer effects to allied cognitive processes are generally reported. It is worth noting that any maintenance effects (when investigated) are even more meagre. In addition, a number of methodological concerns have been raised in relation to the use of: 1. single tasks to assess the effects of a training program; 2. WM tasks differing from those used in the training to assess the effects of WM training; and 3. passive control groups.

These and other crucial issues have so far prevented any conclusions from being drawn on the efficacy of WM training. Bearing in mind that the opportunity to train WM could have a huge impact in the educational and clinical settings, it seems fundamentally important to shed more light on the limits and potential of this line of research.

The aim of the research discussed here is to generate new evidence on the feasibility of training WM in individuals with LD and ID. There are several questions that could be raised in this field. For a start, can WM be trained in this population? Are there some aspects of WM that can be trained more easily than others? Can a WM training reduce the impact of LD and ID on learning outcomes, and on everyday living? What kind of training program is best suited to the promotion of such changes?

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Editorial: Improving Working Memory in Learning and Intellectual Disabilities

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The Editorial on the Research Topic

Improving Working Memory in Learning and Intellectual Disabilities

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INTRODUCTION

Working memory (WM) has been defined as a system for temporarily retaining and manipulating information while performing a variety of cognitive tasks (Baddeley, 1986). To date, the crucial role of WM in activities of everyday life (including reading, writing, arithmetic, learning, language-processing, orientation, imagination) has been demonstrated in an impressive body of research. Several studies have shown an impairment in WM in individuals with learning disabilities (LD) or intellectual disabilities (ID, e.g., Lanfranchi et al., 2004; LD, Peng and Fuchs, 2016).

Given its core role in cognition, the feasibility of training WM has emerged in the literature as a crucial issue, with efforts focusing on analyzing whether and how improving WM might affect cognitive processes associated with WM as well. The results have been contradictory so far, however, with some studies finding WM training effective in producing improvements in the trained task, but few reporting transfer effects to allied cognitive processes, and even fewer identifying any maintenance effects, when investigated (see Melby-Lervåg and Hulme, 2013, for example).

Starting from this literature, the aim of the research discussed here is to add new evidence on the direct and transfer effects of WM training in individuals with LD or ID. Several key points have emerged concerning WM training in these particular populations, as summarized in the following paragraphs.

EFFICACY OF WM TRAINING: SPECIFIC OR TRANSFER EFFECTS?

The results of the studies presented in this research topic seem to indicate that WM is trainable in LD and ID, albeit with some differences coming to light depending on the type of training procedures used. All the research articles showed direct effects of the training considered on the WM task directly trained. However, few of these studies explored and demonstrated the stability of these gains over time (Pulina et al.; Orsolini) and only some of them identified transfer effects. The latter effects were only found for some variables (only for certain aspects of memory not directly trained, e.g., Orsolini; Ottersen and Grill; Pulina et al.), and not for all participants (e.g., Costa et al.), and they did not always persist over time (e.g., Orsolini). Similar results emerged from the meta-analysis conducted by Danielsson et al. on the effects of WM training on individuals with ID.

HOW ARE WM PROCESSES TRAINED?

No consensus has been reached as yet on how best to train WM. There is a certain variability in the WM training procedures adopted to date: some studies have proposed activities focusing on a specific domain (as in the case of Pulina et al.); others have taken a multi-domain approach (e.g., Holmes et al.); others again have suggested that the best solution is to combine the two, i.e., practice with verbal and visuospatial WM together with learning new strategies to use in WM tasks (Danielsson et al.). Another interesting approach, proposed here by several authors (Swanson; Garcia-Madruga et al.), is to combine WM exercises within the context of the learning skill needing to be improved (in the cited articles, this was done to improve problem solving and reading comprehension); the idea is to enhance the likelihood of training gains being transferred to other abilities not trained directly.

Another interesting issue regards the attempt to bring WM training to school, providing the training during regular classroom activities (e.g., Traverso et al.; Re et al.; Costa et al.), or asking teachers to monitor and stimulate children to practice the strategies learned during the WM training (as in van der Donk). This is an important aspect because most WM trainings involve individual sessions separately from the normal school activities. But any training needs to be repeated regularly over a certain period of time in order to be effective, and this could prove an organizational problem for the families of children with LD or ID. Practical obstacles could make parents unwilling or unable to ensure that their children attend training programs. The experiences reported in the present research topic testify to the feasibility of organizing activities that focus on WM and executive processes in the context of normal school activities. This is an aspect that appears to be particularly relevant also in terms of the potential effects on academic outcomes.

In the same vein, the study by Pulina et al. examined the feasibility of parents training their children's WM directly, under the supervision of an expert. The results of this first study are encouraging, suggesting that this might be a good way to train children in a more ecological setting. Of course, more evidence is needed in this sense to confirm as much.

Analyzing the literature on WM in children with LD and ID gives the impression that, depending on the etiology of a given deficit, there might be a particular profile of WM impairment, and children might consequently benefit from different training programs that place more emphasis on some aspects rather than on others. Several studies in this research topic indicate that training programs should be adapted to the type of children with which they are used. For example, Ottersen and Grill showed that a group of children with ID benefited more from a cognitive training that lasted longer and involved less demanding tasks than those applied to children without ID. Pulina et al. also demonstrated the efficacy of a training program in which the material was adapted to the cognitive profile of individuals with Down syndrome.

WHO BENEFITS FROM TRAINING?

The findings of the studies reported in this research topic suggest that any training-induced improvement in WM is not homogeneous for all individuals. It seems to depend on several factors relating to the type of training and to certain individual characteristics.

Concerning the type of training, Titz and Karbach (2014) recently suggested that strategic training produced magnification effects (thereby augmenting individual differences), in the memory domain at least, whereas process-based training (focusing on WM and executive functions, for example) promoted compensation effects (thus reducing individual differences, and consequently benefiting lower-performing individuals). The results of the studies described in this research topic are consistent with this view. In the study by Costa et al., for example, a school-based treatment targeting visuo-spatial WM was administered to two individuals with DS for 6 weeks, after which one of them showed good direct and transfer effects, the other only weak direct effects. The two apparently had different baseline WM levels, and the one with a worse WM at the start achieved greater improvements. These findings suggest that training activities could be particularly effective in children with an initially worse performance, which is in line with a compensation effect (see also Holmes et al.).

In contrast, Swanson showed that children with math disability took more or less advantage of a different strategic training depending on their initial level of WM: children performing at a higher level initially improved to a greater extent after the training. In this case, Swanson's results point to an amplification effect of strategic training. Interestingly, Holmes et al. reported larger transfer effects in children with higher baseline IQ levels.

As concerns individual factors, Alesi et al. explored the role of motivational beliefs and showed that a verbal WM training was more effective for a child with an incremental theory of intelligence than for a child with a static representation of intelligence.

Consistently with these results, Morra and Borella suggests that future studies on the efficacy of WM training should consider baseline performance in WM tasks (and possibly other cognitive and motivational variables too) as an indication of an individual's chances of benefiting from training. For instance, it may be that a minimal WM capacity is needed for any training to generate an improvement, or that there is an ideal capacity level (neither too high nor too low) that makes the training likely to work better.

Considering all these aspects, it appears particularly relevant the suggestion advanced by Konen and Karbach to study the intra-individual dynamics of cognitive training data in order to better elucidate which variables make a given type of training the most effective for a given individual.

CONCLUSION

In the light of all the aspects emerging from the papers reported in this research topic, we are convinced that more research is needed to establish how WM can be trained effectively in individuals with ID and LD.

We hope that all the points raised here might be helpful to all those researchers planning to approach the field of WM training in individuals with LD and ID in the future.

AUTHOR CONTRIBUTIONS

All authors listed, have made substantial, direct and intellectual contribution to the work, and approved it for publication.

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OPINION
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Working memory training: from metaphors to models

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A first research wave on working memory (WM) training created an atmosphere of novelty and enthusiasm. Studies carried out with typical or atypical participants in different age ranges showed that training can improve WM efficiency, and the effects of training can transfer to IQ tests and other valued cognitive abilities (e.g., Klingberg et al., 2002; Jaeggi et al., 2008; Borella et al., 2013).

A second wave of research, in contrast, raised problems and criticisms, thus prompting a vein of skepticism. Issues brought to the fore concerned, for instance, adequacy of the control groups, the appropriate analysis of near and far transfer effects, and how to control for task-specific learning (e.g., Shipstead et al., 2012; Melby-Lervåg and Hulme, 2013; Redick et al., 2013).

A third research wave has started perhaps—and anyway, seems to be urgently needed. Current research should focus on clarifying which effects are obtained by which training programs. Training-related gains on tasks typical of daily life or on school outcomes (when children are considered), and their maintenance, should also be explored, as well as the role of individual differences, motivational and contextual factors, as discussed below. Most important, the theoretical framework of WM training research needs to be spelled out more clearly. (See also von Bastian and Oberauer, 2014).

The first wave yielded a wealth of potentially useful results, but most studies were rather atheoretical. Different research groups used different WM measures, such as complex span or *n*-back tasks. Was there a clear rationale for preferring one WM measure over another? Often, training involved a wide range of WM skills and executive functions; were any training components critical in producing the effects? In addition to specific methodological problems, we must consider a possible bias against publishing non-significant results, and potential interest conflicts inherent in carrying out research in collaboration with corporations that sell commercial WM training programs. These considerations point to a need to map the ground more clearly, with respect to which aspects of training produce which effects. However, this operation requires clear theoretical distinctions.

A simple metaphor—the "muscular metaphor"—seems to underlie many first-wave studies: doing WM gymnastics can strengthen the WM system, making it grow like a well-trained muscle; consequently, a larger WM can manage heavier workloads in complex cognitive tasks. Within this simple metaphorical framework, selecting one or another measure of WM is relatively unimportant. Moreover, using an unanalyzed mix of training components is no problem at all; the more varied the WM gymnastics, the more likely that it strengthens the system.

However, this metaphor is unlikely to explain adequately the WM-training benefits. After all, WM is not a muscle, and perhaps the effect of training is not simply to make it grow. Different WM theories might account differently for any training effects. Componential theories (Baddeley, 1986; Logie, 1995) assume that information is copied to domain-specific short-lived stores, coordinated by an executive system; if one assumes a componential theory, then it seems natural to ask whether a training program affects the domain-specific temporary stores or the central executive. Other theories, instead, assume that attentional resources are at the core of WM capacity—although different models, respectively emphasize activation resources (Pascual-Leone, 1970; Cowan, 2005), control processes (Engle et al., 1999), interference (Oberauer et al., 2012a), or time constraints on attention allocation (Barrouillet et al., 2009). These models view WM as the activated part of long term memory, and do not posit the existence of specialized temporary stores (although Cowan, 2005, does not exclude them in principle). Within these frameworks, one could investigate which attentional resources or control processes are affected by a training program. Improved WM efficiency (e.g., through strategies) should not be confused with expanded WM capacity. Improved performance in a trained WM task may not suffice to produce transfer effects; a specific effect in the trained task could be due to the use of particular strategies, or to a higher level of automation in the process(es) practiced in that task, but not to a greater WM capacity. On the other hand, here we suggest that there could be some transfer effects due to improved efficiency of the attentional processes that control resource allocation and use of WM.

Therefore, if we frame research questions within specific theories, choosing a WM measure is not just a matter of practical convenience; it carries various implications concerning "what" is trained and what changes occur in the cognitive system. Let us compare, for instance, complex span measures with *n*-back measures. To perform an *n*-back task, a person must maintain active representations of the previous *n* items and their serial order, encode the current item, compare it with the first of the memory list, make a decision, respond, drop the first item from the memory list, and update the list by including the last item and rearranging the order, so to continue with the next item—and all these operations must be performed under a certain time pressure. Improved *n*-back performance may reflect improvements in the efficiency or the speed of any or all of the foregoing operations, or in the control processes that manage the task, or in the use of any storage or attentional resources posited by a certain theory (e.g., to allocate activation energy to the relevant representations, or to resist interference from currently irrelevant items). To perform a complex span task, a person must encode one or more items of the processing task, perform the prescribed operations, encode an item of the memory task (possibly binding it with tags for relevance, order, etc.), keep the memory item(s) activated, and start over again with a cycle of the processing task, until recall of memory items is required. The demands of the processing task on WM capacity, control of interference, or speed of processing can vary across different complex span tasks. Improved performance in a complex span task may reflect improvements in any operation, control process, or structural component of the architecture of mind that is involved in the task.

Note that, although the differences between short-term memory tasks and complex span tasks are well-known, some WM training programs for individuals with intellectual disabilities (ID) combined a few WM tasks with other, mainly short-term memory tasks. It follows that it is important to reflect on what the tasks used for training WM involve. To understand improvement in WM measures, one must spell out a clear model of the processes that underlie that measure, and of those that are involved in the training program. It also seems appropriate to use more than one WM measure, so that one can compare measures that involve different processes, which are differently related to the training.

In some cases, detailed models were proposed for WM measures (e.g., Oberauer et al., 2012b for complex spans). Some theoretical approaches, in particular neo-Piagetian ones, emphasize the importance of detailed task analyses that consider the declarative and procedural information involved at each step of a task, as well as the processes that boost or hinder activation of the relevant cognitive units (Pascual-Leone and Johnson, 2011; Morra, 2015). This literature should not be ignored in studies on WM training.

Redick et al.'s (2013) findings provide remarkable food for thought in this line. Their participants, trained in a dual *n*-back task, improved dual n-back performance throughout the training, but showed no transfer to other measures of WM or intelligence. Such results show that a naïve "muscular metaphor" for WM training is clearly inadequate. We suggest that their training program affected task-specific processes, such as encoding the dual (visual-auditory) stimuli or their serial order. Comparing task-analytic models of successful and unsuccessful training studies could provide valuable insights on which types of training are most likely to be effective.

These reflections become crucial when WM training is intended for individuals with ID. Studies on WM training for individuals with ID found mainly near transfer effects, on tasks similar to the trained task. The goal of such programs is to improve the trainees' (normally children) general cognitive abilities, and the functional outcomes that rely on them, so achieving far transfer effects is crucially important. Training gains on untrained tasks were rarely reported, however. In addition, the training benefits in everyday abilities, skills related to academic outcome (in school-aged individuals), or in individual symptoms were examined surprisingly rarely (Melby-Lervåg and Hulme, 2013). When these aspects were considered, the results were contradictory, with benefits in daily life or symptoms being found in some studies, but not in others (Kirk et al., 2015). This inconsistency could be due to different training programs, or to the different measures used to assess far vis-à-vis near transfer effects of training, which are delicate methodological issues. But the picture remains equally cloudy even when we consider studies presenting the same program (i.e., Cogmed in the case of ADHD individuals), and assessing gains in the same cognitive processes (inhibition), or parents' ratings, symptoms, and academic achievement.

Standardized academic achievement tests could also shed light on the efficacy of WM training for children with ID, but they have rarely been considered. Partly because of great variability characterizing the profiles of children with ID, using such measures could enable us to assess the gains not only at group level but also for each individual. Thus, the utility of a training could be assessed from a more "clinical" standpoint. So far, however, the few studies that proposed WM training (in children with typical development) and used standardized measures to test its efficacy failed to demonstrate any effects, although there was evidence of improvement in other WM tasks

(St. Clair-Thompson et al., 2010). Even though funding resources are not always sufficient to enable us to plan unimpeachable training studies (Gathercole et al., 2012), it would be important to schedule follow-up sessions to ascertain maintenance of WM training gains. Examining long-term effects becomes crucial in the case of individuals with ID. The lack of attention to these aspects in training individuals with ID is rather surprising considering how WM is involved in everyday cognitive and school activities. Improving these domains should be a high priority for individuals with ID.

Individual differences should be considered too when attempting to produce cognitive gains by training WM, because individuals with ID each have their own particular cognitive profile. WM training programs could be used in an effort to remedy cognitive impairments, and WM deficits are common in children with ID, but the severity of this impairment may be more pronounced in different processing domains. For instance, poor comprehenders have difficulties in verbal, but not in visuospatial WM tasks (see Carretti et al., 2009). Similarly, individuals with Down syndrome have an impaired verbal WM performance, with relatively more adequate performance in the visuospatial domain. On the other hand, children with nonverbal learning disabilities generally perform poorly on visuospatial, but not on verbal WM tasks. If we take the example of children with Attention Deficit Hyperactivity Disorder (ADHD), however, we find that most studies have focused on training visuospatial and phonological short-term tasks, instead of tasks that require a higher degree of executive control—in which actually they are more impaired, and which hinders more seriously their functional outcomes.

Baseline performance in WM tasks may also provide an indication of individual susceptibility to training. Given the great diversity of profiles seen in children with learning disabilities, it could also be that a minimal WM capacity is needed for any training to produce improvements, and that individuals with severe WM impairments will be unable to benefit from such programs. To the best of our knowledge, however, no WM training study conducted to date examined whether training effects vary across participants diagnosed with ADHD depending on its severity, and on any comorbidities.

Also, the important influence of motivational, emotional factors on WM and intellectual performance cannot be neglected. Recent studies suggest that compliance with a training program is of paramount importance to the improvements it can achieve (Jaeggi et al., 2014). Engagement with the program (training content) is therefore vital, but while typically-developing children can probably rely on their intrinsic motivation to complete a task, this may not be the case for individuals with ID or ADHD. Some training formats can sustain motivation and engagement more than others. Computer games that provide immediate feedback may be more effective than other training formats in motivating children with Down syndrome or ADHD, for instance. Motivation as a potential source of variability across studies was also examined only rarely, but it may have an impact—even on the control group. Although a determined effort is now being made to include active control groups, the proposed activities do not always include features that can sustain motivation, such as rewards (feedback), and they are not always as enjoyable or challenging as the activities used in the training program, so there is a risk of training gains being overestimated.

To sum up, WM training is a promising approach for sustaining individuals with ID. We have emphasized here, however, that while the focus on short-term cognitive benefits was justified in the very first WM training studies, the time has come for new training studies to clarify the theoretical framework, and concentrate on the task analysis of the training, and on the applied training outcomes and their maintenance.

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OPINION
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The benefits of looking at intraindividual dynamics in cognitive training data

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Over the last decade, the prospect of improving or maintaining cognitive functioning has provoked a steadily increasing number of cognitive training studies. Central target populations are individuals at risk for a disadvantageous development, such as older adults exhibiting cognitive decline or children with learning impairments. They rely on cognitive resources to meet the challenges of an independent life in old age or requirements at school.

To support daily cognitive functioning, training outcomes need to generalize to other cognitive abilities. Such transfer effects are, however, highly discussed. For example, recent meta-analyses on working memory training differed in the conclusion on the presence (Au et al., 2015; Karbach and Verhaeghen, 2014) or absence of transfer effects (Melby-Lervåg and Hulme, 2013). Usually training-specific design factors such as type, intensity, duration, and feedback routines are discussed as reasons for such inconsistent findings. However, even individuals participating in exactly the same training regime highly differ in their training outcomes. We argue that it is time to study the individual development during trainings to understand these differential outcomes. It is time to have a closer look at the intraindividual training data.

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Within-Person Information in Training Data

The classical findings of a training study – whether a cognitive training group showed training and transfer effects compared to a control group – could be amended and sometimes even better understood by further analyzing the training sessions on the within-person level. Intraindividual training data could offer four types of information: (1) *Intraindividual performance trajectories* across all training sessions can demonstrate which participants show training effects and when they reach their performance maximum. (2) *Intraindividual performance fluctuations* – between and within training sessions – show which participants vary substantially in their performance (despite general training improvement). (3) *Intraindividual couplings* of performance fluctuations with other variables can reveal which internal and external factors contribute to individual performance and to what extend participants differ in the strength of these relations. (4) *Further combinations* of these types can be considered as well. For example, substantial performance fluctuations (type 2) can in theory be both, an indicator of adaptive (e.g., varying strategies; Siegler, 1994, 2007) or maladaptive processes (e.g., vulnerability to disturbing influences) during training. Relating fluctuations to other variables such as daily motivation and affect (type 3) or to performance trajectories (type 4, here combining 1 and 2) can contribute to exposing them as either beneficial or obstructive for the individual training success.

Rationale of the Approach

There is a strong rationale behind this approach of looking at the intraindividual and dynamic characteristics of cognitive training data. Until recently, the training phase of intervention studies constituted a black box and we gradually tested hypothesized mechanisms through the variation of training conditions. Combining this tradition with within-person analyses is a more efficient approach to understanding how cognitive training works, for whom it works, and in which contexts and situations it works by combining the benefits of two different research perspectives. The cognitive training field provides cumulating evidence for the role of individual differences in training (e.g., Lövdén et al., 2012; Karbach and Unger, 2014, for a review), where some individuals benefit more than others. Most of the time, however, one can only speculate about the underlying mechanisms that lead to these differences. Measurement intensive research, such as the field of ambulatory assessment, provides cumulating evidence that individuals differ in intraindividual cognitive processes. They differ in the strength of cognitive performance fluctuations (i.e., short-term variations) and their couplings with possible antecedents and consequences (e.g., Riediger et al., 2014; Könen et al., 2015).

Combining both perspectives is reasonable, because a central assumption behind cognitive training is that it fosters intraindividual change in cognitive performance. But how exactly do individuals come from A to B (i.e., pre to post level)? Dynamic systems theory predicts that a later state of cognition (y_{t+1}) is a function of an earlier state (y_t) with the function being an adaptive mechanism to perturbation ($y_{t+1} = f(y_t)$; cf. Weisstein, 1999; van Geert and Steenbeek, 2005). In our case, the perturbation would be a challenging cognitive training and individuals do respond to this situation. Ideally, they develop new cognitive resources because they experience a prolonged mismatch between their resources and the situational demands (cf. Lövdén et al., 2010). Practically, some individuals gain more than others, even if the training is adaptive and well designed (thus, neither too easy, nor too difficult). Individuals likely vary in within-person processes over time that eventually produce between-person differences in training outcomes. Consequently, it is just a logical step to look at the intraindividual level to find out what happens over the course of the training.

Implications for Specific Populations

A within-person approach to cognitive training data is all the more beneficial the more heterogeneous the trained individuals are. Good examples to illustrate this point are specific populations, such as children with learning disabilities and older adults. On the one hand, they demonstrate between group differences compared to healthy controls or young adults, and on the other hand they likely exhibit substantial within group differences. Such differences are of major concern because they can influence training outcomes or even mask effects. Therefore, both populations are particularly useful to highlight the benefits of a within-person approach.

Learning disabilities constitute an important target for cognitive training, because they have been related to substantial working memory impairments (e.g., Schuchardt et al., 2008; Fischbach et al., 2014). However, the profile of these impairments varies considerably between disabilities (e.g., reading vs. spelling disability, Brandenburg et al., 2014). Varying impairments can influence training outcomes because the initial performance level is often related to training and transfer gains (e.g., Zinke et al., 2013; Karbach et al., 2014). Consequently, individuals sharing a specific learning disability might not only function differently from healthy controls, but also from those with other learning disabilities. Further, they likely show a substantial amount of within-group variability and may, for example, vary in the etiology of the learning disability and with regard to possible treatments they previously received (cf. Shah et al., 2012). In cases with such crucial heterogeneity, within-person analyses can reveal *whether and to what extent* participants perform differently in the course of a cognitive training (i.e., show differential intraindividual effects). For example, they might show different cognitive performance trajectories and different antecedents and consequences of performance fluctuations (i.e., differ in the internal and external factors contributing to individual performance). A related within-person finding comes from a sample of elementary school children. Daily working memory performance was related to last night's sleep quality and this within-person coupling varied reliably between children. It was stronger for low performing children, indicating that they were more vulnerable to the influence of last night's sleep (Könen et al., 2015).

Further promising examples for the usefulness of within-person analyses come from training research with older adults. Older adults demonstrated on average a slower growth during working memory training than younger adults (Bürki et al., 2014) and their performance fluctuated less in all tasks of a broad cognitive training (working memory, episodic memory, and processing speed, Schmiedek et al., 2013). In addition, their performance fluctuations in reasoning and perceptual speed were positively associated with practice-related gains on the same tasks (Allaire and Marsiske, 2005), implying that fluctuations likely indicated an adaptive process in this case. Taken together, these examples demonstrate that the performance of older adults during cognitive trainings differs from the performance of younger adults, which is valuable additional information on top of between-person differences in training outcomes (e.g., in Schmiedek et al., 2010). They suggest a need to question what causes these differences and whether older adults' behavior can be modified through, for example, instruction and feedback (e.g., Garrett et al., 2012). Interestingly, the within-person relation between daily motivation and daily working memory training performance was considerably lower in older compared to younger adults (Brose et al., 2010), raising the question whether there are untapped motivational resources and whether the effectiveness of cognitive trainings for older adults may be improved by building more on these motivational resources. Still, much more research is needed to further confirm and elaborate these first recent findings.

Statistical Modeling

Suitable modeling approaches are, for example, multilevel modeling (e.g., Brose et al., 2012; Schmiedek et al., 2013), structural equation modeling (SEM; e.g., Brose et al., 2010; Bürki et al., 2014), dynamical systems analysis (e.g., Gasimova et al., 2014), and combinations thereof (e.g., multilevel SEM, e.g., Könen et al., 2015). We suggest using or at least starting with multilevel models because they are easy to access and to apply (e.g., closely related to standard regression, implemented in all commonly used software packages) and they are perfectly suitable to study intraindividual trajectories, fluctuations, and couplings. In these models, a certain number of measurement occasions (e.g., training sessions, Level 1, within-person level) are nested within a certain number of individuals (Level 2, between-person level). One can, for instance, predict a Level 1 variable (e.g., daily cognitive performance) with another Level 1 variable (e.g., daily motivation) and test the mean intraindividual effect (fixed effect) and examine whether individuals (Level 2) differ reliably in the strength of this relation (random effect). Hoffman and Stawski (2009) provide a detailed discussion of multilevel analyses with longitudinal data.

Practical Considerations

There is already a number of existing cognitive training studies with data suitable for all or at least a part of the proposed within-person analyses (e.g., Bürki et al., 2014). We want to encourage the field to further explore the potential of the existing data and to consider within-person processes when designing future training studies. Therefore, one should pay particular attention to the number of measurement occasions, the sample size, and the sensitivity of the measures to fluctuations.

The number of measurement occasions (K) and the sample size (N) should be reviewed together in a multilevel context. Cognitive trainings are expected to change cognitive performance on a construct level, so the frequency of training sessions (here: K) is usually high. Whether a given K is sufficient for a certain within-person analysis depends on N as well as the size and nature of the effect of interest (e.g., an intraindividual coupling). The typical 10–20 training sessions applied in cognitive trainings (cf. Melby-Lervåg and Hulme, 2013, Appendix) are sufficient for within-person analyses if N is appropriate. The first step to calculate the necessary N would be to conduct a traditional power analysis concerning the central transfer effects of the training (e.g., with G*Power; Faul et al., 2007). Then one could use the resulting N of trained participants as a lower starting point for Monte Carlo simulations on the multilevel parameters (to estimate the probability of recovering known population parameters given K and N; for example with Mplus; see Bolger et al., 2012; Bolger and Laurenceau, 2013; for a step-by-step description). One should simulate different combinations of K and N and could also consider other design factors (e.g., the number of observed indicators) to find an optimal trade off and study design (cf. von Oertzen and Brandmaier, 2013). In case an existing N is slightly lower than preferred, Bayesian estimation could be eligible (Hox et al., 2012).

Variables that might impact daily cognitive performance (e.g., current motivation, affect, and health) should be observed with every training session, if feasible. This allows for the estimation of couplings over time. For instance, Brose et al. (2012) found that working memory performance during a cognitive training in young adults was lower on days with reduced motivation, reduced control of attention, and enhanced negative affect. To allow for such analyses, one has to consider the temporal dynamics of the variables and carefully select measures that are sensitive to fluctuations. For example, an affect scale has to capture the current state and should not include items for rare affective states. The variables of interest could be assessed with short scales (see Ziegler et al., 2014) to reduce testing time and participant burden. The reliability of these scales and their sensitivity to fluctuations can be analyzed with multilevel models (e.g., Wilhelm and Schoebi, 2007). We highly recommend the handbook of Mehl and Conner (2012) for a detailed and elaborate introduction to measurement intensive research.

Summary and Outlook

Cognitive training data could offer more information than is currently used in the field. We suggest analyzing intraindividual performance trajectories, fluctuations, and couplings and to consider such within-person analyses when designing future training studies. This seems to be particularly promising for studies with heterogeneous samples. Individuals likely vary in within-person effects over time that eventually produce between-person differences in training outcomes. Thereby, a within-person approach could contribute to understanding training outcomes and to generating theories about the underlying mechanisms.

Some hypotheses could then be further tested and validated through classic variations of training conditions. Experimental variation is the only way to ensure valid causal inferences in cognitive psychology. However, it is practically impossible to test all thinkable explanations for the current heterogeneous findings in training research only in this way. It seems much more feasible to test certain mechanisms that were already identified in the intraindividual dynamics of the training data. This highlights how both perspectives complement each other and could be combined to an efficient approach to study the mechanisms that drive or hamper cognitive training success.

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Improving working memory in children with low language abilities

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This study investigated whether working memory training is effective in enhancing verbal memory in children with low language abilities (LLA). Cogmed Working Memory Training was completed by a community sample of children aged 8–11 years with LLA and a comparison group with matched non-verbal abilities and age-typical language performance. Short-term memory (STM), working memory, language, and IQ were assessed before and after training. Significant and equivalent post-training gains were found in visuo-spatial short-term memory in both groups. Exploratory analyses across the sample established that low verbal IQ scores were strongly and highly specifically associated with greater gains in verbal STM, and that children with higher verbal IQs made greater gains in visuo-spatial short-term memory following training. This provides preliminary evidence that intensive working memory training may be effective for enhancing the weakest aspects of STM in children with low verbal abilities, and may also be of value in developing compensatory strategies.

Keywords: working memory, SLI, language, intervention, cognitive training, verbal IQ

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Introduction

Impairments in working memory are common in many developmental disorders (Martinussen et al., 2005; Carretti et al., 2009) and have been suggested to act as barriers to educational achievement (Swanson and Sachse-Lee, 2001; Gathercole and Alloway, 2006, 2008; Archibald and Joanisse, 2009). This has led to widespread interest in the possibility that the working memory abilities of children who are poor learners could be enhanced through intensive training in memory-taxing activities. In both children with attention deficit hyperactivity disorder (ADHD) and those with low working memory alone, Cogmed working memory training (Cogmed, 2005) enhances performance on untrained measures of working memory (e.g., Klingberg et al., 2005; Holmes et al., 2010; Chacko et al., 2013; Dunning et al., 2013). Benefits of training have also been reported in other developmental populations including survivors of pediatric cancer with poor working memory (Hardy et al., 2011) and typically developing preschool children (Thorell et al., 2009). The novel issue addressed by the present study is whether the benefits of working memory training are modulated by the language-related abilities of the trainees.

Working memory provides the temporary storage of information needed to guide ongoing cognitive activities. A variety of models of working memory have been advanced that vary widely in their specificity and scope (Unsworth and Engle, 2007; Cowan, 2010; Oberauer et al., 2012). The multi-component model developed originally by Baddeley and Hitch (1974) and elaborated by

Baddeley (2000) has proved to be a particularly useful framework for characterizing the development of working memory during childhood (Bayliss et al., 2005; Alloway et al., 2006; Henry, 2011). The model consists of a central executive that controls the allocation of attentional resources required to maintain information in working memory. This is supplemented by specialized limited-capacity stores that maintain verbal and visuo-spatial information, and an episodic buffer that integrates multi-modal representations within working memory. Two broad classes of test assess the different components of this model. STM tasks involve the simple recall or recognition of information in the form in which it was presented, and assess the capacity of either the verbal or visuo-spatial store according to the domain of the stored information. Examples of STM paradigms are digit span (verbal) and block span (visuo-spatial). The central executive is often assessed by complex span tasks imposing significant processing as well as storage. Examples include backward digit span (the recall of digits in reverse sequence) and Mr. X (a visuo-spatial task involving spatial comparisons of two images and the retention of sequences of spatial information, Alloway et al., 2006).

Cogmed training has been suggested to improve the neural efficiency of the brain networks involved in working memory through intensive practice (Westerberg and Klingberg, 2007; Karbach and Schubert, 2013; Astle et al., 2015). It has also been identified as a potential solution to developmental impairments of working memory problems (Klingberg, 2010; Sonuga-Barke et al., 2013). In the present study, we investigated whether Cogmed training can overcome the working memory problems typically found in children with low language learning abilities. Children diagnosed with Specific Language Impairment (SLI), a condition characterized by poor language learning in the absence of general intellectual problems, have been widely reported to have deficits on measures of both verbal STM and verbal complex memory span (Montgomery, 1995; Bishop et al., 1999; Botting and Conti-Ramsden, 2001; Archibald and Gathercole, 2006). In contrast, their performance on visuo-spatial memory tasks is appropriate for their age (Bavin et al., 2005; Archibald and Gathercole, 2006). A similar profile of predominantly verbal impairments in working memory is also present in children with reading difficulties (Catts et al., 2002; Pickering, 2006).

It has been proposed that deficits in the phonological loop may underlie some of the language learning problems of children with SLI (Baddeley et al., 1998; Archibald and Gathercole, 2007). However, the more widely accepted view is that developmental impairments of language such as SLI arise from a core deficit in phonological coding which impacts on any activities (including memory tasks) with significant demands on the quality of phonological representations (de Jong, 1998; Bishop and Snowling, 2004; Catts et al., 2006). These two views generate conflicting hypotheses regarding the impact of training on children who are poor language learners. A deficit that originates in the phonological loop may be compensated for either directly by improvements in the efficiency of the working memory neural substrate resulting from intensive adaptive training (Klingberg, 2010) or more indirectly from improved strategy use (Dunning and Holmes, 2014). Alternatively, if the core deficit is in phonological coding and the temporary storage problems for verbal materials are therefore downstream from this, training that taxes STM and working memory would not be expected to ameliorate the continuing encoding deficit. On this basis it is predicted that children with poor language would have a diminished response to training on verbal memory tasks compared with individuals with typical language abilities. The aim of the present study was to test these contrasting hypotheses.

A variety of memory training programs exist (e.g., N-back training; Jaeggi et al., 2008), but the one most widely used in research studies with children is Cogmed Working Memory Training, which involves training for 25 days on a variety of memory-taxing activities employing both visuo-spatial and verbal materials. It has been applied across many studies to populations with domain-general deficits in STM and working memory, including children with ADHD and those with working memory problems in the absence of a diagnosed attentional deficit. In these groups, the benefits of training extend across untrained verbal and visuo-spatial complex memory tasks (Klingberg et al., 2005; Holmes et al., 2009, 2010; Gray et al., 2012; Chacko et al., 2013; Dunning et al., 2013; Rapport et al., 2013) and visuo-spatial STM tasks (Klingberg et al., 2005; Holmes et al., 2010; Dunning et al., 2013). Training benefits for verbal STM are less consistent. They are present in some children (Klingberg et al., 2002, 2005; Holmes et al., 2009) but not in others (Holmes et al., 2009; Gray et al., 2012; Dunning et al., 2013). Differences in the transfer tests employed across studies may contribute to these inconsistencies.

The impact of Cogmed training was compared between children with poor language abilities (LLA) and a comparison group of children with age-appropriate language that were matched on non-verbal IQ. This design is appropriate for investigating differential responses to training across groups, but not for quantifying the highly specific benefits of a particular training program due to the absence of active or passive intervention conditions. Members of the LLA group were selected through community screening on measures of both an expressive language (sentence repetition) and a receptive language (picture-word matching) test. None of the children were diagnosed with language impairments (although their problems had in many cases been recognized by their schools) but their language profile corresponds closely to that of children with SLI and related language learning problems meaning the results will nonetheless be relevant to this group too (e.g., Bishop et al., 2000; Conti-Ramsden et al., 2001). However, the standard SLI exclusionary criterion of a marked discrepancy between language and non-verbal abilities was not applied (Bishop et al., 1999; Tomblin and Zhang, 1999). The reason for this is that because working memory and fluid intelligence are known to be closely linked (Engle et al., 1999; Jaeggi et al., 2008), the exclusion of low scorers could potentially eliminate individuals with working memory problems. The current selection approach also enabled us to evaluate the extent to which Cogmed training was beneficial for a sample that were more representative of the majority of poor language learners in school than children with a diagnosis of SLI.

A secondary aim of the study was to investigate whether the children's responses to training on measures of working memory were mediated by a broader range of individual differences in their cognitive abilities other than the selection measures of language. To provide the necessary power for these exploratory correlational analyses, data from both groups was combined. While no specific hypotheses were generated, it was speculated that pre-training strengths in working memory may support the development of new and possibly compensatory strategies through training (Dunning and Holmes, 2014). Support for this would be provided if high baseline memory performance was associated with greater training gains on the working memory transfer tests.

Materials and Methods

Participants

A total of 179 children aged 8–10 years attending two primary schools in south–east England were screened on a receptive language test [Peabody Picture Vocabulary Test (PPVT), Dunn and Dunn, 2007], an expressive language test [Recalling Sentences subtest of the Clinical Evaluation of Language Fundamentals (CELF), Semel et al., 2006], and a test of non-verbal reasoning [Matrix Reasoning subtest of the Wechsler Abbreviated Scales of Intelligence (WASI), Wechsler, 1999]. All children were native English speakers (87 males, mean age 9 years, 3 months, SD = 10.7 months). Of the screened sample, 16 children with standard scores <86 on PPVT and scaled scores <7 on CELF Recalling Sentences formed the LLA group. A comparison group of 16 children were individually matched on age to within 90 days, gender, and on non-verbal reasoning. The two groups differed on CELF Recalling Sentences, $t(30) = -10.692$, $p < 0.001$, $d = 3.784$, and on PPVT, $t(30) = -7.69$, $p < 0.001$, $d = 2.987$. There were no group differences on the non-verbal reasoning task, $t(30) = -0.244$, $p = 0.809$, $d = 0.086$. Both groups scored in the low average range on this task.

Consent to continue to the training phase was not obtained for one child in the LLA group, and two further children (one in each group) withdrew before any further testing was completed. Two children in the LLA group failed to complete training (one withdrew and the other moved schools). Data are reported here only for the remaining children who completed training (LLA, $n = 12$, males = 7, mean age 9 years, 9 months, SD = 8.4 months; comparison group, $n = 15$, males = 8, mean age 9 years, 9 months, SD = 9.5 months). Descriptive statistics for the screened sample and both groups are shown in **Table 1**. The LLA group scored at a significantly lower level on the Recalling Sentences test, $t(25) = -11.687$, $p < 0.001$, $d = 4.513$ and the PPVT, $t(25) = -6.613$, $p < 0.001$, $d = 2.938$, with no significant group differences in non-verbal reasoning, $t(25) = -0.503$, $p = 0.619$, $d = 0.194$.

Procedure

Following screening, participants completed a set of pre-training assessments in a one-to-one session that lasted approximately 1.5 h. They then took part in 20 45-min sessions of Cogmed Working Memory Training over the following 8 weeks in small groups in school supervised by a research assistant. Upon completion of training, all pre-training tasks were re-administered in individual sessions. The researchers conducting the pre- and post-training assessments and supervising training were blind to group membership.

Working Memory

Participants completed eight subtests of the Automated Working Memory Assessment (AWMA, Alloway, 2007) before and after training: two tests each of verbal STM (Digit Recall, Word Recall), visuo-spatial STM (Dot Matrix, Block Recall), verbal working memory (Backward Digit Recall, Listening Recall), and visuo-spatial working memory (Mr. X, Spatial Recall). The verbal STM and working memory tasks required spoken responses. Pointing responses were required for the visuo-spatial tasks. The STM tasks required the immediate serial recall of either verbal or visuo-spatial information (e.g., recalling a digit list in forward order). The working memory tasks had an additional executive load in the form of processing either the storage material or other relevant information prior to recall (e.g., reversing digit sequences prior to recall). Standard scores were derived for individual tests. Composite scores for each of the four aspects of working memory were calculated by averaging standard scores for each pair of tests.

Language

At the pre-training assessment, participants completed a test of phonological processing, and verbal STM the Children's Test of Non-word Repetition (CNRep, Gathercole and Baddeley, 1996), and the Understanding Spoken Paragraphs subtest of the CELF (Semel et al., 2006), a measure of listening comprehension. The same assessments were completed again after training, in addition to the PPVT (Dunn and Dunn, 2007) and CELF Recalling Sentences tests.

TABLE 1 | Language and non-verbal reasoning profiles of screening sample and selected groups.

		CELF Recalling Sentences		Peabody Picture Vocabulary Test (PPVT) vocabulary		Matrix Reasoning	
	n	***M***	**SD**	***M***	**SD**	***M***	**SD**
Screening sample	179	9.220	3.170	100.630	13.600	47.280	10.120
LLA	12	3.750	1.603	81.083	4.078	41.250	6.917
Comparison	15	10.800	1.521	103.067	10.886	42.600	6.936

IQ

Prior to training, the Similarities and Vocabulary (verbal IQ), and Block Design (performance IQ) subtests of the WASI (Wechsler, 1999) were administered. The fourth subtest, Matrix Reasoning, was administered at screening. All four measures of the WASI were administered after training. Composite indices of verbal and performance IQ were calculated.

Working Memory Training

Participants completed 20 sessions of Cogmed Working Memory Training RM (Cogmed, 2005). Each training session lasted approximately 45 min and involved repeated practice on span-like STM and working memory tasks. Participants completed eight out of a possible 12 tasks in each session, with 15 trials on each task. Seven of the tasks involved the serial recall of visuo-spatial information. Of these, four required mental manipulation (e.g., spatial rotation) prior to recall (visuo-spatial working memory) and three required simple serial recall (visuo-spatial STM). Three further tasks required the serial recall of verbal information in the same order (verbal STM) or in reverse or ascending order (verbal working memory). Two other tasks required the recall of verbal information associated with specific spatial locations, one in forward order (STM) and one in reverse sequence (working memory). All responses were made by clicking with the computer mouse. The difficulty of the tasks adapted to match the children's performance level on a trial-by-trial basis. Full details about the training program are provided at www.cogmed.com/rm.

Results

Pre-Training

Descriptive statistics for the STM and working memory tasks are provided in **Table 2**. Language and IQ scores are presented in **Table 3**. Separate multivariate analyses of variance (MANOVAs) were conducted on the STM, working memory, language, and IQ measures. Univariate *F* tests were performed to compare performance between the LLA and comparison groups on the individual measures. Bonferroni corrections were made to correct for multiple testing. Thresholds for statistical significance were $p < 0.0125$ for STM, working memory and IQ, and $p < 0.006$ for language measures.

Short-Term Memory

There was a significant group effect on the STM measures, Hotelling's $T^2(4, 22) = 7.497$, $p < 0.001$, $\eta^2_\rho = 0.577$. Univariate analyses revealed significant group differences on each of the individual verbal STM subtests and the resulting verbal STM composite score, with effect sizes ranging from $d = 1.6$ to 2.12. In all cases, the LLA group scored at a significantly lower level than the matched comparison group. The groups did not differ significantly on the visuo-spatial STM tasks.

Working Memory

The group effect was not significant, Hotelling's $T^2(4, 22) = 1.535$, $p = 0.227$, $\eta^2_\rho = 0.218$. The group difference on the verbal working memory composite score did not withstand the correction for

TABLE 2 | Descriptive statistics and group comparisons before and after training for working memory measures.

	LLA group							Comparison group							Pre-training group differences			Main effect of training			Group x training interaction		
	Pre-training		Post-training		Pre to post			Pre-training		Post-training		Pre to post											
	M	SD	*M*	SD	*t*	*p*	*d*	*M*	SD	*M*	SD	*t*	*p*	*d*	*F*	*p*	*d*	*F*	*p*	η^2_ρ	*F*	*p*	η^2_ρ
Short-term memory																							
Digit Recall	83.875	10.964	90.717	14.474	−3.105	0.010	0.538	107.140	11.014	109.927	17.009	−0.741	0.471	0.199	29.864	0.000	2.117	4.275	0.049	0.146	0.758	0.392	0.029
Word Recall	85.767	12.164	89.008	7.994	−0.910	0.382	0.322	104.167	10.831	106.287	11.008	−0.629	0.539	0.194	17.256	0.000	1.600	1.181	0.287	0.045	0.05	0.822	0.002
Verbal STM	84.821	10.584	89.863	10.415	−2.489	0.030	0.480	105.653	9.174	108.107	11.644	−1.052	0.311	0.236	30.008	0.000	2.109	5.559	0.027	0.182	0.66	0.423	0.026
Dot Matrix	94.075	6.963	106.058	19.822	−2.030	0.067	0.895	93.360	10.736	109.873	17.862	−3.727	0.002	1.155	0.040	0.844	−0.081	15.522	0.001	0.383	0.39	0.537	0.015
Block Recall	89.325	11.931	103.908	17.751	−3.268	0.007	0.983	91.440	8.804	102.520	17.932	−2.608	0.021	0.829	0.281	0.601	0.204	17.099	0.000	0.406	0.32	0.577	0.013
VS STM	91.700	7.287	104.983	17.108	−3.057	0.011	1.089	92.400	7.698	106.197	15.535	−3.988	0.001	1.188	0.058	0.812	0.093	24.420	0.000	0.494	0.01	0.926	0.000
Working memory																							
Listening Recall	93.867	13.890	97.067	7.260	−0.836	0.421	0.303	103.067	13.915	104.793	12.681	−0.396	0.698	0.130	2.919	0.100	0.662	0.682	0.417	0.027	0.06	0.807	0.002
Backward Digit Recall	92.833	9.571	95.842	13.252	−0.855	0.411	0.264	100.400	12.648	108.387	10.825	−2.406	0.030	0.680	2.939	0.099	0.681	5.104	0.033	0.170	1.05	0.316	0.040
Verbal WM	93.350	6.133	96.454	6.986	−1.063	0.311	0.473	101.733	9.885	106.590	10.704	−1.500	0.156	0.472	6.574	0.018	1.047	3.174	0.087	0.113	0.15	0.698	0.006
Mr X	98.250	15.493	98.317	14.453	−0.014	0.989	0.004	98.267	15.248	102.913	10.538	−1.147	0.271	0.360	0.000	0.998	0.001	0.572	0.456	0.022	0.54	0.469	0.021
Spatial Recall	97.542	16.293	101.675	16.670	−1.295	0.222	0.251	102.380	10.044	108.460	12.072	−2.412	0.030	0.550	0.901	0.352	0.367	6.491	0.017	0.206	0.24	0.631	0.009
VS WM	97.896	13.396	99.996	12.544	−0.633	0.539	0.162	100.323	10.963	105.687	9.385	−1.974	0.069	0.527	0.269	0.609	0.199	3.093	0.091	0.110	0.59	0.449	0.023

TABLE 3 | Pre and post training scores by group, and group comparisons for language and IQ.

		LLA Group							Comparison group							Pre-training group differences			Main effect of training			Group x training interaction		
		Pre-training		Post training		Pre to post training			Pre-training		Post-training		Pre to post											
		M	SD	*M*	SD	*t*	*p*	*d*	*M*	SD	*M*	SD	*t*	*p*	*d*	*F*	*p*	*d*	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Language																								
CELF	Recalling Sentences	3.750	1.603	3.917	1.881	−0.518	0.615	0.096	10.800	1.521	10.600	2.098	0.480	0.638	−0.111	136.583	0.000	4.514	0.004	0.952	0.000	0.448	0.510	0.018
	Understanding Spoken Paragraphs	5.667	2.807	6.917	2.610	−1.820	0.096	0.462	9.533	1.642	9.867	2.066	−0.536	0.601	0.180	20.013	0.000	1.738	2.190	0.100	0.104	0.975	0.333	0.038
PPVT	Vocabulary	81.083	4.078	82.667	9.267	−0.628	0.543	0.237	103.067	10.886	99.133	9.819	1.175	0.260	−0.380	43.730	0.000	2.938	0.288	0.596	0.011	1.589	0.219	0.060
CN-Rep	Total	20.417	6.882	29.667	4.250	−5.088	0.000	1.662	31.000	3.684	34.533	2.924	−3.486	0.004	1.069	23.259	0.000	2.003	14.733	0.000	0.626	8.354	0.008	0.250
	2 Syllables	8.500	1.446	9.500	0.674	−1.970	0.074	0.943	9.533	0.915	9.667	0.617	−0.487	0.634	0.174	5.124	0.033	0.875	4.304	0.048	0.147	2.517	0.125	0.091
	3 Syllables	6.167	2.209	8.000	1.206	−2.823	0.017	1.074	7.667	1.345	8.800	1.014	−2.747	0.016	0.961	4.747	0.039	0.844	16.049	0.000	0.391	0.894	0.354	0.035
	4 Syllables	2.833	2.368	5.667	2.387	−4.017	0.002	1.192	6.867	1.767	8.067	1.163	−2.167	0.048	0.819	25.724	0.000	1.951	20.845	0.000	0.455	3.148	0.076	0.120
	5 Syllables	2.917	1.505	6.500	1.883	−6.967	0.000	2.115	6.933	1.223	8.000	1.195	−4.298	0.001	0.882	28.646	0.000	2.945	75.313	0.000	0.751	22.06	0.000	0.469
IQ																								
WASI	Verbal IQ	88.333	8.542	91.917	14.625	−1.553	0.149	0.309	103.200	12.143	110.933	8.128	−3.112	0.008	0.763	12.848	0.001	1.437	10.673	0.003	0.299	1.435	0.242	0.054
	Performance IQ	89.083	9.356	92.083	11.333	−2.283	0.043	0.290	89.800	5.480	94.867	8.855	−3.078	0.008	0.707	0.062	0.806	0.097	13.069	0.001	0.352	0.893	0.354	0.034

multiple comparisons ($p = 0.018$, $d = 1.05$). Significant group differences were not found either for measures of visuo-spatial working memory or for the individual verbal working memory subtests.

Language

A MANOVA revealed a significant group effect for the CELF language tasks, Hotelling's $T^2(2, 24) = 84.943$, $p < 0.001$, $\eta_\rho^2 = 0.876$, and for CN-Rep, Hotelling's $T^2(4, 22) = 17.325$, $p < 0.001$, $\eta_\rho^2 = 0.759$. Total scores for the LLA group were significantly lower than those of the comparison group across all language tasks. On non-word repetition, the LLA group performed significantly more poorly at syllable lengths four and five, with no group difference at shorter syllable lengths.

IQ

The group effect for the IQ tests was significant, Hotelling's $T^2(2, 24) = 6.444$, $p = 0.006$, $\eta_\rho^2 = 0.349$. Univariate F tests revealed significant group differences in verbal IQ but not in performance IQ. The scores of the LLA group were lower than those of the comparison group on the verbal IQ test.

Training

Significant main effects of training were observed for the whole sample from pre- to post-test on two visuo-spatial STM tasks, Dot Matrix, Block Recall, and for the derived composite visuo-spatial STM score (see **Table 2**). Scores were higher after training on Digit Recall ($p = 0.05$), Backward Digit Recall ($p = 0.02$), Spatial Recall ($p = 0.017$), and the verbal STM composite score ($p = 0.03$), but in all cases these effects did not meet significance at the Bonferroni threshold. No other main effects for the STM and working memory measures reached significance. Significant gains from pre- to post-test were also observed for the total non-word repetition score and for performance on this test at syllable lengths 3 and 5. There was a main effect of training on both verbal and performance IQ, with significantly higher scores after training (**Table 3**).

Pre- to post-training differences were analyzed separately for each group in paired-sample t-tests. Significant increases in scores were observed after training for the comparison group on the following measures: Dot Matrix, Block Recall, visuo-spatial STM, Backward Digit Recall, Spatial Recall, total non-word repetition score, accuracy of repeating 3, 4, and 5 syllable non-words, and both performance IQ and verbal IQ. Significant pre- to post-changes did not withstand the correction for multiple comparisons for some tasks, although the effect sizes were substantial: Block Recall ($d = 0.829$), Backward Digit Recall ($d = 0.680$), Spatial Recall ($d = 0.550$), CN-Rep 3 and 4 syllable non-words ($d = 0.961$ and 819, respectively). This reflects the relatively low statistical power of the study.

For the LLA group, significant gains were found on Digit Recall, verbal STM, Block Recall, visuo-spatial STM, total non-word scores, and performance at syllable lengths 3, 4, and 5, and performance IQ. Gains on the verbal STM composite measure were no longer significant when corrections were made for multiple comparisons, although the effect size was moderate in magnitude, $d = 0.48$. Changes in non-word repetition scores at syllable length 3 did not withstand the multiple comparison correction, but the effect size was large ($d = 1.074$). After correction for multiple comparisons, gains for performance IQ were small ($d = 0.290$) and non-significant.

To investigate group differences in training gains, a series of 2 × 2 ANOVAs with time (pre, post) and group (LLA, comparison) were performed. The outcomes of these analyses are displayed in **Tables 2** and **3**. There were no significant differences in the impacts of training on memory scores in the two groups. Significant group × time interactions were observed for total non-word repetition scores and for performance at syllable length 5. Training gains were significantly greater for the LLA group on both measures. No other training-related differences between groups reached significance. An equivalent pattern of results emerged when group differences in gains scores were compared.

Correlational Analyses

Initial exploratory correlational analyses were performed between baseline cognitive abilities and gains in STM and working memory on tests that were not used for selection purposes. For these analyses, data from both groups were combined and composite scores derived where there were multiple variables for a single construct in order to reduce error and maximize the case to variable ratio. **Table 4** shows the correlations between measures of IQ, listening comprehension and non-word repetition and gains in each aspect of working memory calculated by the difference between post-training and pre-training scores. Pre-training verbal IQ was highly and negatively correlated with gains in verbal STM ($r = -0.548$), indicating that greatest training benefits were obtained for the children with lowest verbal IQs. There were no other significant associations between pre-training scores and gains in any of the four composite memory scores.

Next, links between pre-training abilities and the variance in post-training working memory scores that could not be predicted by the same working memory assessments taken prior to training were explored. First, the residual variance in post-training scores was calculated from the best-fitting linear function with pre-training scores as the dependent variable, for each of the four working memory composite scores. Correlation coefficients were then calculated between pre-training measures and residual post-training scores. Verbal IQ was significantly negatively associated with the verbal STM residual training score ($r = -0.382$, see **Figure 1A**). This indicates that the relationship between verbal IQ and scores on verbal STM after training was not a simple function of a pre-training association between verbal IQ and verbal STM that had a secondary impact on post-training scores.

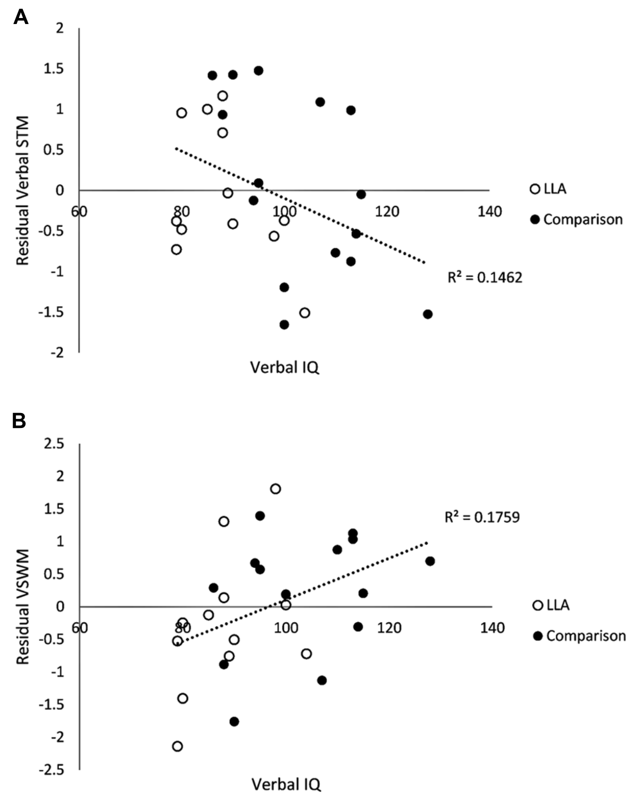

FIGURE 1 | Scatter plot of baseline verbal IQ and residual training scores in verbal STM (A) and visuo-spatial working memory (B).

TABLE 4 | Correlations between gains in working memory (post minus pre training scores) and baseline ability scores (above horizontal) and between residual training scores in working memory and baseline ability scores (below horizontal).

	Verbal STM	VS STM	Verbal WM	VS WM	Verbal IQ	Performance IQ	Understanding Spoken Paragraphs	CN-Rep Total
Verbal STM	–	0.001	0.343	0.081	−0.548**	−0.194	0.003	−0.256
VS STM	0.040	–	0.153	0.471*	0.082	0.357	−0.187	0.163
Verbal WM	0.322	0.270	–	0.056	−0.046	−0.136	0.096	0.059
VS WM	−0.048	0.575**	0.265		0.178	0.083	−0.022	0.345
Verbal IQ	−0.382*	0.067	0.208	0.419*	–	0.251	0.446*	0.487*
Performance IQ	−0.172	0.350	−0.039	0.377	0.251	–	−0.171	0.118
Understanding Spoken Paragraphs	0.148	−0.191	0.341	−0.006	0.446*	−0.171	–	0.409*
CN-Rep Total	−0.037	0.149	0.301	0.483*	0.487*	0.118	0.409*	–

***denotes significance <0.01, *significant at the <0.05 level.*

Two further significant associations emerged from the analyses of the training residual scores. Post-training residual scores on visuo-spatial working memory were highly associated both with verbal IQ ($r = 0.419$; **Figure 1B**) and non-word repetition ($r = 0.483$).

Discussion

This study compared the benefits of working memory training for children with LLA and a comparison group with typical language skills. Prior to training, the LLA children scored at relatively low levels on verbal measures of both STM and working memory, and similarly, to the comparison group on visuo-spatial memory tasks. This is consistent with previous reports of close associations between verbal abilities such as vocabulary and verbal STM, both in unselected samples of children (Gathercole et al., 1999; Majerus et al., 2006) and individuals with SLI (Gathercole and Baddeley, 1989; Conti-Ramsden et al., 2001).

The primary aim of the study was to test between predictions derived from contrasting theories of developmental language impairments concerning responses to working memory training of the LLA group. On the basis of the phonological processing deficit account of developmental language impairment (e.g., Bishop and Snowling, 2004), it was predicted that their gains in verbal aspects of working memory would be minimal as the nature of the training program would not be expected to tax input processing skills. In contrast if, like children with SLI, this group have a core deficit in verbal STM (Baddeley et al., 1998; Gathercole, 2006), training that enhances this memory component would be expected to yield significant gains.

A mixed pattern of response to training emerged for verbal STM measures. The comparison group made no gains on any verbal STM measure following training, consistent with findings from studies with other populations including children with low working memory and those with ADHD (Holmes et al., 2009; Gray et al., 2012; Dunning et al., 2013). However, the LLA group improved significantly on one of the two verbal STM measures (digit span, but not word span), although here the training by group interaction was not significant. No strong conclusions can therefore be drawn about whether training has a substantial reliable impact on serial recall measures of verbal STM in the group with LLA.

This group did, however, show a marked differential increase in repetition accuracy for the lengthiest multisyllabic items on the test of non-word repetition relative to the comparison group. The finding is important, as it has been suggested that difficulties in repeating non-words in children with the more severe condition of SLI may reflect underlying verbal STM deficits that also contribute to their vocabulary learning difficulties (Baddeley et al., 1998; Gathercole, 2006). An intervention that targets this ability could therefore have potential for gains in language learning. However, caution is required in interpreting these results in the absence of control training conditions in the present study; as a consequence, training is confounded with repeat testing. The improved accuracy of repeating five-syllable non-words in the LLA group after training (whose pre-training performance was extremely low at 29% compared with 69% for the comparison group) may simply reflect a practice effect rather than a genuine differential benefit of training. This effect was also shown in the comparison group but at a reduced rate, possibly because some of the group's baseline scores may be close to ceiling. Further studies with randomized allocation of participants to working memory training and suitable control conditions are needed to tease these possibilities apart.

In line with many previous studies (e.g., Melby-Lervåg and Hulme, 2013), both groups made substantial gains on visuo-spatial STM. This outcome is likely to reflect the large number of Cogmed tasks requiring the mental manipulation and storage of visual material. Verbal and performance IQ scores also increased following training for both groups. In the absence a control intervention condition, these improvements at post-assessment are difficult to interpret as they may reflect non-specific features of training such as daily structured engagement and regular feedback rather than the consequences of cognitive improvements following memory-taxing practice. Indeed, evidence from randomized controlled trials has yielded little evidence of selective enhancement of nonverbal reasoning with working memory training (e.g., Redick et al., 2013).

A secondary aim of the study was to investigate whether responses to training are modulated by individual differences prior to training. Exploratory analyses performed on data from the two groups combined to form a single sample revealed some strong predictive links between pre-training scores and training outcomes. First, training improved visuo-spatial working memory to the greatest extent for children with higher verbal abilities. While not a specific a priori prediction, this pattern of findings is broadly consistent with the predictions from the verbal STM account of language impairment (Baddeley et al., 1998) that training targeting the core hypothesized deficit of verbal storage will enhance recall accuracy. However, support for this hypothesis in the analyses performed at the group level (LLA and comparison) was equivocal, as discussed above. The apparent inconsistency in the findings may reflect the fact that group assignment was based on different measures of language to the variables included in these exploratory individual difference analyses. The children in the LLA group were selected in this study on the basis of their performance on two verbal measures, a picture-word matching vocabulary test that required a pointing response (Dunn and Dunn, 2007) and a sentence repetition task. In contrast, verbal IQ is derived from a vocabulary test requiring the generation of definitions, and a similarities test involving comparison of the meanings of different words. It may therefore be the case that facility with the semantic aspects of language is a more critical determinant of response to training than the more phonologically based language abilities tapped by the screening tests.

Verbal IQ was both a positive and a negative predictor of children's responses to working memory training. First, individuals with the lowest baseline verbal IQs made the greatest gains following training in verbal STM. Voluntary rehearsal is widely considered to commence on average at 7 years of age (Flavell et al., 1966; Gathercole et al., 1994), although in lower-achieving children such as the present sample this may be delayed. One possibility is that for these children, the repeated daily practice on multiple Cogmed tasks involving the retention of serial order of verbal material (digits and letters) may promote the development of simple rehearsal strategies, which in turn enhance verbal STM performance. Similar gains have certainly been demonstrated through explicit rehearsal strategy training in younger typically developing children (Johnston et al., 1987). This finding is encouraging, because verbal STM is often the weakest aspect of working memory in children with LLA. There may therefore be particular therapeutic value for working memory training in this population and, potentially, for children with more severe language learning deficits including SLI.

Second, individuals with higher baseline verbal IQs and nonword repetition scores made the greatest improvements on visuo-spatial working memory following training. These preliminary findings indicate that children's responses to training may be directly modulated by their cognitive profiles, and that robust verbal abilities may be vital for the development of new strategies to meet the complex demands of visuo-spatial working memory tasks. For example, it may be easier for children with a strong facility for language to use verbal labels recode stimuli such as spatial locations or colors, providing them with additional ways of retaining the memory items. Consistent with this speculation, recent work has established that Cogmed training is associated with the development of efficient verbal grouping strategies (e.g., Dunning and Holmes, 2014).

This study is, to our knowledge, the first to evaluate whether responses to working memory training are modulated by children's baseline cognitive skills. There are two key findings. First, working memory abilities do not appear to constrain responsiveness to training: the benefits of training for working memory in children with LLA accompanied by poor verbal STM and working memory were largely equivalent to those without language difficulties. Second, training appears to be particularly beneficial for verbal STM in individuals with low verbal abilities indexed by verbal IQ. Also, high verbal IQ may afford children opportunities to develop compensatory strategies through training. These results provide preliminary evidence that baseline cognitive abilities do indeed modulate the impact of working memory training, possibly in multiple ways.

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Cognitive strategy interventions improve word problem solving and working memory in children with math disabilities

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This study investigated the role of strategy instruction and working memory capacity (WMC) on problem solving solution accuracy in children with and without math disabilities (MD). Children in grade 3 ($N = 204$) with and without MD subdivided into high and low WMC were randomly assigned to 1 of 4 conditions: verbal strategies (e.g., underlining question sentence), visual strategies (e.g., correctly placing numbers in diagrams), verbal + visual strategies, and an untreated control. The dependent measures for training were problem solving accuracy and two working memory transfer measures (operation span and visual-spatial span). Three major findings emerged: (1) strategy instruction facilitated solution accuracy but the effects of strategy instruction were moderated by WMC, (2) some strategies yielded higher post-test scores than others, but these findings were qualified as to whether children were at risk for MD, and (3) strategy training on problem solving measures facilitated transfer to working memory measures. The main findings were that children with MD, but high WM spans, were more likely to benefit from strategy conditions on target and transfer measures than children with lower WMC. The results suggest that WMC moderates the influence of cognitive strategies on both the targeted and non-targeted measures.

Keywords: math disabilities, strategy training, working memory, cognitive strategies, problem solving

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Introduction

Although several studies have identified some of the cognitive difficulties in problem solving in children at risk for math difficulties (Swanson and Beebe-Frankenberger, 2004; Andersson, 2010; Fuchs et al., 2010; Geary, 2010), few studies have directly linked deficiencies on cognitive measures to treatment outcomes. One cognitive process that plays a major role in problem solving performance is working memory capacity (WMC). Measures of WMC predict problem solving performance in cross-sectional and longitudinal studies even when measures of calculation, reading, speed, vocabulary, and classroom ratings of inattention have been entered into the regression analyses (Swanson et al., 2008; Zheng et al., 2011). Given the importance of WMC in problem solving performance, this study will test whether strategy instruction compensates for individual differences in WMC in children at risk for math difficulties (MD) on problem solving tasks.

Previous studies show that adjusted post-test scores in problem solving accuracy were a function of the type of strategy instruction implemented as well as WMC capacity at pretest

(Swanson et al., 2013b; Swanson, 2014). The interaction was interpreted as suggesting that strategy effects were more pronounced for children with relatively higher WMC than lower WMC. The authors further interpreted their findings as suggesting that children with relatively smaller WMC were overtaxed by certain strategies, which in turn lead to poor learning outcomes (e.g., problem solving accuracy) after training. There were, however, two major problems related to these studies. First, the influence of WMC on problem solving accuracy was *post-hoc* (WMC viewed as a covariate). That is, the authors relied on the pick-point procedure (e.g., Rogosa, 1980) to assess the effects of WMC. Without designating the influence of WMC a priori and as part of the research design, inferences about causality are in question.

The second limitation was that transfer effects to working memory tasks were not directly assessed. Previous studies by these authors (Swanson et al., 2013a; Swanson, 2014) assumed that strategy training would have a positive influence on both problem solving and working memory because both tasks share a common mechanism. This common mechanism was controlled attention specifically, the ability to coordinate process and storage demands despite interfering information (cf. Engle et al., 1999). Unfortunately, their studies did not directly test whether strategy training that directed children's attention to relevant propositions within word problems within the context of interference (i.e., increasing number of irrelevant propositions) would have a positive influence on WM. Although they found transfer to a verbal WM measure (operation span), these findings maybe simply due to training with verbal material rather than directly influencing general WM performance. To address this issue, the concurrent study assesses transfer to both verbal and visual-spatial WM measures.

In summary, the purpose of this intervention study is to determine whether WMC plays an important role in strategy intervention outcomes related to problem solving accuracy in children with MD. Also of interest, is whether strategy instruction that focuses on helping children with MD solve problems, in the context of increasing inference, influences WM performance. In contrast to previous studies that focused on verbal WM (Swanson, 2014), both verbal and visual-spatial WM measures were administered. A randomized control trial was used where children with MD and without MD were assigned to one of three treatment groups: (1) verbal strategies, (2) visual-spatial strategies, or (3) a combination of both verbal and visual-spatial strategies. Embedded within each of the treatment conditions were lesson plans that gradually increased inferring information (the number of irrelevant propositions) within word problems across training sessions. This type of strategy training directed children to attend to relevant propositions while simultaneously increasing irrelevant propositions within the context of the word problem. This training was motivated by several studies showing that learning to differentiate between relevant and irrelevant information is significantly correlated with solution accuracy and students at risk for MD (e.g., Passolunghi and Siegel, 2001; Passolunghi et al., 2001).

To this end, this study addresses three questions:

1). Do cognitive strategies place different demands on WMC in children with MD?

One hypothesis tested is that children with MD who meet a certain threshold of WMC would have spare working memory resources to benefit from cognitive strategies. Because information has to pass through working memory before it can be consolidated into long-term memory, the limited capacity of working memory can be considered the bottleneck for learning. Thus, individuals with MD but relatively higher WMC are better able to utilize cognitive strategies than children with lower WMC. A contrasting hypothesis is that cognitive strategies compensate for the excessive processing demands placed on WMC due to the extraneous load of the problem solving task. Children with relatively low WMC may be more responsive to cognitive strategies because it helps them compensate for working memory limitations. In contrast, children with relatively higher levels of WMC may experience a level of redundancy or unnecessary processing related to strategy training that does not facilitate learning. Thus, we predict that WMC will interact with treatment outcomes (see Swanson, 2014, for further discussion of these hypotheses).

2). Are some cognitive strategies more effective than others for children with MD?

Although several strategy conditions may improve solution accuracy, relative to the control condition, some strategies may play a more important role for children with MD than their average-achieving peers. Previous studies have shown that because the combined strategy draws upon separate verbal and visual-spatial storage capacities, the combination of these storage systems opens up the possibility for more information to be processed (e.g., Mayer, 2005). Thus, the study explores whether a combination of both verbal and visual-spatial strategies may be more beneficial for enhancing problem solving accuracy relative to strategy conditions that emphasize verbal or visual-spatial strategies in isolation.

3). Does practice solving problems that gradually increase irrelevant information influence WM performance?

We assumed that training that includes gradual increases in competing information within the context of relevant information may improve working memory. As previously stated, we do not expect strategy instructions to directly modify WM *per se*, but rather to increase the retrievability of information. Previous studies have attempted to influence WM by teaching WM direct, but these studies have not found changes that extend beyond trained tasks, and therefore have not yielded changes in academic performance (e.g., Melby-Lervåg and Hulme, 2013). Some studies have found a generalization to non-targeted related processes (visual WM training was related to recognizing visual spatial patterns, Klingberg et al., 2005), or a delayed sleeper effect (Holmes et al., 2009) on math, but strategies to improve or compensate for WM limitations has not been shown, at this point, to make direct or substantial improvement on important classroom tasks such as math problem solving performance. Perhaps one of the reasons for the poor transfer is that the WM training has **not** been embedded within academic instruction. Thus, treatment conditions in this study will include training related to identifying irrelevant propositions (sentence) across lesson plans. We assumed that training that includes gradual increases in competing information within the context of relevant information may improve controlled attention, and therefore have influence on working memory performance. Thus, we tested whether WM performance improved as a function of strategy conditions.

Methods

Participants

Participants were comprised of 204 third grade students from two public school districts in southern California. The research was carried in accordance of the Human Subjects committee and written informed consent at the University of California-Riverside protocol number (HS-O6-099) and Federal grant number USDE R324A090002 Institute of Education Sciences. Written informed consent was received from parents and/or guardians prior to testing and intervention in accordance with the Declaration of Helsinki. This data was gathered in 2010 as part of a larger research project that occurred from 2009 to 2014. The overall goal of the project was to identify an array of strategy conditions that facilitate problem solving in children with math disabilities. Of the 204 children selected for this study, 101 were female and 103 were male. Ethnic representation of the sample was 116 Anglo, 38 Hispanic, 16 African American, 11 Asian, and 28 mixed and/or other (e.g., Anglo and Hispanic, Native American). The mean SES of the sample was primarily low SES to middle SES based on free lunch participation, parent education, and occupation. However, the sample varied from low middle class to upper middle class.

Definition of Risk for Math Disabilities (MD)

The 25th percentile cut-off score on standardized math measures has been commonly used to identify children at risk (e.g., Fletcher et al., 1989; Siegel and Ryan, 1989). Because the focus of this study was on children's word-problem solving difficulties, we examined children who performed in the lower 25th percentile on norm-referenced word-problem solving math tests. We chose to focus on children with MD in grade 3 because this is when word problems are introduced into the curriculum. Our criteria for defining MD was a score between the 25th and 90th percentile on a measure of fluid intelligence (Raven Colored Progressive Matrices Test-RCMT), and a score below the 25th percentile (below a standard score of 90 or scale score of 8) on standardized word problem solving math tests. The story problem subtests from the Test of Math Ability (TOMA, Brown et al., 1994) and Key Math (Connolly, 1998) were used to identify children below the 25th percentile (scale score of 8). This procedure separated the sample into 94 children with MD (46 females) and 110 children (55 females) without MD. **Table 1** shows the means and standard deviations for children with and without MD.

As shown in **Table 1**, performance on standardized measures of word problem solving accuracy for the MD sample was below the 25th percentile (scale score at or below 8, standard score below 90), whereas their norm-referenced scores on calculation, reading comprehension and fluid intelligence were above the 25th percentile. No significant differences emerged between children with and without MD as a function of ethnicity, $\chi^2_{(5,\ N=204)} = 1.26$, $p > 0.05$ or gender, $\chi^2_{(1,\ N=204)} = 0.005$, $p > 0.10$.

Design and Treatment Conditions

Random Assignment

Twenty-two classrooms were randomly assigned to each treatment. All children within each classroom were sent parent permission forms. From the sample of children within each classroom in which permission was granted, a battery of tests were administered to determine children were at risk for MD. Based on the administered tests discussed below, children were stratified as at risk if they performed above or below a median score in WMC based on preliminary data collected in 2009. An approximately equal number of children without MD were randomly selected (stratified by WMC, gender and ethnicity). Thus, the sample included children assigned to a control group ($N = 56$), or to one of three treatment conditions [Verbal-emphasis ($N = 49$), Verbal + Visual Strategies (Diagramming; $N = 53$), and Visual-emphasis (Diagramming; $N = 46$)].

Common Instructional Conditions

All children in the study participated with their peers in their home rooms on tasks and activities related to the district wide math school curriculum. The school wide instruction across conditions was the enVisionMATH Learning Curriculum (Pearson Publishers, 2009). A number of the elements within the curriculum were also utilized in our treatments (e.g., find the pattern, etc…). However, in contrast to the district instruction, our treatment conditions directly focused on specific components of problem solving over consecutive sessions presented in a predetermined order. In addition, the lesson plans for the experimental condition focused directly on the propositional structure of word problems.

Experimental Conditions

Each experimental treatment condition included 20 scripted lessons administered over 8 weeks. Iterations of the treatment lesson plan are reported in Swanson et al. (2013a; Appendix A in Supplementary Materials). We briefly summarize the procedures here (also see Swanson, 2014, for a complete description).

Each lesson was 30 min in duration and was administered three times a week in small groups of four to five children. Lesson administration was done by one of six tutors (doctoral students). Children were presented with individual booklets at the beginning of the lesson, and all responses were recorded in the booklet. Each lesson within the booklet consisted of four phases: warm-up, instruction, guided practice, and independent practice.

The warm-up phase included two parts: calculation of problems that required participants to provide the missing numbers ($9 + 2 = x$, $x + 1 = 6$; $x - 5 = 1$), and a set of puzzles based on problems using geometric shapes. This activity took approximately 3–5 min to complete.

TABLE 1 | Comparison of children with and without math disabilities on pretest and moderator variables as a function of high and low WM.

	Total sample			Math disabled				Average achievers			
	N = 204			Low-WM		High-WM		Low-WM		High-WM	
	Mean	*SD*	Reliability	Mean (*N* = 63)	*SD*	Mean (*N* = 32)	*SD*	Mean (*N* = 45)	*SD*	Mean (*N* = 65)	*SD*
Age	106.26	7.08		107.17	8.72	108.53	6.36	103.79	5.41	105.92	5.94
CLASSIFICATION											
TOMA-S	8.16	2.35	0.84	6.27	1.08	6.84	1.07	9.09	2.20	9.97	2.05
Key-math-S	9.20	3.43	0.93	5.76	2.66	7.33	1.15	11.39	1.98	10.87	2.19
Average-S	9.00	2.99	0.87	6.28	1.91	6.7	1.61	11.57	1.66	11.12	1.59
FLUID INTELL.											
Raven-ST	104.46	12.5	0.99	99.35	12.66	100.84	10.92	110	11.14	107.16	11.76
READING											
TORC-S	10.47	2.19	0.80	9.48	2.19	9.81	2.17	10.93	1.97	11.42	1.86
WRAT-ST	105.28	12.29	0.81	98.21	10.39	105.56	12.39	106.51	8.72	111.42	12.8
CALCULATION											
WIAT_ST	99.36	11.24	0.86	95.16	10.64	98.16	10.65	100.87	9.85	103.27	11.7
WRAT_ST	100.19	11.17	0.81	94.63	10.66	97.91	11.29	103.19	9.22	104.94	10.23
WORKING MEMORY											
Rconceptwm-R	5.50	4.78	0.80	3.03	2.13	7.75	4.10	3.44	2.82	8.32	5.98
Rdigsent-R	7.00	4.94	0.84	4.56	2.97	8.75	5.09	5.00	3.15	10.05	5.55
Update-R	6.46	4.46	0.84	3.78	2.58	9.00	4.69	4.19	2.67	9.57	4.25
WM span[a]	−0.04	2.04		−1.64	0.86	1.34	1.28	−1.36	0.88	1.87	1.7
CRITERION MEASURES											
CMAT_R	8.06	3.07	0.90	6.14	3.04	7.78	2.80	8.6	2.42	9.75	2.54
Visual matrix-R	13.73	8.51	0.90	11.39	7.20	17.02	10.64	13.31	8.39	14.78	8.09
Oper Span-R	4.67	4.29	0.87	4.23	3.59	4.47	4.25	4.48	4.09	5.37	5.04

_R at the end refers to Raw Score, _S at the end refers to Standard or Scale Score; TOMA, Test of Math Ability; CMAT, Comprehensive Test of Math Abilities; KEY-Math, Key Math test; Average_S, mean scale-score (TOMA, KEYM); WRAT, Wide Range Achievement Test; TORC, Test of Reading Comprehension; CONCEP, conceptual span; Composite[a] = mean z-score of WM span (conceptual span, digit/sentence span, and updating).

The instruction phase lasted approximately 5 min. At the beginning of each lesson, the strategies and/or rule cards were either read to the children (e.g., to find the whole, you need to add the parts) or reviewed. Depending on the treatment condition, children were taught the instructional intervention (Verbal strategy, Diagramming, or Verbal strategy + Diagramming). The steps for the Verbal-emphasis approach included: find the question and underline it, circle the numbers, put a square around the key word, cross out information not needed, decide on what needs to be done (add/subtract/or both), and solve it. For the Visual-emphasis condition (diagramming) students were taught how to use two types of diagrams. The first one represented how parts made-up a whole. The second type of diagram represented how quantities are compared. The diagram consisted of two empty boxes, one bigger and the other smaller, in which the students were to fill in the correct numbers representing the quantities. An equation with a question mark was presented. The question mark acted as a placeholder for the missing number provided in the box. Finally, for the combined Verbal + Visual (diagramming) Strategy condition, an additional step (diagramming) was added to the 6 Verbal Strategy steps described above. This step included directing students to fill in the diagram with given numbers and identifying the missing numbers (question) in the corresponding slots in the boxes.

The third phase, *guided practice*, lasted 10 min and involved students working on three practice problems. Tutor feedback was provided on the application of steps and strategies to each of these three problems. In this phase, students also reviewed example problems from the instructional phase. The tutor assisted students with finding the correct operation, identifying the key words, and providing corrective feedback on the solution.

The fourth phase, *independent practice*, lasted 10 min and required students to independently answer another set of three word problems without feedback. If the student finished the independent practice tasks before the 10 min were over, they were presented with a puzzle to complete. Student responses were recorded for each session to assess the application of the intervention and problem solving accuracy. In order to make application comparisons across treatment, point values were converted to z-scores. For the Visual–emphasis condition, points were recorded for correctly choosing the correct diagram, correctly filling in the numbers for the diagram, identifying the correct operations, and correctly solving the problem. For the Verbal + Visual-Strategy condition, points were recorded for correctly choosing the diagram, inserting correct numbers, applying strategies, identifying the correct operations, and correctly solving the problem. For the Verbal-emphasis condition, points were recorded for identifying the correct numbers, applying strategies (e.g., underlining), identifying the correct operations, and solution accuracy.

Increments of Irrelevant Propositions

Word problems for each *independent practice* session included three parts: question sentences, number sentences, and irrelevant sentences. For each problem in the independent practice session, at least two number sentences were relevant to problem's solution and one sentence served as the question sentence. The number of sentences, however, gradually increased across the training sessions. The number of sentences were as follows: Lessons 1 through 7 focused on identifying critical information for word problems four sentences long with one irrelevant sentence, lessons 8 and 9 focused on five-sentence-long word problems with two irrelevant sentences, lessons 10 through 15 focused on six-sentence-long word problems with three irrelevant sentences, lessons 16 and 17 focused on seven-sentence-long word problems with four irrelevant sentences, and lesson 18 through 20 focused on eight-sentence-long word problems with five irrelevant sentences.

Treatment Fidelity

Independent evaluations were carried out to determine the treatment fidelity. During the lesson sessions, tutors were randomly evaluated by an independent observer (a post-doctoral student, a non-tutoring graduate student, and/or the project director). The observers independently filled out evaluation forms covering all segments of the lesson intervention. Points were recorded on the accuracy to which the tutor implemented the instructional sequence based off of a rubric. Observations of each tutor occurred for six sessions and was randomly distributed across instructional sessions. Inter-rater agreement was calculated on all observations and exceeded 90% across all observed categories.

Tasks and Materials

Prior to treatment implementation, a battery of group and individually administered tasks were administered. The tasks are described in detail elsewhere (Swanson et al., 2013a), but summarized below. Experimental tasks are described in more detail than published and standardized tasks. Tasks were divided into classification, pretest-only (moderator measures), and pretest/posttest measures. The sample reliabilities for each measure are reported in **Table 1** and varied from 0.60 to 0.98.

Classification Measures

Word Problems

Two measures were administered to assess word problem solving ability. The word problem subtests from the Test of Math Ability (TOMA-2; Brown et al., 1994) and KeyMath (KEYM, Connolly, 1998) were administered. Subtests from these measures yielded a scale score ($M = 10$, $SD = 3$).

Arithmetic Computation

The arithmetic subtests from the *Wide Range Achievement Test* (WRAT-III; Wilkinson, 1993) and the *Wechsler Individual Achievement test* (WIAT; Psychological Corporation, 1992) were administered. Both subtests required written computation to problems that increased in difficulty. Problems began with simple calculations ($2 + 2 =$) to algebra. The dependent measure was the number of problems correct, which yielded a standard score ($M = 100$, $SD = 15$).

Fluid Intelligence

To determine if all children were in the normal range on a measure of fluid intelligence, the *Raven Colored Progressive Matrices* (Raven, 1976, RCMT) was administered. Children were required to circle the replacement piece that best completed the patterns. After the introduction of the first matrix, children completed their booklets at their own pace. Patterns progressively increased in difficulty. The dependent measure (raw score range 0–36) was the number of problems solved correctly, which yielded a standardized score ($M = 100$, $SD = 15$).

Working-Memory (WM) Measures

Three tasks were administered in this study to identify individual differences in WMC at pretest. A composite score was computed based on the z-scores of each these three tasks described below. Based on the median score z-score for the tasks below, the sample was divided into high and low WMC groups.

Conceptual Span Task

The purpose of this task was to assess the participant's ability to organize sequences of words into abstract categories (Swanson, 1992, 2013). The participant was presented with a set of words (one every 2 s), asked a discrimination question, and then asked to recall the words that "go together." For example, a set might have included the following words: "shirt, saw, pants, hammer, shoes, nails." The discrimination question was, "Which word, 'saw' or 'level,' was said in the list of words?" Thus, the task required participants to transform information encoded serially into categories during the retrieval phase. The difficulty of the sets ranged between two categories of two words to five categories of four words. The dependent measure was the highest set recalled correctly (range of 0–8) in which the process question was answered correctly.

Digit/Sentence Span

This task assessed the child's ability to remember numerical information embedded in a short sentence (Swanson, 1992, 2013). Before stimulus presentation, the child was shown a card depicting four strategies for encoding numerical information to be recalled. The pictures portrayed the strategies of rehearsal, chunking, association, and elaboration. The experimenter described each strategy to the child before the administration of targeted items. After all strategies have been explained, the child was then presented with numbers in a sentence context. For example, item 3 stated, "Now suppose somebody wanted to have you take them to the supermarket at 8 6 5 1 Elm Street?" The numbers were presented at 2-s intervals, followed by a process question (i.e., "What was the name of the street?"). Then, the child was asked to select a strategy from an array of four strategies that represented the best approximation of how he or she planned to practice the information for recall. Finally, the examiner prompted the child to recall the numbers from the sentence in order. No further information about the strategies was provided. Students were allowed 30 s to remember the information. Recall difficulty for this task ranged from 3 to 14 digits; the dependent measure was the highest set correctly recalled (range = 0–9) in which the process question was answered correctly.

Updating

Because WM tasks were assumed to tap into a measure of controlled attention referred to as updating (e.g., Miyake et al., 2000), an experimental updating task, adapted from Morris and Jones (1990), was also administered. A series of one digit numbers were presented that varied in set lengths of nine, seven, five, and three. No digit appeared twice in the same set. The examiner told the child that the length of each list of numbers might be three, five, seven, or nine digits. Participants were then told that they should only recall the last three numbers presented. Each digit was presented at approximately 1-s intervals. After the last digit was presented, the participant was asked to name the last three digits in order. In contrast to the aforementioned WM measures that involved a dual-task situation where participants answered questions about the task while retaining information (words or spatial location of dots), the current task involved the active manipulation of information such that the order of new information added to or replaced the order of old information. That is, to recall the last three digits in an unknown ($N = 3$, 5, 7, 9) series of digits, the order of old information must be kept available (previously presented digits), along with the order of newly presented digits. Thus, task performance reflected the activity of both the phonological system as well as the executive system. The dependent measure was the total number of sets correctly repeated (range 0–16).

Pretest and Posttest Measures

Targeted Measure of Word Problem Solving Accuracy

Because children were classified as at risk for MD on the TOMA and KeyMath, a separate norm-referenced measure of word problem solving accuracy was administered at pretest and posttest: the Story Problem subtest from the Comprehensive Mathematical Abilities Test (CMAT; Hresko et al., 2003). The technical manual for this subtest reported adequate reliabilities (>0.86) and moderate correlations (>0.50) with other math standardized tests (e.g., the Stanford Diagnostic Mathematics Test). The test included story problems that increased in solution difficulty. Two forms of the measures were created that varied only in names and numbers. The two forms were counterbalanced across presentation order.

Transfer Measures

We were interested in how well treatment effects that combined strategy instruction with a practice that included a gradual increase in identifying irrelevant proposition would generalize to working memory tasks. Two working memory tasks were administered.

Operation Span

A version of the Turley-Ames and Whitfield (2003) operation span task, modified for children (Swanson et al., 2010), was administered at pretest and posttest. Two identical forms were created and counterbalanced for presentation order. The operation span test assessed WM span by having participants solve simple math problems while remembering unrelated to-be-remembered (TBR) words that followed each math problem. After each simple addition or subtraction operation, a TBR word was visually and orally presented for later recall. Our measure differed from those in the Turley-Ames and Whitfield tasks in two ways. First, a list of high-frequency words derived from Fry's Most Frequently Used Word List and the Dolch reading list served as the TBR words for pre- and post-operation span measures. Second, only one-digit addition and subtraction math problems were used. Prior to the study, TBR words were assigned randomly to math operations. Similar to Turley-Ames and Whitfield measures, operation-word sequences were presented in five parts: (a) a number from 1 to 18, (b) an addition or subtraction sign, (c) a number from 1 to 18, and (d) "= ____." When the "d" part of the operation was presented, the participant read the math problem aloud, reported an answer, and the experimenter recorded the participant's answer. After providing an answer for the math problem, the TBR word was revealed for 5 s and read aloud by the participant.

Operation-word sequences were presented in increasing set size. Children completed two practice trials with a set size of two. Children were then presented with operation-word sequences in sets of 2, 3, 4, and 5 with two trials for each set size for a total of 10 sets. Children received points toward their span score for correctly solving the math problems, for the number of correctly recalled words, and for the correct order of word recall. This scoring procedure was implemented to prevent giving participants credit for recalling words at the expense of solving the math problems incorrectly.

Visual Matrix Task

The purpose of this task was to assess the ability of participants to remember visual sequences within a matrix (Swanson, 1992, 2013). Participants were presented a series of dots in a matrix and were allowed 5 s to study the matrix. The matrix was then removed and participants were asked, "Are there any dots in the first column?" To ensure the understanding of columns prior to the test, participants were shown the first column location and practiced finding it on blank matrices. In addition, for each test item, the experimenter pointed to the first column on a blank matrix (a grid with no dots) as a reminder of the first column location. After answering the discriminating question (by circling "Y" for yes or "N" for no), students were asked to draw the dots they remembered seeing in the corresponding boxes of their blank matrix response booklets. The task difficulty ranged from a matrix of four squares and two dots to a matrix of 45 squares and 12 dots. The dependent measure was the highest set recalled correctly (range of 0–11) in which the process question was answered correctly.

Covariate

Several studies have found that WM was unrelated to problem solving accuracy when reading proficiency scores were entered into the regression analyses (Swanson et al., 1993; Fuchs et al., 2006). Thus, it was necessary to administer reading measures at pretest because of their potential to partial out the effects of WM on problem solving accuracy in post-test treatment outcomes.

Word Recognition

Word Recognition was assessed by the reading subtest of the WRAT-III. The task provided a list of words of increasing difficulty. The child's task was to read the words until 10 errors occurred. The dependent measure was the number of words read correctly.

Reading Comprehension

Reading comprehension was assessed by the Passage Comprehension subtest from the Test of Reading Comprehension (TORC-III, Brown et al., 1995). The purpose of this task was to assess the child's comprehension of topic or subject meaning's during reading activities. Comprehension questions were drawn from the reading of short-paragraphs. The dependent measure was the number of questions answered correctly.

Results

Table 1 provides the means, standard deviations, and reliability (Cronbach α) of the measures for the total sample. The means and standard deviations were further divided into children with and without MD, and further divided into high and low working memory span groups based on a median split of the WM composite score (mean z-score of updating, digit-sentence span, conceptual span) administered at pretest. As expected from a median split of the total sample, children with MD were more likely to yield low WM span scores (67% of MD sample) than children without MD (40%), $\chi^2_{(1,\ N=204)} = 13.87$, $p < 0.001$. Thus, it is important to note in our sample that not all children with MD in problem solving suffered from low WM skills.

For analyses purposes, post-test criterion measures were converted to z-scores based on pretest performance ($M = 0$, $SD = 1$). The z-score transformation allowed for comparison across various dependent measures as well as the identification of outliers (absolute z-score > 3.5). There were no outliers e identified in this data set. **Table 2** provides the posttest z-scores based on the mean and standard deviations at pretest, as well as posttest scores adjusted for pretest and the reading composite scores. Also reported are the gain z-scores (posttest minus pretest) that were uncorrected for pretest performance.

For archival purposes, Appendix A in Supplementary Materials shows the raw pretest, posttest, and gain performance as a function of treatment conditions (Verbal-emphasis, Verbal + Visual Strategy, Visual-emphasis, and control), MD status (non MD vs. MD), and WM span (high vs. low), respectively. Also reported are the sample sizes for each treatment as a function of the subgroups.

Comparisons at Pretest

Prior to analyzing treatment effects at post-test, comparison was made between pretest measures as a function of treatment conditions as well as a function of math and WMC subgroups.

The criterion measures used to assess treatment effects were the CMAT, Operation Span, and Visual Matrix Span. A MANCOVA was computed between the four treatment conditions at pretest on these criterion measures. The MANOVA was not significant, Wilks' $\Lambda = 0.94$, $F_{(9,\ 464)} = 1.39$, $p > 0.05$. One-Way ANOVAs were also computed on fluid intelligence (Raven), reading composite scores (WRAT-III and TORC), and the WM composite score as a function of treatment conditions. The results were non-significant for the fluid intelligence,$F_{(3,\ 198)} = 1.22$, $p > 0.05$, reading, $F_{(3,\ 198)} = 1.54$, $p > 0.05$, and for the WM composite score, $F_{(3,\ 198)} = 0.51$, $p > 0.05$.

Although children were randomly assigned to treatment conditions, it was necessary to determine if preexisting differences emerged on demographic and classification measures. A chi-square test indicated no significant differences emerged among the 4 treatment conditions as a function of MD status, $\chi^2_{(3,N=204)} = 2.15$, $p > 0.05$, or gender, $\chi^2_{(3,N=204)} = 4.88$, $p > 0.10$. In addition, no significant differences emerged in the proportion of high and low WM span groups across treatment conditions, $\chi^2_{(3,N=204)} = 2.83$, $p > 0.05$. A further comparison was made amongst the classification measures between the two math groups. A MANOVA was computed between children with MD and without MD (NMD) on standard scores for problem solving (TOMA, Key Math, CMAT), reading (WRMT, WRAT), RCMT, and math calculation (WRAT, WIAT). As expected, the MANOVA was significant, Wilks'$\Lambda = 0.27$, $F_{(6,\ 178)} = 78.67$, $p < 0.001$. All the univariates (ps < 0.05) were significant and in favor of children without MD. The standard scores are shown in **Table 1**. It is important to note that although fluid intelligence, reading, and calculation scores were in the normal range for children with MD, children without MD had a clear advantage across these aptitude and achievement measures.

Post-test Performance

The primary analysis for this study was a mixed ANCOVA on post-test scores. The random effects included children nested within classrooms. In contrast to a traditional ANCOVA, where significance is tested against the residual error, the test of fixed effects in mixed models is tested against the appropriate error terms as determined by the model specification. The method also overcomes some of the limitations of a traditional ANCOVA because it does not require that missing data be ignored and provides a valid means to addressing standard errors. The estimates for criterion were based with full-information maximum-likelihood, and utilized robust standard errors (Huber-White) to allow for the non-independence of observations from children nested within the classroom. Because the cells were unbalanced and missing data, a Kenward-Roger correction was used to obtain the degrees of freedom.

Problem Solving Accuracy

A 2 (MD status: MD vs. NMD risk) × 2 (WMC: high and low WM ability) × 4 (treatment condition) mixed ANCOVA (pretest and reading as covariates) was computed on the CMAT scores. The covariate for reading was a composite score (WRAT, TORC). The results indicated a significant main effect for MD status, $F_{(1,\ 163)} = 7.43$, $p < 0.01$ and treatment, $F_{(3,\ 163)} = 3.13$, $p < 0.01$. A significant effect also occurred for the WMC x treatment

TABLE 2 | Z-scores for posttest, gain, and adjusted posttest scores as a function of treatment conditions, md status, working memory level, and criterion measures.

Variable	Verbal-emphasis			Verbal + Visual			Visual-emphasis			Control		
	Mean	*SD*	ADJ	Mean	*SD*	ADJ	Mean	*SD*	ADJ	Mean	*SD*	ADJ
MD-LWM												
CMAT2[a]	−0.37	0.80	0.28	0.03	1.06	0.42	−0.45	1.37	0.10	−0.32	0.87	0.21
Visual-Span2	0.06	1.01	0.007	0.63	1.09	0.52	−0.13	0.94	−0.05	−0.51	0.79	−0.36
Oper-Span2	0.03	1.02	0.40	0.17	0.74	0.21	0.21	0.76	0.29	0.14	0.76	0.40
Gain Scores												
CMAT-G	0.59	0.43		0.54	0.69		0.28	0.58		0.29	0.82	
Visual-Span-G	0.27	1.3		0.85	1.08		0.52	1.00		−0.26	1.1	
Oper-Span-G	0.49	0.66		0.15	0.33		0.25	0.33		0.37	0.54	
MD-HWM												
CMAT2[a]	0.70	0.43	0.52	0.06	1.09	0.15	0.55	0.56	0.43	0.24	0.93	0.08
Visual-Span2	0.10	1.22	−0.12	0.34	0.98	0.21	1.65	0.53	1.54	−0.74	0.47	−0.39
Oper-Span2	0.24	0.93	0.32	0.25	0.8	0.22	1.42	1.00	1.75	0.5	1.25	0.29
Gain Scores												
CMAT-G	0.72	0.85		0.30	0.38		0.33	0.8		0.07	0.27	
Visual-Span-G	−0.79	1.43		−0.22	1.33		1.38	1.36		−0.24	1.05	
Oper-Span-G	0.42	0.68		0.23	0.3		1.87	1.25		0.19	0.48	
NMD-LWM												
CMAT2[a]	0.82	0.53	0.69	0.42	0.53	0.19	0.47	0.71	0.42	0.74	0.57	0.75
Visual-Span2	0.06	1.09	−0.02	0.83	1.37	0.93	−0.03	0.77	0.02	0.04	0.7	0.14
Oper-Span2	−0.04	0.64	0.13	0.04	0.75	0.25	0.80	1.05	0.96	0.59	0.96	0.43
Gain Scores												
CMAT-G	0.65	0.64		0.11	0.27		0.42	0.74		0.74	0.77	
Visual-Span-G	−0.2	0.97		1.19	1.73		0.09	1.17		0.35	1.13	
Oper-Span-G	0.21	0.56		0.35	0.55		0.91	1.02		0.35	0.76	
NMD-HWM												
CMAT2[a]	1.20	0.6	0.58	0.96	0.89	0.52	0.94	0.53	0.49	0.42	0.87	0.23
Visual-Span2	0.64	0.94	0.59	0.93	0.84	0.87	0.08	0.85	0.05	−0.03	0.93	−0.23
Oper-Span2	0.79	1.12	0.45	0.83	1.33	0.41	0.45	0.72	0.42	0.24	1.01	0.39
Gain Scores												
CMAT-G	0.41	0.39		0.46	0.61		0.41	0.63		0.16	0.49	
Visual-Span-G	0.36	1.18		0.8	1		0.16	1.03		−0.48	1.24	
Oper-Span-G	0.39	0.78		0.32	0.64		0.48	0.7		0.48	0.71	

ADJ, Adjusted mean post-test for covariates and cell size; LWM, low working memory; HWM, high working memory, Verbal-emphasis, N = 11 for MD-LWM and N = 10-MD-HWM, N = 12 for non NMD-LWM and N = 16 for NMD-HWM, Verbal + Visual Strategies, N = 20 for MD-LWM and N = 12 MD-HWM, N = 6 for non MD-LWM and N = 17 for NMD-HWM, Visual-emphasis, N = 15 for MD-LWM and N = 4 MD-HWM, N = 10 for non MD-LWM and N = 15 for NMD-HWM. Control, N = 20 for MD-LWM and N = 5 MD-HWM, N = 15 for NMD-LWM and N = 14 for NMD-HWM.

[a] *Two after measure is the posttest score, _g, gain score; CMAT, Comprehensive Math Abilities Test; Oper, Operation Span; Visual-span, Visual matrix span measure.*

interaction, $F_{(3, 163)} = 3.56$, $p < 0.05$, and the MD status × WMC × treatment interaction, $F_{(3, 163)} = 2.65$, $p < 0.001$. The covariates were significant for pretest, $F_{(1, 163)} = 86.63$, $p < 0.001$ and reading, $F_{(1, 163)} = 19.60$, $p < 0.0001$. As expected, the adjusted posttest scores were significantly lower for children with MD when compared to children without MD (Adjusted $M = 0.28$, $SE = 0.04$ vs. 0.48, $SE = 0.04$) and post-test scores were significantly ($ps < 0.05$) higher for the verbal emphasis condition when compared to other conditions (adjust *M*'s = 0.54, 0.32, 0.36, 0.32 for verbal, verbal + visual, visual emphasis and control condition, respectively).

A test of simple effects on adjusted posttest scores within treatment conditions yielded significant performance differences among subgroups the included children with MD but low WM (MD-LWM), children with MD but relatively high WM (MD-HWM), children without MD but low WM (NMD-LWM), and children without MD but high WM (NMD-HWM). Significant effects occurred for the verbal + visual condition, $F_{(3, 163)} = 4.89$, $p < 0.1$ and control condition $F_{(3, 163)} = 3.80$, $p > 0.05$. No other significant effects occurred (all $ps > 0.05$). A Tukey test yielded significant ($ps < 0.05$) subgroup differences within the verbal + visual condition (MD-LWM = NMD-HWM > NMD-LWM = MD-LWM), and control condition (NMD-LWM > NMD-HWM = MD-LWM = MD-HWM).

When comparisons were made across treatment conditions within each subgroup, no significant treatment effects were found for the MD-LWM subgroup, $F_{(3,\ 163)} = 1.11$, $p > 0.05$. Significant treatment effects were found for the MD-HWM subgroup $F_{(3,\ 163)} = 4.69$, $p < 0.01$ (verbal = visual > verbal + visual = control), NMD-LWM subgroup, $F_{(3,\ 163)} = 10.48$, $p < 0.01$ (control = verbal > visual > verbal + visual), and the NMD-HWM subgroup, $F_{(3,\ 163)} = 2.97$, $p < 0.05$ (verbal = verbal + visual = visual > control).

In general, the important pattern related to the three-way interaction was that children with low WMC and at risk for MD did not benefit from the strategy conditions when compared to the control conditions. Thus, we did not find support for the assumption that strategy conditions were more likely to help children with MD but low WMC, than children with MD but relatively higher WMC.

Transfer

As before, a mixed level 2 (high vs. low risk for MD) × 2 (high and low WM ability) × 4 (treatment condition) ANCOVA (pretest and reading as covariates) was computed on posttest scores for the transfer measures.

Visual Matrix

A mixed 2 (MD vs. NMD risk) × 2 (high and low WMC ability) × 4 (treatment condition) ANCOVA (pretest and reading as covariates) was computed on the adjusted visual-matrix scores. The results indicated a significant main effect for treatment, $F_{(3,\ 161)} = 5.67$, $p < 0.01$, and for the MD status x treatment interaction, $F_{(3,\ 161)} = 20.47$, $p < 0.01$,WMC × treatment interaction, $F_{(3,\ 161)} = 2.86$, $p < 0.05$, and the MD status × WMC × treatment interaction, $F_{(3,\ 161)} = 3.73$, $p < 0.001$. The covariates were significant for pretest, $F_{(1,\ 161)} = 32.64$, $p < 0.001$, but not reading, $F_{(1,\ 161)} = 0.11$, $p > 0.05$. As expected, the adjusted posttest scores were significantly higher for children with higher WMC than lower WMC (Adjusted $M = 0.31$, $SE = 0.07$ vs.0. 15, $SE = 0.12$), and scores were significantly ($ps < 0.05$) higher for the verbal + visual condition when compared to other treatment conditions (adjust M's = 0.12, 0.63, 0.39, −0.21 for verbal, verbal + visual, visual emphasis, and control conditions, respectively).

Within treatment conditions, a significant subgroup effect occurred for the verbal, $F_{(3,\ 161)} = 3.04$, $p < 0.05$, verbal + visual, $F_{(3,\ 161)} = 17.67$, $p < 0.001$, and control conditions $F_{(3,\ 161)} = 3.83$, $p < 0.01$. No other significant effects occurred. A Tukey test indicated that the significant (ps < 0.05) subgroup differences occurred within the verbal (NMD-HWM > NMD-LWM = MD-LWM > MD-HWM), verbal + visual (NMD-HWM = NMD = LWM > MD-LWM = MD-HWM) and control conditions (NMD-LWM > NMD-HWM = MD-LWM = MD-HWM).

When comparisons were made across treatment conditions within each subgroup, no significant treatment effects were found for the NMD-HWM subgroup, $F_{(3,\ 161)} = 2.17$, $p > 0.05$, or the MD-HWM subgroup, $F_{(3,\ 161)} = 1.79$, $p > 0.05$. Significant treatment effects were found for the MD-LWM subgroup $F_{(3,\ 161)} = 2.69$, $p < 0.05$ (verbal + visual > visual > verbal > control), and the NMD-LWM subgroup, $F_{(3,\ 161)} = 15.90$, $p < 0.01$ (verbal + visual > control > verbal = visual).

In summary, the results contrast with the post-test problem solving findings for children with MD but low WMC. The previous results suggested that the verbal + visual condition yielded significantly higher post-test visual-spatial WM scores for children with and without MD who also have low WMC when compared to other conditions.

Operation Span

A 2 (MD vs. NMD risk) × 2 (high and low WM ability) × 4 (treatment condition) mixed ANCOVA (pretest and reading as covariates) was computed on the post-test operation span scores. The results yielded a significant effect for treatment, $F_{(3,\ 170)} = 9.44$, $p < 0.01$, WMC, $F_{(1,\ 170)} = 4.10$, $p < 0.01$, and the MD status × WMC × treatment interaction, $F_{(3,\ 163)} = 2.65$, $p < 0.001$. The covariates were significant for pretest, $F_{(1,\ 170)} = 272.77$, $p < 0.001$, but not reading, $F_{(1,\ 170)} = 3.40$, $p = 0.07$. The adjusted posttest scores were significantly higher for children with higher WMC when compared to children with lower WMC (Adjusted $M = 0.53$, $SE = 0.06$ vs. 0.37, $SE = 0.03$), and scores were higher for the visual emphasis condition when compared to other conditions (adjust M's = 0.32, 0.28, 0.83, 0.38 for verbal, verbal + visual, visual emphasis and control condition, respectively).

Within treatment conditions, a test of simple effects on adjusted posttest scores yielded significant performance differences among subgroups within the visual emphasis condition, $F_{(3,\ 170)} = 20.80$, $p < 0.01$. No other subgroup differences occurred within treatments ($ps > 0.05$). A Tukey test showed that significant (ps < 0.05) subgroup effects within the visual-emphasis condition were related to higher post-test performance for children MD and high WMC (MD-HWM > NMD-LWM > NMD-HWM > MD-LWM).

When comparisons were made across treatment conditions, no significant treatment effects were found for the MD-LWM subgroup, $F_{(3,\ 170)} = 1.10$, $p > 0.05$, or the NMD-HWM subgroup, $F_{(3,\ 170)} = 0.03$, $p > 0.05$. Significant treatment effects were found for the MD-HWM subgroup, $F_{(3,\ 170)} = 5.46$, $p < 0.01$ (visual > verbal + visual = control > verbal emphasis) and the NMD-LWM subgroup, $F_{(3,\ 170)} = 4.60$, $p < 0.01$(visual > control > verbal + visual > verbal).

In summary, the results indicated an advantage at post-test for the visual emphasis condition relative to the control condition for the operation span measures, but these effects were isolated to children with MD with relatively higher WMC.

Effect Sizes

In summary, a number of significant interactions for posttest outcomes occurred as a function of treatment conditions and subgroups. However, because of small sample sizes (see Appendix A in Supplementary Materials), the experiment may have been underpowered. To partially address this issue, effect sizes (ESs) were computed. We calculated Hedge's $g = \gamma / [(SD_1^2)\ (N_1) + (SD_2^2)\ (N_2)/2]^{1/2}$ where γ was the HLM coefficient for the adjusted posttest mean difference between treatment (adjusted for pretest and reading and adjusted for both level-1 and level-2 covariates), and N_1 and N_2 were the sample sizes. SD_1 and

SD_2 were the standard deviations for the unadjusted posttest treatment conditions, respectively.

Table 3 shows ESs comparing each treatment within each subgroup. For the interpretation of the magnitude of the effect sizes, Cohen's (1988) distinction was used: (1) an ES of 0.20 is considered small, and (2) an ES of 0.50 and 0.80 is considered moderate and large, respectively. For the purposes of this study, only ESs above 0.50 were considered meaningful. As shown in **Table 3**, the first left three columns show ESs for the control condition (treatment = 4) when compared to verbal-emphasis (treatment = 1), verbal + visual (treatment = 2), and visual-emphasis (treatment = 3) conditions. A negative effect size favored the strategy conditions over the control condition.

Children with MD

For the MD- low WMC subgroup (MD-LWM), no meaningful effect sizes emerged related to problem solving accuracy. The only ESs of importance was the large ESs ($ES = 0.92$) in favor of the combined verbal + visual conditions relative to control conditions on post-test measures of visual-spatial WM.

For children with MD, but high WM spans, a high ES ($ES = 0.70$) occurred in favor of the verbal-emphasis treatment when compared to the control condition on the problem solving measure. A clear advantage relative to the condition was also found for the visual-emphasis condition for the visual-spatial WM transfer task ($ES = 3.89$), and the operation span transfer task ($ES = 1.27$).

Children without MD

For children without MD but low WM spans, no clear advantage was found for a specific strategy condition when compared to the control condition on posttest problem solving accuracy scores. An advantage at post-test was found relative to the control condition for the verbal + visual condition on the transfer measures of visual-spatial WM ($ES = 0.85$), and the visual emphasis condition for the operation span transfer measure ($ES = 0.53$).

For children without MD but high WM spans, a slight advantage was found for the verbal emphasis condition when compared to the control condition on measures of post-test problem solving ($ES = 0.47$). In addition, the verbal and verbal + visual conditions exceeded the control condition on posttest measures of visual-spatial WM ($ES = 0.88, 1.25$), whereas no strategy advantage was found for strategy conditions on the operation span measure (ES vary from 0.02 to 0.06).

Discussion

This study investigated the role of strategy instruction on word problem solving accuracy in children with MD. Three important findings occurred. First, support was found for the notion that strategy instruction facilitates solution accuracy but the effects of strategy instruction were moderated by individual differences in WM span. Second, some strategies yielded higher post-test scores than others, but these findings were qualified as to whether children were or were not at risk for MD. Finally support was found for strategy training on problem solving measures in facilitating a transfer to working memory measures. Given these general findings, the results will now be placed within the three questions that directed this study.

Do Cognitive Strategies Place Different Demands on WMC in Children with MD?

Initially, we assumed that strategy training would be more beneficial for children with MD than for children without MD. That is, we assumed that any potential three-way interactions (ability group × WMC × treatment) would reflect variations

TABLE 3 | Effect sizes on post-test means adjusted for pretest, reading and random effects.

	1 vs. 4	2 vs. 4	3 vs. 4	1 vs. 3	2 vs. 3	1 vs. 2
MD-LWM						
CMAT	0.08	0.22	−0.10	0.15	0.27	−0.14
Visual-Span	0.42	**0.92**	0.36	0.06	0.55	−0.48
Oper-Span	0.01	−0.25	−0.14	0.13	−0.11	0.22
MD-HWM						
CMAT	**0.70**	0.07	0.44	0.19	−0.28	0.43
Visual-Span	0.26	**0.69**	**3.89**	−1.52	−1.47	−0.30
Oper-Span	0.03	−0.07	**1.27**	−1.51	−1.81	0.12
NMD-LWM						
CMAT	−0.11	−1.00	−0.53	0.44	−0.35	0.94
Visual-Span	−0.18	**0.85**	−0.16	−0.04	0.89	−0.80
Oper-Span	−0.36	−0.20	**0.53**	−0.98	−0.74	−0.18
NMD-HWM						
CMAT	0.47	0.33	0.36	0.16	0.04	0.08
Visual-Span	**0.88**	**1.25**	0.31	0.60	0.97	−0.31
Oper-Span	0.06	0.02	0.03	0.03	−0.01	0.03

1, Verbal-emphasis Condition; 2, Verbal + Visual Condition; 3, Visual-emphasis Condition, and 4, Control. Bold positive ES reflects moderate (>0.50) to high ESs (>0.80) outcomes in favor of strategy conditions relative to control condition. CMAT, Comprehensive Math Abilities Test, Oper, Operation Span, Visual-span, Visual matrix span measure.

within the group of children with MD. This assumption was based on several investigations showing that children with MD are more likely to experience greater processing constraints in cognition, especially on WM tasks, when compared to children without MD (e.g., Koonz and Berch, 1996; Swanson and Beebe-Frankenberger, 2004; Andersson and Lyxell, 2007). For example, students with MD struggle on both letter and number-based WM span tasks (Koonz and Berch, 1996; see Bull and Espy, 2006, for review). Several studies also suggest that children with MD have difficulty inhibiting irrelevant information from entering WM (Bull et al., 2008). In addition, studies have shown that strategy training helps low span participants allocate WM resources more efficiently when compared to high span participants (e.g., Turley-Ames and Whitfield, 2003). Thus, we expected that children with MD, especially those with low WM span, would benefit more from strategy instruction than children without MD (children with high spans). The present results did not support this hypothesis.

The general pattern was that regardless of MD status, children with higher WM spans were more likely to benefit from strategy conditions than children with low spans. When compared to the control condition, post-test solution accuracy for children with MD but with higher WMC, yielded effect sizes within the moderate range when strategy conditions included a verbal or visual emphasis ($ES = 0.70$ and 0.44, respectively). Likewise, children without MD but with higher WMC, yielded a moderate effect size ($ES = 0.47$) related to adjusted post-test solution accuracy when strategy conditions included a verbal emphasis. In contrast, effect sizes related to post-test problem solving for strategy conditions when compared to control conditions, were in the low range for children with low WMC. Thus, there is weak support for the assumption that strategy training is more advantageous for children with low WMC than high WMC on post-test measures of problem solving.

Are Some Cognitive Strategies More Effective than Others for Children with MD?

The results were clear in answering this question. No strategies that included low span children with MD yielded post-test effect sizes in the moderate range. In contrast, high span children with MD were more likely to yield post-test effect sizes in the moderate to high range for the verbal or visual-emphasis strategy conditions. The results do present a different picture, however, when post-test measures included visual-spatial WM. A post-test advantage was found for children with MD and low WMC when strategy conditions combined verbal and visual information (verbal + visual condition, $ES = 0.92$). Likewise, children with MD but with high WMC improved in visual-spatial WM when conditions included visual information (verbal + visual, and visual emphasis, $ES = 0.69$ and 3.89, respectively). Based on the assumption that visual WM in children with MD is relatively intact (Swanson and Jerman, 2006), we anticipated that visual-spatial strategies would yield higher accuracy scores when compared to verbal strategy conditions. The results showed that both high and low WM span groups benefitted from visual strategies, however children with low WM span needed the combination of both verbal and visual strategies.

Does Practice Solving Problems That Gradually Increase Irrelevant Information Influence WM Performance?

We found partial support for the assumption that problem solving training facilitated improvement in WM performance. We assumed this occurred because word problem solving required focused attention to relevant propositions in text in the face of irrelevant propositions; and strategy training helped children focus attention to relevant propositions, which in turn, influenced solution accuracy. Likewise, we assumed that practice in controlled-attention, i.e., activities that maintain (e.g., update) information in the face of interference or distraction, influenced WM performance (see Engle et al., 1999; Kane and Engle, 2003, for a review). We say "partial support" for this finding because only children with MD and relatively high WMC capacity improved on both transfer measures (visual-span and operation span) as a function of the same instructional condition (visual-emphasis treatment). The only other group to show transfer to both WM measures included children without MD but low WM. We have no explanation for this finding. Part of the difficulty of unraveling this interaction is that practice related to solving problems with increasing interference (gradual increases in irrelevant sentence proposition) was not separated from the overt cognitive strategy instruction. Thus, we cannot infer that such practice enhanced transfer to the WM measures.

The results do inform current controversies, however, on the influence of WM training on academic performance. For example, in an analysis by Kane et al. (2007) on WM strategy training studies, they concluded that although strategies may improve WM performance, the post-test outcomes reveal a weak relationship between WM span and achievement. Our results suggest, however, that academic tasks that training processes related to WM (controlled attention) may in fact influence later WM performance. This inference on our part is consistent with several studies that suggest WM is related to attentional control (e.g., Engle et al., 1999; Bayliss et al., 2003; Kane et al., 2007), and attentional control is important when performing complex problem solving tasks (e.g., Kyllonen and Christal, 1990; Unsworth, 2010).

Limitations

There are at least two limitations to this study. The first is that sample size was small for some of the cells. This was especially true when identifying high WM span participants in the sample with MD and the low WM span participants in the sample of children without MD. Thus, there may be a loss of power in testing for significant interactions. The magnitude of the effect sizes does show, however, that high span participants with MD status benefited from the strategy conditions across a number of dependent measures.

Second, the control treatment conditions were highly effective in yielding positive gains in post-test performance. The schools in which the study was implemented utilized an evidence-based math curriculum and teachers within each classroom placed a high emphasis on fluency in mathematical skills. Although we showed gains in problem solving performance for the majority of children in the strategy conditions relative to this control condition, not all children benefited from the strategy conditions. For example, strategy conditions had no significant influence on solution accuracy on CMAT for low span children without MD. We have no explanation for this finding except that perhaps the school wide curriculum is well matched to this sample.

Implications

Our findings have two applications to current research. First, the results are consistent with studies suggesting that strategies facilitate problem solving for children with MD. However, those strategies that are most beneficial must be adapted to the WM level of the child. A second application relates to interventions to designed to improve WM. No studies we are aware of have shown that WM training directly influences academic outcomes. The alternative we took to enhance transfer, was to embed WM demands within the curriculum and to provide children with strategies to handle these increased WM demands. Although the mechanism that underlies this transfer is unclear, we did find transfer in two groups of children: (1) those with high WMC, but low achievement, and (2) those with low WMC but high achievement. Thus, further studies that place WM demands within the curriculum would potentially clarify those mechanisms.

In summary, the results suggest that WMC moderates treatment outcomes for children MD. Unfortunately, these outcomes are primarily isolated across the majority of measures to children with relatively higher WMC.

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Supplementary Material

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2015.01099

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Investigating the Improvement of Decoding Abilities and Working Memory in Children with Incremental or Entity Personal Conceptions of Intelligence: Two Case Reports

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One of the most significant current discussions has led to the hypothesis that domain-specific training programs alone are not enough to improve reading achievement or working memory abilities. Incremental or Entity personal conceptions of intelligence may be assumed to be an important prognostic factor to overcome domain-specific deficits. Specifically, incremental students tend to be more oriented toward change and autonomy and are able to adopt more efficacious strategies. This study aims at examining the effect of personal conceptions of intelligence to strengthen the efficacy of a multidimensional intervention program in order to improve decoding abilities and working memory. Participants included two children (M age = 10 years) with developmental dyslexia and different conceptions of intelligence. The children were tested on a whole battery of reading and spelling tests commonly used in the assessment of reading disabilities in Italy. Afterwards, they were given a multimedia test to measure motivational factors such as conceptions of intelligence and achievement goals. The children took part in the T.I.R.D. Multimedia Training for the Rehabilitation of Dyslexia (Rappo and Pepi, 2010) reinforced by specific units to improve verbal working memory for 3 months. This training consisted of specific tasks to rehabilitate both visual and phonological strategies (sound blending, word segmentation, alliteration test and rhyme test, letter recognition, digraph recognition, trigraph recognition, and word recognition as samples of visual tasks) and verbal working memory (rapid words and non-words recognition). Posttest evaluations showed that the child holding the incremental theory of intelligence improved more than the child holding a static representation. On the whole this study highlights the importance of treatment programs in which both specificity of deficits and motivational factors are both taken into account. There is a need to plan multifaceted intervention programs based on a transverse approach, considering both cognitive and motivational factors.

Keywords: personal conceptions of intelligence, working memory, learning disabilities, dyslexia, intervention program, children, case report

INTRODUCTION

One of the most significant current discussions has led to the hypothesis that domain-specific training programs alone are not enough to improve decoding abilities or working memory (Ho and Guthrie, 2013; Jaeggi et al., 2014). It is becoming increasingly evident that personal conceptions of intelligence play a key role as prognostic variables in the planning of training programs to rehabilitate reading and memory deficits. This is because of the way intelligence is conceived is assumed to sustain and maintain the readiness to recover own personal difficulties and to be oriented toward change and autonomy through training (Pepi et al., 2008).

In their original model, Dweck and colleagues hypothesized two theories or personal conceptions concerning the nature of intelligence and ability, namely incremental and entity theories (Dweck and Leggett, 1988; Faria, 1998; Dweck, 1999). In particular, incremental theorists conceive their intelligence as a resource which can be increased through personal engagement and effort. Consequently, they tend to choose learning goals which allow them to prefer challenging tasks and employ successful strategies in order to improve their abilities. Whilst, entity theorists perceive their ability as a unchangeable talent with which the person is endowed. Consequently, they are likely to prefer performance goals aimed at demonstrating their abilities and obtain positive evaluations from others (Dweck, 1999; Pepi et al., 2015).

Experimental research has shown a positive relationship between incremental personal conceptions of intelligence and school success (Stipek and Gralinski, 1996; Robins and Pals, 2002; Pepi et al., 2006). Moreover, intervention programs aimed at teaching incremental conceptions of intelligence were demonstrated to reduce achievement discrepancies; for example, students taught in incremental view, compared with control groups, were found to achieve higher grades in maths and science performance (Aronson et al., 2002; Good et al., 2003). Furthermore, personal conceptions of intelligence are predictive over time; in a longitudinal study Blackwell et al. (2007) followed 7th graders over 2 years and found that their mindset at the beginning of junior high school was associated to their trajectories of maths achievement. Students holding an incremental mindset had higher gains in maths grades compared to their peers holding an entity mindset.

With regard to reading training programs, research suggests that domain-specific training programs alone are not sufficient to improve reading abilities. Considering the mutual enhancement among a student's cognitive and emotional-motivational attributes in the reading abilities, an integrated program was demonstrated to be more efficacious (Cox and Guthrie, 2001; Guthrie et al., 2007; Villavicencio and Bernardo, 2013). This is because a training program tapping simultaneously cognitive and motivational abilities is assumed to sustain more effectively the maintenance and generalization of the obtained gains (Pepi et al., 2000). Pepi et al. (2008) compared improvements in reading accuracy and speed abilities of pupils with incremental and entity personal conceptions of intelligence following reading decoding treatment. The results showed that both groups improved their abilities in reading decoding but incremental theorists showed larger gain percentage scores than static ones. Moreover, in the incremental group, gains on reading accuracy and speed were found to be more relevant at Follow-up after 3 months. Previously obtained results were corroborated (Pepi et al., 2004) which revealed more consistent improvements in reading comprehension by an incremental group following metacognitive training. This study assessed gains in reading performance after a meta-reading training in children 8.7 years of age diagnosed with generalized reading problems and holding incremental or entity theories of intelligence. After taking part in metacognitive training, incremental pupils, who saw their own ability as a potential they could increase, made significantly fewer errors than static pupils, who considered their skills as a gift which cannot be changed. Taken together, these two studies demonstrated how incremental theories of intelligence accounted in contributing to improve both reading components: decoding and comprehension. Moreover, support was provided to the key role of theories of intelligence in influencing reading success by increasing the students' motivation to learn and reinforcing achieved results (Faria et al., 2006).

Nevertheless, personal conceptions of intelligence seem to influence working memory (WM) training and may effect on their efficacy. The widely recognized relevance of working memory for every-day life and educational tasks is responsible for the growing attempts to implement training programs aimed at improving cognitive mechanism to maintain and manage task-relevant information during performances (Daneman and Merikle, 1996; Gathercole et al., 2004, 2006; Passolunghi, 2006; Klingberg, 2010; Loosli et al., 2011).

However, considerable evidence raised controversy concerning the efficacy of working memory training. Recently, Melby-Lervåg and Hulme (2012) conducted a systematic meta-analytic review over 23 studies to assess practical and clinical benefits as a result of working memory programs. They examined near and far-transfer effects of above-mentioned training concluding that the most consistent effects were on related but not trained in visuospatial WM memory, namely near-transfer effects (Holmes et al., 2009, 2010). Conversely, the effects on tasks going beyond the trained ability were less reliable, namely far-transfer (Morrison and Chein, 2011). Null effects of WM trainings were reported by other authors (Zinke et al., 2011). In the attempt to explain this controversy, Jaeggi et al. (2014) argued that methodological issues and individual differences could account for these contrasting results. Firstly, methodological issues concern the nature of tasks, the quality of instructions, the optimal duration and intensity of training, the adoption of group vs. single-subject research plans, the random assignment of participants to the trained and the control groups, the correct pre- and post-test evaluations, and the role of reward and motivation ...Secondly, individual differences concern chronological and mental age, personality, previous abilities, as well as level of motivation. Jaeggi et al. (2014) reported the largest transfer effects only when participants showed high levels of intrinsic motivation. This was the experimental condition in which participants were not rewarded to participate or were modestly paid (Jaeggi et al., 2008, 2010). Consequently, the authors concluded that extrinsic factors, such as monetary rewards, tend to limit enjoyment and intrinsic motivation by decreasing the performance. Moreover, Jaeggi et al. (2014) found that theories of intelligence effected on benefits from WM training. In their study 175 volunteer participants were recruited and administered two working memory interventions. Results showed that individuals holding an entity theory revealed to disengage from challenging tasks and not improve following 4 weeks of intervention. Whilst, incremental participants self-reported higher levels of engagement by obtaining more consistent gains on visuospatial abilities.

GOALS

In view of these theoretical assumptions, the aim of this study is to assess the effect of personal conceptions of intelligence to strengthen the efficacy of a multidimensional intervention program to improve decoding abilities and working memory. Two 10 year-old pupils with developmental dyslexia were the participants, one holding the incremental personal conception of intelligence and one the entity conception. It was hypothesized that the multidimensional training would result in significantly more improvements in the pupil with the incremental representation of own abilities because incremental theories tend to address toward change and autonomy, to adopt more adaptive goals and efficacious strategies (Pepi et al., 2004, 2008; Jaeggi et al., 2014). The multidimensional training was implemented by integrating sessions aimed to train reading decoding abilities and sessions aimed to train verbal working memory over 3 months. More accurately, it consisted of specific tasks to improve both visual and phonological strategies such as sound blending, word segmentation, alliteration test and rhyme test, letter recognition, digraph recognition, trigraph recognition and word recognition. Tasks to enhance verbal working memory based on exercises of rapid words and non-words recognition.

This integrated intervention was chosen as a remediating intervention for our pupils because dyslexic pupils have been proven to have deficits in both phonological loop and central executive as demonstrated by their poorer performance in complex WM span tests (Jeffries and Everatt, 2004; Reiter et al., 2004; De Jong, 2006; Dahlin, 2011). Moreover, improvements in reading speed after a computerized WM training in adult dyslexic readers were documented (Horowitz-Kraus and Breznitz, 2009).

A single-subject study design was employed in this study. Such design allows primarily to evaluate the benefits of intervention programs in applied and clinical research. Moreover, it is mainly sensitive to individual differences whilst group designs are more sensitive to difference in group means.

BACKGROUND

Two Italian girls with developmental dyslexia and different personal conceptions of intelligence, attending the fifth grade of primary school, participated in the study.

Interviews with parents and teachers allowed to rebuild a picture of the learning history of the two girls. Both girls were from average socio-economic backgrounds. A history of neurological impairments or speech and language development problems were excluded. Perceptual competences concerning hearing and visual acuity were found to be typical. No family history of psychiatric diseases was reported. No emotional or behavioral disorders were reported. Both attended public primary schools and had followed conventional reading education. At age 9 both girls had been certified by a public institution as dyslexics, in line with current legislation. Families reported that their children had never been engaged in specific reading or working memory therapy.

As shown in **Table 1**, Alice was 10 years and 4 months old at the time of assessment, Marta was 10 years. Both girls had normal IQ (Alice: 114; Marta: 110), specific reading decoding difficulties in accuracy (Alice: 18 errors; Marta: 17 errors), and WM level was under the average (Alice: 82; Marta: 82).

The participants were recruited on the basis of their personal conceptions of intelligence: Alice had an incremental personal conception of intelligence, while Marta had an entity profile.

Prior to beginning the study, written informed consent was provided by each participant's parents. Moreover, appropriate local ethics committee approval was obtained from the University of Palermo.

MATERIALS AND PROCEDURE

Procedure

The study was divided into four phases: Pre-Test phase in September, multidimensional intervention program of reading and Working memory skills from October to December, Post-Test phase in January and Follow-Up phase in March.

At the Pre-Test phase an assessment was carried out over four sessions an hour each in order to detect the baseline.The cognitive and motivational profiles of the girls were investigated. As for the cognitive profile, girls were administered a battery of reading and spelling tests commonly employed in the assessment of reading disabilities in Italy. This battery incorporated the WISC-IV (Wechsler, 2012), the Text Comprehension and Decoding Test (Cornoldi and Colpo, 2001), and the Word and Non-word Test (Zoccolotti et al., 2005). As for the motivational profile, the girls were administered the P.M.S. (Alesi et al., 2008).

Working Memory Subtest Derived From WISC-IV

The Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2012) was an individual test measuring Intelligence Quotient for children with chronological age ranging 6–16. The WISC-IV provided the general Intelligence Quotient (IQ) and four indexes: Verbal Comprehension (VC), Perceptual Reasoning (PR), Working Memory (WM), and Processing Speed (PS).

The WM subtest measured the ability to monitor and manipulate mental representations and composed of two tasks: Digit Span (Forward and Backward) and Letter-Number Sequencing.

The Digit Span test consisted of sequences of numbers with increasing level of difficulty according to the length for each trial. Children were asked to repeat immediately and in the same or in

TABLE 1 | Characteristics of the two participants at the Pre-Test.

	Alice (Incremental pupil)	Marta (Entity pupil)
Chronolgical age (months)	124	120
Grade level	5th	5th
Personal conception of intelligence	Incremental	Entity
WISC-IV QIT	114 (117 standard score)	110 (112 standard score)
WISC-IV WM	82 (14 standard score)	82 (14 standard score)
WISC-IV Digit span	7 standard score	7 standard score
WISC-IV Letter-number Sequencing	7 standard score	7 standard score
WISC-IV VC	124 (42 standard score)	116 (38 standard score)
WISC-IV PR	102 (31 standard score)	100 (30 standard score)
WISC-IV PS	130 (30 standard score)	123 (28 standard score)
Reading comprehension	8 correct answers (0.18 z score)	7 correct answers (-0.27 z score)
Reading decoding accuracy	18 errors (1.95 z score)	17 errors (1.79 z score)
Reading decoding speed	2.4 syll/s (-1.1 z score)	2.37 syll/s (-1.12 z score)
Short non-word accuracy	9 errors (3.3 z score)	6 errors (1.84 z score)
Short non-word speed	37 s (0.93 z score)	36 s (0.80 z score)
Long non-word accuracy	18 errors (4.38 z score)	18 errors (4.38 z score)
Long non-word speed	59 s (0.08 z score)	90 s (2.04 z score)
Short word (high frequency of use) accuracy	6 errors (5.72 z score)	3 errors (2.49 z score)
Short word (high frequency of use) speed	31 s (2.88 z score)	28 s (2.08 z score)
Long word (high frequency of use) accuracy	8 errors (3. 3 z score)	5 errors (1.72 z score)
Long word (high frequency of use) speed	43 s (1.77 z score)	60 s (3.85 z score)
Short word (low frequency of use) accuracy	6 errors (2.41 z score)	9 errors (4.22 z score)
Short word (low frequency of use) speed	32 s (1.05 z score)	41 s (2.56 z score)
Long word (low frequency of use) accuracy	13 errors (3.28 z score)	17 errors (4.84 z score)
Long word (low frequency of use) speed	58 s (1.24 z score)	89 s (3.82 z score)

the backwards order the list of numbers verbally presented at the rate of 1 number per second by the experimenter. The raw score was the number of stimuli correctly remembered.

The Letter-Number Sequencing test consisted of a series of numbers and letters. Children were asked to provide them back. The raw score was the total number of items correctly answered. Raw scores were changed into standard scores.

Reading Comprehension

The Reading Comprehension (Cornoldi and Colpo, 2001) assessed reading comprehension abilities. Pupils were asked to read a story suited to and standardized for their school grade and to answer to following 10 multiple-choice questions concerning characters and events described in the story according to their understanding of the story. The score was defined by the number of correct answers and ranged from 0 to 10. The cut-off was 5 correct choices. This cut-off (a score under 5) defines suggestions for the need of training intervention.

Reading Decoding

The Reading Decoding Test (Cornoldi and Colpo, 2001) assessed reading decoding abilities. Pupils were asked to read a text aloud. The test provided two scores: accuracy and speed. So the parameters of evaluation were the number of errors and the time of execution indicated in seconds. With regard to accuracy, the score 1 was given to errors such as long pause, addition or omission of syllables, words, or lines. The score 0.5 was given to errors such as accent shift, hesitation or self-correction. The cut-off was 8 or less errors. With regard to speed, the total score was obtained by calculating the seconds per number of syllables of text read. Average performance was score of 1.83 syllables/seconds or more.

Phonological—Visual Decoding

In the Word and Non-word Reading Test (Zoccolotti et al., 2005). Three reading tasks on word and non-word reading were administered. Accuracy and speed were assessed. With regard to accuracy, for each task, the score 1 was given for each correct item and 0 for incorrect items. The speed was the time of execution indicated in seconds. The raw data thus obtained were then converted to standard scores by using tables in the manual. The cut-off was the performance below the 5th percentile.

School Motivational Profiles

P.M.S. (Alesi et al., 2008) was a Multimedia Instrument, created by Visual Basic 6.0, to measure motivational factors such as the conceptions of intelligence, achievement goals, perception of controllability and causal attributions. It consisted of a story which illustrated 4 scenes from school life (1. a geography class; 2. reading a text; 3. working out a maths problem; 4. a science class) and 4 scenes from everyday life (1. assembling a jigsaw puzzle; 2. a sports race; 3.

Participating in a birthday party; 4. playing a video game). Each unit presented the character (a boy/a girl) involved in school or everyday life affair and contained 4 items close-ended questions aimed at evaluating personal conceptions of intelligence (incremental vs. entity), achievement goals (learning vs. performance), controllability of effort (controllability vs. uncontrollability of effort) and causal attributions (effort, ability, luck, ease/difficulty of the task). On the whole the program provides a global qualitative index to identify Personal Conceptions of Intelligence.

Psychometric properties are as follows: regarding the validity, the factor analysis in principal components extracted two factors, the first one (incremental view) explained almost 22% of the total variance of the results and the second one (entity view) explained almost 20% of the total variance of the results in normative sample. The test-retest reliability ranged from 0.41 to 0.79 (Alesi and Pepi, 2008).

After the Pre-test Phase the Girls Took Part in T.I.R.D.

Multimedia Training for the Rehabilitation of Dyslexia (Rappo and Pepi, 2010) and in a Multimedia Training to improve the WM abilities (Sacchi, 2012)[1]. The treatment program took place over 12 sessions twice a week in a quiet room, one pupil at a time, with the same experimenter providing training tasks (See **Table 2**).

The T.I.R.D. consisted in specific tasks to rehabilitate both visual and phonological strategies. The software, written in the coding language Visual Basic 6.0 (Perry, 1998), has three parts, two for collecting administrative data and one for training. The first administrative part gathers information about the testing situation and participants' demographics. The second administrative part is a summary of all the collected data. The training program consisted in 356 growing difficulty tasks and subdivided into four units. Units 1 and 3 included phonological tests such as fusion, segmentation, alliteration, rhymes, and non-word reading. Units 2 and 4 included visual tests such as letter search, digraphs search, trigraph search, word search, and reading of words written in unusual format. The third part of the software consisted of the data visualization form containing the results of the training. The training was carried out over 12 sessions, 40 min long.

TABLE 2 | Treatment program (T.I.R.D. and Multimedia Training to improve the WM abilities) daily sessions.

	Tasks of the T.I.R.D.	Training of WM (number of cards)
Day 1	Fusion and alliteration	Memory task: 4/6 cards
Day 2	Segmentation and rhymes	Memory task: 6/8 cards
Day 3	Fusion and alliteration	Memory task: 6/8 cards
Day 4	Segmentation and rhymes	Memory task: 8/12 cards
Day 5	Letter search and digraphs search	Memory task: 8/12 cards
Day 6	Letter search and trigraph search	Memory task: 12/16 cards
Day 7	Fusion and alliteration	Memory task: 12/16 cards
Day 8	Segmentation and rhymes,	Memory task: 16/20 cards
Day 9	Fusion and alliteration	Memory task: 16/20 cards
Day 10	Segmentation and rhymes,	Memory task: 20/24 cards
Day 11	Word search and reading of words written in unusual format	Memory task: 20/24 cards
Day 12	Word search and reading of words written in unusual format	

[1]Free Educational Software www.ivana.it.

The units of T.I.R.D. were reinforced by specific units to improve verbal working memory.

This free Software was produced by Ivana Sacchi (www.ivana.it). The training consisted in memory tasks with a one to one match activities of the cells. Cards containing animal images and animal names appeared on the display and the task was to match an image to the corresponding name (see **Figure 1**). The number of cards to be used varied from 4 to 30. The software allowed the creation of specific fully customized routes: the color of the graphic interface could be changed, cards with new designs on them could be inserted, the font (printed capital letters or italics) could be changed and a sound reinforcement (the selection of the card, exact pair, couple wrong) could be added. Correct image—name pairs disappeared, after having been matched. The exposure time of the cards could be set at the top of the task (the time required to study the position of the cards and hold them in mind).The WM training was carried out in 11th sessions of increasing difficulty which lasted no more than 10 min each and was administered after the software TIRD. More specifically, the first session allowed girls to familiarize with the software with 4/6 cards. On the first day children were familiarized with the task.

On the second and third day the number of tiles was 6/8 and cards covered after 5 s. On the fourth and 5th day the number of tiles was 8/12 and cards covered after 10 s. On the 6th and 7th day the number of tiles was 12/16 and cards covered after 15 s. On the 8th and 9th day the number of tiles was 16/20 and cards covered after 20 s. On the 10th and 11th day the number of tiles was 20/24 and cards covered after 25 s.

Participants were asked to correctly match a figure and a corresponding word. Each pair correctly operated by the child was reinforced with a sound, while each incorrect pair was not reinforced. The use of this software had been adapted in order to strengthen the manipulation of data hold in the mind. After the matching activity, when image—name pairs disappeared, the girls had to repeat the name of animals beginning with the letter named by the psychologist. For example, in the second and third day of the program (**Figure 1**), the girls were asked to remember the names of animals beginning with "b," such as beaver and bear. During each session the pupils could train for up to 10 min.

We selected this program to train WM because it fitted well with the nature of tasks provided by the TIRD and because each unit would not be too long (lasting no more than 50 min), and tiring or boring for the girls.

Following the multidimensional intervention program phase, the post-test phase included re-evaluation of reading decoding difficulties, in both accuracy and speed, and the Working Memory IQ. The 3-month follow-up consisted of the same tasks as at post-test.

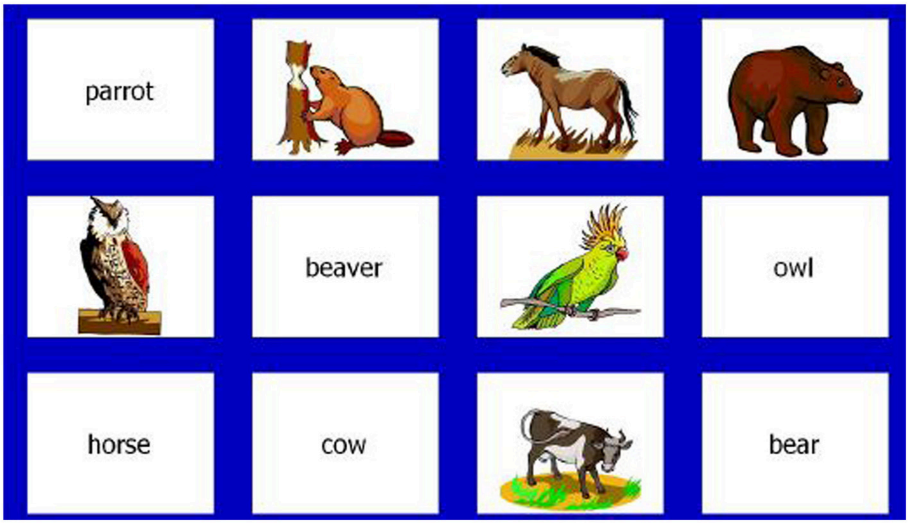

FIGURE 1 | Example of Working Memory training—second and third day of the program.

RESULTS

The Reliable Change Index[2] was used to verify changes between Pre-Test, post-test, and follow-up (Jacobson and Truax, 1991).

After the multidimensional intervention program phase both Alice and Marta improved their accuracy of reading decoding accuracy from Pre-Test to post-test. In particular Alice decreased the number of the errors from 18 to 14, while Marta from 17 to 13 ($SD = 6.2$; reliability = 0.95). None of the two significantly improved in reading speed. Regarding the WM, only Alice showed significant improvements. In particular, the IQ scores improved from 82 to 100 ($SD = 13.4$; reliability = 0.88). Alice and Marta did not show any change from Post-Test to Follow-Up.

Finally, only Alice showed significant improvements from Pre-Test to Follow-Up in reading decoding accuracy and WM abilities. In particular Alice decreased the number of errors from 18 to 12.5, and improved her WM ability from 82 to 103 (See **Tables 3–6**).

In contrast with Marta, Alice's scores, at Pre-Test, post-test and follow-up phases, showed a steady improvement in reading decoding accuracy and WM ability (See **Figures 2–4**).

DISCUSSION

The goal of this study was to assess the role of personal conceptions of intelligence in order to strengthen the efficacy of a multidimensional intervention program to improve decoding abilities and working memory in dyslexia. In order to do this, we described two case studies of two Italian pupils with developmental dyslexia and low WM abilities. Alice had an incremental personal conception of intelligence, whilst Marta showed an entity personal conception of intelligence. Their performances on reading decoding and WM abilities were equivalent at baseline and were compared from Pre-Test to post-test and follow up. Alice was 10 years and 4 months old at the time of testing, Marta was 10 years. Both the girls had normal IQ. They had specific reading decoding difficulties in accuracy and speed and their WM abilities were under the average. Both Alice and Marta were administered a multidimensional training which combined units aimed at training reading decoding abilities and units aimed to train verbal working memory over 3 months. Following the training, with concern regards to reading accuracy abilities, both pupils seem to have enhanced their skills. The performance on reading accuracy tasks improved because errors decreased of 22.22% in Alice and 23.53% in Marta.

Concerning working memory abilities, Alice improved more than Marta. The performance on WM tasks significantly increased by 42.86% in Alice and only 7.14% in Marta.

As previously described, the two girls showed similar cognitive profiles as regards to their performance on WISC Working Memory (Marta = 14; Alice = 14) and WISC Perceptual Reasoning (Marta = 31 and Alice = 30). Differences were found on WISC Verbal Comprehension (Marta = 42; Alice = 38) and WISC Processing Speed (Marta = 30; Alice = 28), but these differences cannot be considered significant (Wechsler, 2012). It may be possible that processing abilities create a better condition to benefit from a training were based on memory tasks requiring to match an animal image to the corresponding name. Another possible explanation could be the influence of the T.I.R.D. Multimedia Training for the Rehabilitation of Dyslexia consisting in specific tasks to rehabilitate both visual and phonological strategies. This is consistent with more consistent and stable improvement in reading decoding accuracy shown by Marta.

However, given that the intellectual profiles between the two girls were equivalent, it was hypothesized that the main factor contributing for differences in training gains could be Alice's personal conceptions of intelligence. In particular her

[2]The formula for the Reliable Change Index is: $RC = (X_2 - X_1)/S_{diff}$, where $X_2 - X_1$ is the difference between posttest and pretest scores and S_{diff} is the standard error of measurement (www.abdn.ac.uk/j.crawford/pages/dept/Compare_Two_Cases.htm).

TABLE 3 | Characteristics of Alice in the Pre-Test, Post-Test, and Follw-up.

	Pre-test	Post-test	Follw-up
WISC-IV QIT	114 (117 standard score)	124 (119 standard score)	126 (121 standard score)
WISC-IV WM	82 (14 standard score)	100 (20 standard score)	103 (21 standard score)
WISC-IV Digit Span	7 standard score	8 standard score	9 standard score
WISC-IV Letter-Number Sequencing	7 standard score	12 standard score	12 standard score
Reading decoding accuracy	18 errors (1.95 z score)	14 errors (1.31 z score)	12.5 errors (1.06 z score)
Reading decoding speed	2.4 syll/s (-1.1 z score)	2.37 syll/s (-1.12 z score)	2.51 syll/s (-1.01 z score)
Short non-word accuracy	9 errors (3.3 z score)	10 errors (3.79 z score)	7 errors (2.33 z score)
Short non-word speed	37 s (0.93 z score)	53 s (2.95 z score)	45 s (1.94 z score)
Long non-word accuracy	18 errors (4.38 z score)	13 errors (2.62 z score)	11 errors (1.92 z score)
Long non-word speed	59 s (0.08 z score)	66 s (0.52 z score)	60 s (0.14 z score)
Short word (high frequency of use) accuracy	6 errors (5.72 z score)	5 errors (4.65 z score)	3 errors (2.49 z score)
Short word (high frequency of use) speed	31 s (2.88 z score)	27 s (1.81 z score)	24 s (1.01 z score)
Long word (high frequency of use) accuracy	8 errors (3. 3 z score)	6 errors (2.25 z score)	4 errors (1.19 z score)
Long word (high frequency of use) speed	43 s (1.77 z score)	44 s (1.89 z score)	41 s (1.52 z score)
Short word (low frequency of use) accuracy	6 errors (2.41 z score)	7 errors (3.1 z score)	5 errors (1.81 z score)
Short word (low frequency of use) speed	32 s (1.05 z score)	37 s (1.89 z score)	32 s (1.05 z score)
Long word (low frequency of use) accuracy	13 errors (3.28 z score)	12 errors (2.87 z score)	6 errors (0.54 z score)
Long word (low frequency of use) speed	58 s (1.24 z score)	54 s (0.89 z score)	46 s (0.19 z score)

TABLE 4 | Characteristics of Marta in the Pre-Test, Post-Test, and Follw-up.

	Pre-test	Post-test	Follw-up
WISC-IV QIT	114 (117 standard score)	110 (108 standard score)	109 (107 standard score)
WISC-IV WM	82 (14 standard score)	85 (15 standard score)	82 (14 standard score)
WISC-IV Digit Span	7 standard score	7 standard score	7 standard score
WISC-IV Letter-Number Sequencing	7 standard score	8 standard score	7 standard score
Reading decoding accuracy	17 errors (1.79 z score)	13 errors (1.15 z score)	18 errors (1.95 z score)
Reading decoding speed	2.37 syll/s (-1.12 z score)	2.37 syll/s (-1.12 z score)	2.18 syll/s (-1.27 z score)
Short non-word accuracy	6 errors (1.84 z score)	9 errors (3.3 z score)	10 errors (3.79 z score)
Short non-word speed	36 s (0.80 z score)	40 s (1.31 z score)	47 s (2.19 z score)
Long non-word accuracy	18 errors (4.38 z score)	9 errors (1.21 z score)	14 errors (2.97 z score)
Long non-word speed	90 s (2.04 z score)	73 s (0.97 z score)	82 s (1.54 z score)
Short word (high frequency of use) accuracy	3 errors (2.49 z score)	1 error (0.34 z score)	2.5 errors (1.96 z score)
Short word (high frequency of use) speed	28 s (2.08 z score)	31 s (2.88 z score)	27 s (1.81 z score)
Long word (high frequency of use) accuracy	5 errors (1.72 z score)	3 errors (0.67 z score)	2 errors (0.14 z score)
Long word (high frequency of use) speed	60 s (3.85 z score)	48 s (2.38 z score)	52 s (2.87 z score)
Short word (low frequency of use) accuracy	9 errors (4.22 z score)	10 errors (4.82 z score)	9 errors (4.22 z score)
Short word (low frequency of use) speed	41 s (2.56 z score)	33 s (1.22 z score)	43 s (2.9 z score)
Long word (low frequency of use) accuracy	17 errors (4.84 z score)	9 errors (1.71 z score)	11 errors (2.5 z score)
Long word (low frequency of use) speed	89 s (3.82 z score)	77 s (2.90 z score)	82 s (3.34 z score)

incremental personal conception of intelligence could act as a potential mechanism of change by orienting her perception of abilities as something changeable and improvable through effort and hard work. Moreover, this is consistent with previous studies (Pepi et al., 2004, 2008) and supports an important role for conceptions of intelligence in influencing school success, both in terms of the students' willingness to learn and of the achieved results (Faria et al., 2006).

The most interesting result was that significant differences between Alice and Marta were maintained at a 3-month follow-up. In Alice, changes of both accuracy and working memory were more consistent at Follow-up: advantages were maintained after 3 months. In particular, the performance on reading accuracy tasks had improved and errors decreased of 30.56%. Her performance on WISC-IV WM increased by 50% from Pre-Test to Follow-up showing a gain from post-test to follow-up of 5%. Contrastingly, in Marta the significant improvement in accuracy reading decoding from Pre-Test to Post-test disappeared at Follow-up.This result was necessary evidence not only for the efficacy of

TABLE 5 | Reliable change index for alice.

	Pre-test to Post-test	Post-test to Follow-up	Pre-test to Follow-up
Reading decoding accuracy	RCI > 1.96; $p < 0.05$	Not significant	RCI > 1.96; $p < 0.05$
Reading decoding speed	Not significant	Not significant	Not significant
WM	RCI > 1.96; $p < 0.05$	Not significant	RCI > 1.96; $p < 0.05$

TABLE 6 | Reliable change index for marta.

	Pre-test to Post-test	Post-test to Follow-up	Pre-test to Follow-up
Reading decoding accuracy	RCI > 1.96; $p < 0.05$	Not significant	Not significant
Reading decoding speed	Not significant	Not significant	Not significant
WM	Not significant	Not significant	Not significant

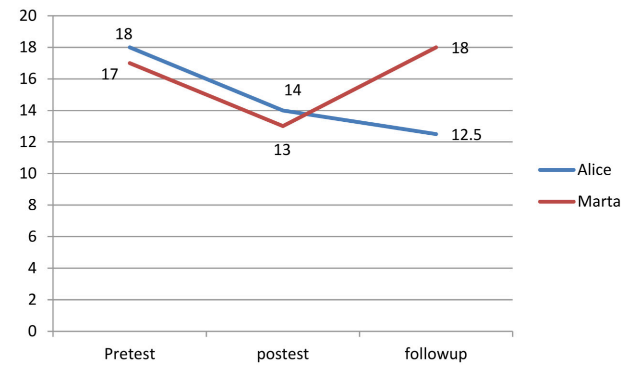

FIGURE 2 | Reading decoding accuracy scores (errors).

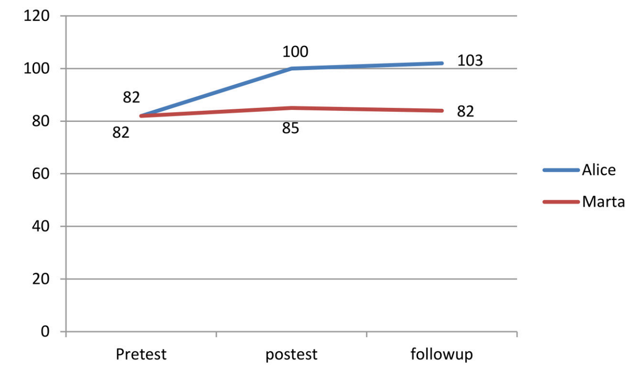

FIGURE 4 | WM standard scores.

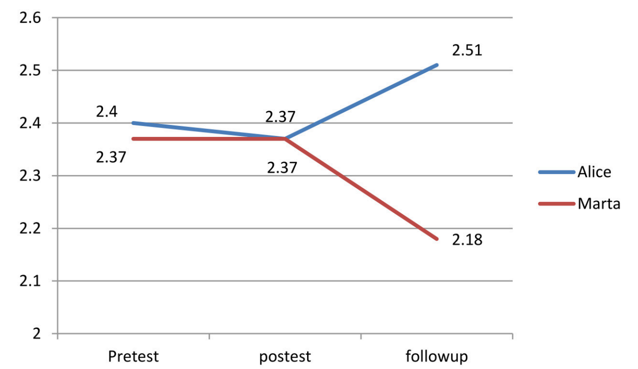

FIGURE 3 | Reading decoding speed (syllables/seconds).

the multidimensional intervention proposed, but for the role of personal conceptions of intelligence in effecting improvements as well as maintaining positive effects. This is a very exciting result as it supports the ongoing debate concerning the maintenance over time of WM training programs (Melby-Lervåg and Hulme, 2012) by providing evidence of a potential mechanism able to effect reliable long-term improvements.

On the whole, the pupil who believes that it is possible to enhance one's abilities and performance will tend to interpret and manage learning as a long-term process. This means "…. to defer gratification, foregoing chances to succeed on difficult tasks in the immediate future. Such students prefer learning goals based on their desire to acquire new knowledge and master new skills" (Alesi et al., 2012, p. 971). In contrast, the static pupil who believes that abilities are relatively fixed will tend to focus mostly on current performance because she interprets the effort as an indicator of her inadequate ability. Consequently, she prefers easy tasks and employs superficial strategies in order to favor easily achievable goals which ensure positive judgements of own capacity (Pepi et al., 2000). As such, personal conceptions of intelligence would be a good prognostic factor in the evaluation of programs aimed at overcoming specific deficits in decoding or working memory domains. The way in which intelligence is conceived supports the readiness to surmount specific difficulties through treatment programs because students are more likely to be oriented toward change and autonomy, adopt more successful strategies and process decisions and action plans with ever increasing awareness. The incremental conceptions of intelligence predict an upward evolutionary trajectory in training programs, whilst the entity conceptions predict a flat trajectory (Dweck, 1999).

CONCLUDING REMARKS

The main strength of this study lies in contributing to the current literature with respect to the debate around the controversy concerning the efficacy of domain-specific intervention programs. The findings further support the relevance of treatment programs in which both specificity of deficits and individual differences are taken into account (Jaeggi et al., 2014). However, the data needs to be interpreted with caution because it derived from the analysis of two case studies weakening the generalizability of the current findings. As suggested by the hierarchy of evidence proposed by Sackett (1989) this research, ranked as case report, shows a low level of evidence (V level) which "may contain extremely useful information about clinical course and prognosis, but can only hint at efficacy" (pag.3S). Moreover, another possible shortcoming of this study is that at the present time we have data derived from follow-up at 3 months. Long-term maintenance of obtained gains needs to be re-evaluated by follow-up at 6 months. Finally, the direction of the link between motivational patterns and domain-specific impairments is theoretically unclear and is now the subject of wide discussion. It is more correct to suppose a mutual relationship in which maladaptive motivational patterns are a consequence of reading or WM deficit although reading and WM deficits may also lead to more negative motivational profiles.

Notwithstanding these limitations, the research carried out suggests some interesting implications on the educational and clinical fields for future practice. This can be used to develop targeted evidence-based programs which need to take account both of the specificity of disability and of the factors relating to motivational domain in order to maximize the maintenance and generalization of obtained improvements.

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The effectiveness of working memory training with individuals with intellectual disabilities – a meta-analytic review

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Working memory (WM) training has been increasingly popular in the last years. Previous studies have shown that individuals with intellectual disabilities (ID) have low WM capacity and therefore would benefit by this type of intervention. The aim of this study was to investigate the effect of WM and cognitive training for individuals with ID. The effects reported in previous studies have varied and therefore a meta-analysis of articles in the major databases was conducted. Inclusion criteria included to have a pretest–posttest design with a training group and a control group and to have measures of WM or short-term memory. Ten studies with 28 comparisons were included. The results reveal a significant, but small, overall pretest–posttest effect size (ES) for WM training for individuals with ID compared to controls. A mixed WM approach, including both verbal and visuo-spatial components working mainly on strategies, was the only significant training type with a medium ES. The most commonly reported training type, visuo-spatial WM training, was performed in 60 percent of the included comparisons and had a non-significant ES close to zero. We conclude that even if there is an overall effect of WM training, a mixed WM approach appears to cause this effect. Given the few studies included and the different characteristics of the included studies, interpretations should be done with caution. However, different types of interventions appear to have different effects. Even if the results were promising, more studies are needed to better understand how to design an effective WM intervention for this group and to understand if, and how, these short-term effects remain over time and transfer to everyday activities.

Keywords: intellectual disabilities, working memory training, visuo-spatial working memory, short-term memory, strategy training

Introduction

Working memory (WM) has been defined as a system for the temporary holding and manipulation of information during the performance in a range of cognitive tasks (Baddeley, 1986). Until now, the critical role of WM in everyday life (e.g., reading, writing, arithmetic, learning, language-processing, orientation, imagination) and for individuals with intellectual disabilities (ID) has been shown in an impressive number of studies (for a review, see Baddeley, 1986).

One theoretical framework often used in research that assesses short-term memory (STM) and WM in individuals with ID, is Baddeley's model (Baddeley and Hitch, 1974; Baddeley, 2000).

This model comprises of four components. The *central executive,* that can be seen as a limited-capacity processor responsible for attentional control over actions and for processing and coordinating the two slave systems called the *phonological loop* (for retaining linguistic information), and the *visuo-spatial sketchpad* (for retaining visuo-spatial information). Finally, the *episodic buffer,* added more recently to the model, is a multidimensional storage system that binds information from different sources in a unique code (Baddeley, 2000).

The distinction between the central executive system and specific memory storage systems (i.e., the phonological loop and the visuo-spatial sketchpad) is, in some ways, parallel to the distinctions between WM and STM.

A number of tasks involving both verbal and non-verbal material have been used so far to assess WM and STM. Experimental tasks assessing WM and the influence of the central executive component typically involve storage, processing, and effortful mental activity (Miyake and Shah, 1999; Kail and Hall,

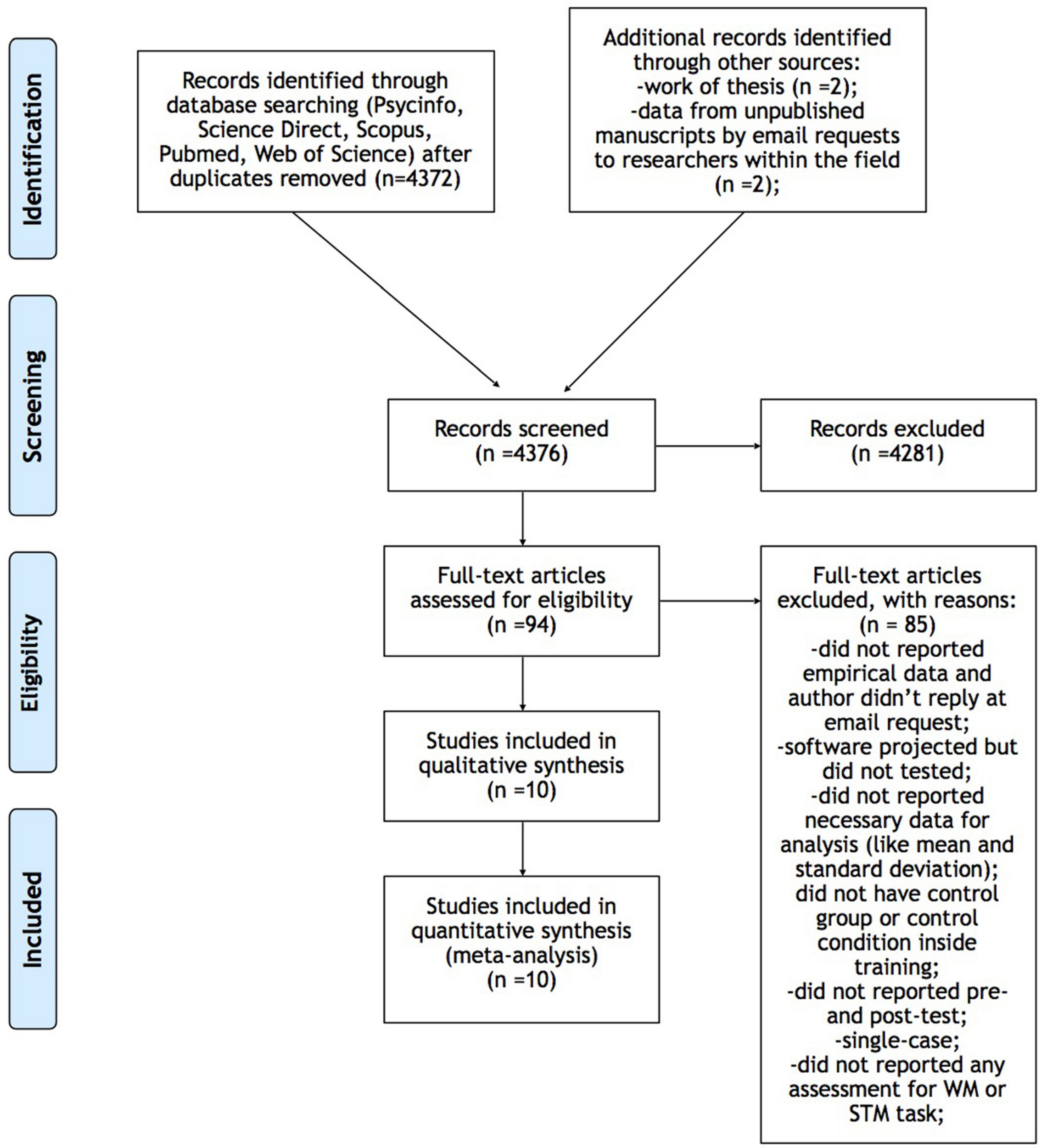

FIGURE 1 | Details about the literature search method and the criteria for inclusion and exclusion of studies.

2001). In contrast, STM tasks typically involve situations where participants passively retain small amounts of material, and minimal resources from long-term memory are activated to perform the task. STM tasks involve participants reproducing items in the order they were presented immediately after their presentation, and no cognitive processing is required (digit or word span forward tasks).

Several studies have previously shown the relationship between WM and intelligence, starting from the pioneering work of Just and Carpenter (1992). They found that intellectual performance may be enhanced if the individual is able to maintain more information in a temporary store and to simultaneously process it. Subsequently a series of correlational studies found high correlations between WM and intelligence (e.g., Kyllonen and Christal, 1990; Kane et al., 2005; Oberauer et al., 2005). In particular it has been shown that WM tasks, but not STM ones, are significantly related to intelligence, when the common variance reflecting the storage component present in both of them is removed (Engle et al., 1999).

Moreover, WM showed a predictive power for intellectual performance (Belacchi et al., 2010), as well as academic achievement areas such as literacy and numeracy (Alloway and Alloway, 2010), school readiness (Fitzpatrick and Pagani, 2012), and mathematical skills (Alloway and Passolunghi, 2011).

Previous studies have shown that individuals with ID have lower WM not only compared with typically developing individuals of the same chronological age (Henry, 2001; Henry and MacLean, 2002; Hasselhorn and Mähler, 2007; Van der Molen et al., 2007, 2009; Alloway, 2010; Schuchardt et al., 2010), but, at least in some aspects, even compared with typically developing children of the same mental age (Henry and MacLean, 2002; Van der Molen et al., 2007, 2009; Henry and Winfield, 2010).

Deficits were reported in verbal STM (Russell et al., 1996; Henry and MacLean, 2002; Lanfranchi et al., 2002; Bayliss et al., 2005; Van der Molen et al., 2007, 2009; Henry and Winfield, 2010; Schuchardt et al., 2010) and in WM (Lanfranchi et al., 2002; Danielsson et al., 2012), while visuo-spatial STM seems to be relatively preserved (Henry and MacLean, 2002; Rosenquist et al., 2003; Van der Molen et al., 2007, 2009; Henry and Winfield, 2010; Schuchardt et al., 2010).

However, contrasting findings regarding this tentative profile have been found (e.g., Bayliss et al., 2005; Hasselhorn and Mähler, 2007; Van der Molen et al., 2007), suggesting there probably is no unique profile for individuals with ID, but rather that other variables should also be considered. For example, Henry (2001) suggest that the level of severity might determine what areas are affected, with only verbal STM affected in individuals that have borderline ID and all STM and WM aspects impaired in individuals with mild ID.

Moreover, specific etiologies might have a particular STM/WM profile. For example, it has been shown that individuals with Down syndrome have an impaired verbal STM (e.g., Lanfranchi et al., 2004) in both verbal and visuo-spatial WM (e.g., Lanfranchi et al., 2012) while visuo-spatial STM seems to be relatively preserved, at least in his sequential component (e.g., Carretti et al., 2013). On the contrary, individuals with William's syndrome showed a relatively preserved verbal STM and a relatively impaired visuo-spatial STM (e.g., Jarrold et al., 1999). Although, also in this case, both verbal and visuo-spatial WM were impaired (e.g., Lanfranchi et al., 2014). Finally, a profile of selective impairment only, in both verbal and visuo-spatial

TABLE 1 | Characteristics of the working memory (WM) training studies included in the meta-analysis.

Study	Mean age training group	Mean age control group	*n* training group	*n* control group	Participants diagnosis	Type of training	Control treatment
Atia (2010)	30.1	30.1	7	6	Intellectual disabilities (ID)	VS WM	Untreated
Bennett et al. (2013)	9.5	9.5	10	11	Down syndrome	VS WM	Untreated
Conners et al. (2001)	10.8	10.8	6	5	Down syndrome	Verb WM	Visual activity
Danielsson et al. (2008)[1]	11.4	11.2	25	28	ID	VS WM	Math activity
Moalli (2006)	13.6	14.3	12	18	Down syndrome	Mixed WM	Knoledge on memory
Moalli et al. (2004)	13.8	12.6	8	8	Down syndrome	Mixed WM	Knowledge on memory
Pérez Sánchez et al. (2006)	21.5	22	10	10	Down syndrome	Verb short-term memory (STM)	Computer class
Smith and Jarrold (2014)[1]	16.2	14.0	9	8	Down syndrome	Verb STM	Visual activity
Söderqvist et al. (2012)	9.7	9.7	22	19	ID	VS WM	Non-adaptive memory training
Van der Molen et al. (2010)	15.2	15.3	41	27	Borderline intellectual functioning	VS WM	Non-adaptive memory training

[1] *This is a poster presented at a conference. Additional data has been provided by the authors after email request.*

TABLE 2 | Pretest–posttest effect sizes (ESs) both for the training group and the training group minus control group analyses.

Study	Training type	Test type	Training group			Control group included		
			Cohen's *d*	Lower C.I.	Upper C.I.	Cohen's *d*	Lower C.I.	Upper C.I.
Atia (2010)	VS WM	VS WM	0.75	−0.33	1.83	−0.29	−1.43	0.86
Atia (2010)	VS WM	VS STM	0.55	−0.52	1.61	0.24	−0.87	1.34
Bennett et al. (2013)	VS WM	Verb WM	0.25	−0.63	1.13	0.55	−0.30	1.40
Bennett et al. (2013)	VS WM	VS WM	0.98	0.05	1.91	0.95	0.07	1.82
Bennett et al. (2013)	VS WM	Verb STM	0.12	−0.75	1.00	0.17	−0.67	1.02
Bennett et al. (2013)	VS WM	VS STM	0.61	−0.28	1.51	0.87	0.01	1.73
Conners et al. (2001)	Verb WM	Verb WM	0.61	−0.56	1.77	0.04	−1.18	1.26
Conners et al. (2001)	Verb WM	VS WM	0.28	−0.85	1.42	0.54	−0.65	1.73
Danielsson et al. (2008)	VS WM	Verb WM	−0.05	−0.79	0.69	−0.27	−1.02	0.49
Danielsson et al. (2008)	VS WM	VS WM	−0.84	−1.61	−0.07	−0.06	−0.84	0.73
Danielsson et al. (2008)	VS WM	Verb STM	0.00	−0.74	0.74	−0.30	−1.05	0.46
Danielsson et al. (2008)	VS WM	VS STM	1.61	0.76	2.47	−0.28	−1.17	0.60
Moalli (2006)	Mixed WM	Verb WM	0.64	−0.09	1.37	0.03	−0.67	0.73
Moalli (2006)	Mixed WM	VS WM	0.99	0.23	1.76	0.99	0.28	1.70
Moalli (2006)	Mixed WM	Verb STM	0.51	−0.22	1.24	0.31	−0.38	1.01
Moalli (2006)	Mixed WM	VS STM	1.01	0.24	1.77	1.08	0.37	1.79
Moalli et al. (2004)	Mixed WM	Verb STM	0.51	−0.22	1.24	0.31	−0.38	1.01
Moalli et al. (2004)	Mixed WM	VS STM	1.01	0.24	1.77	1.08	0.37	1.79
Pérez Sánchez et al. (2006)	Verb STM	Verb STM	0.72	−0.19	1.63	0.74	−0.13	1.60
Pérez Sánchez et al. (2006)	Verb STM	VS STM	0.32	−0.56	1.21	0.30	−0.58	1.18
Smith and Jarrold (2014)	Verb STM	Verb STM	0.27	−0.66	1.20	0.03	−0.92	0.99
Söderqvist et al. (2012)	VS WM	Verb WM	0.30	−0.29	0.90	0.42	−0.19	1.04
Söderqvist et al. (2012)	VS WM	VS WM	0.42	−0.17	1.02	0.41	−0.21	1.03
Söderqvist et al. (2012)	VS WM	Verb STM	−0.30	−0.90	0.29	−0.67	−1.29	−0.06
Van der Molen et al. (2010)	VS WM	Verb WM	0.31	−0.18	0.80	0.12	−0.39	0.64
Van der Molen et al. (2010)	VS WM	VS WM	0.36	−0.13	0.85	−0.14	-0.66	0.38
Van der Molen et al. (2010)	VS WM	Verb STM	0.27	−0.21	0.76	0.09	−0.43	0.60
Van der Molen et al. (2010)	VS WM	VS STM	0.29	−0.20	0.78	−0.19	−0.71	0.33

WM, has been found in individuals with Fragile X syndrome (Lanfranchi et al., 2009).

Taken together, these results suggest that at least some aspects of STM and/or WM are impaired even with respect to mental age in individuals with ID.

Considering the before-mentioned relationship established between WM and intelligence, academic achievement and everyday life, we believe that it is very important to verify whether it is possible to effectively train this important cognitive function in individuals with ID.

A previous meta-analytical study, addressed the more general question whether WM training is effective or not (Melby-Lervåg and Hulme, 2012). The results were not too optimistic, showing that the programs produced short-term improvement in WM, but these gains were not always maintained at the follow-up and were not generalized to other skills. One limit of the Melby-Lervåg and Hulme (2012) review is that it includes different types of clinical conditions. For this reason the aim of the present study is to perform a meta-analytic review only on individuals with ID in order to assess the effect of WM training, considering, the effect on the specific ability directly trained, so called direct effect, and effects on other types of WM and STM, so called near-transfer effects.

Materials and Methods

Protocol and Registration

This meta-analysis was conducted following the directions of "Practical meta-analysis" written by Lipsey and Wilson (2000) and Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement by Moher et al. (2009).

Eligibility Criteria

In the present paper we considered all the studies where at least one of the WM components, as described by Baddeley (2000) model, was trained. For this reasons, we considered training that works on verbal STM (phonological loop), visuo-spatial STM (visuo-spatial sketch pad) and verbal and visuo-spatial WM (central executive).

To be included, a study had to consider a STM/WM intervention (that could be verbal, visuo-spatial or mixed) and

TABLE 3 | The ESs broken down on the two main variables, type of training and type of memory test.

Memory test	Training type			
	Visuo-spatial WM	**Mixed WM**	**Verbal WM**	**Verbal STM**
Training group				
Verbal WM	0.22 (0.22)	0.64 (0.58)	0.24 (0.60)^	–
Visuo-spatial WM	0.29 (0.21)	0.99 (0.60)	0.28 (0.58)^	–
Verbal STM	0.03 (0.22)	1.01 (0.46)*	–	0.50 (0.33)
Visuo-spatial STM	0.69 (0.24)*	0.84 (0.45)	–	0.33 (0.45)^
Total training group	0.29 (0.11)**	0.88 (0.26)**	0.44 (0.42)	0.44 (0.27)
Training group minus control group				
Verbal WM	0.20 (0.20)	0.03 (0.60)	0.04 (0.62)	–
Visuo-spatial WM	0.17 (0.19)	0.99 (0.61)	0.54 (0.61)^	–
Verbal STM	−0.18 (0.20)	0.83 (0.47)	–	0.42 (0.35)
Visuo-spatial STM	0.08 (0.23)	0.91 (0.46)	–	0.30 (0.45)
Total Training group minus control group	0.07 (0.10)	0.74 (0.15)**	0.30 (0.43)	0.38 (0.26)

Effect sizes at the top for the training group analysis and at the bottom for the training group minus control group analysis. SE is presented within brackets.
$*p < 0.05$, $**p < 0.001$.
^Only one ES; therefore not computed.

use a design that allowed training effects to be tested. This meant at least having a pretest–posttest design, and a training- and a control group. The study had to include measures of WM and/or STM. Participants were individuals below the age of 30, in order to avoid confounding due to the early cognitive decline that often occurs in this population. Participants should also have an IQ below 70 (according to one of the criteria for diagnosing ID) or declared as having ID or Borderline Intellectual Functioning. Individuals with Borderline Intellectual Functioning were also included, since a growing body of literature shows that the profile of memory deficits in this population is similar to that of individuals with ID (e.g., Alloway, 2010; Schuchardt et al., 2010).

Although we agree with the methodological issues in studies of WM training raised by Melby-Lervåg and Hulme (2012), we decided to include both randomized and non-randomized studies, as well as studies with treated and untreated control groups.

Information Sources, Search Strategy, Literature Search

Electronic databases (Science Direct, Scopus, Pubmed, Web of Science, and Psycinfo) were searched. The following keyword for the electronic databases search were used: (cognitive enrichment OR cognitive improvement OR cognitive intervention OR cognitive training OR WM training) AND (developmental disorder OR ID OR intellectual disability OR intellectual disorder OR intellectual incapacities OR intellectual incapacity OR mental retardation OR Down syndrome OR Fragile × syndrome OR Prader Willi syndrome OR Williams syndrome) AND (child OR childhood OR children OR development OR developmental OR juvenile OR youth NOT adult). The search was conducted on September 11, 2014 and results were imported to the reference management system Mendeley[1] where duplicates were removed. Literature was searched also by scanning reference lists, searching in prior reviews and personal requests to researcher in the field.

Figure 1 shows details about the literature search method and the criteria for inclusion and exclusion of studies.

Procedure

The focus on this meta-analysis is the direction and magnitude of the effects across studies, which is represented by the effect size (ES). The ES is, according to Lipsey and Wilson (2000), more suited for meta-analyses than significance testing. Effect sizes standardize findings across studies such that they can be directly compared, regardless of sample size or usage if study measures differs. This meta-analysis followed Lipsey and Wilson (2000) and used the *Standardized Mean Difference* (d) as ES for all included studies. The choice to use d was based on: (1) the included studies have group contrasts on the dependent variable, (2) all dependent variables are (i) inherently continuous and (ii) measured on a continuous scale, plus, (3) the included studies used different measures and scales. The ES was also corrected for a small sample upwardly bias (Lipsey and Wilson, 2000). Hedges (1981) concluded that the correction is necessary for all studies with $n < 20$. In order to use a consistent formula for all ESs in this meta-analysis, the correction is made even when the sample size is larger than $n = 20$. Rather than to use the pooled SD to calculate the ES (which is recommended by Lipsey and Wilson, 2000), the SD from the control group was used; it can be assumed that the variation is larger in the experimental group due to natural heterogeneity in the population. In cases where there was more than one ES per group, the mean ES is calculated as in Lipsey and Wilson (2000; s. 102).

A Random Effects Model was used to calculate the analog to the ANOVA analyses, which is preferable to use prior to the fixed model, since we can assume that the mean of the super population is different in training studies (Lipsey and Wilson, 2000).

Results

Information about the included studies can be found in **Table 1**, which includes mean age, number of participants, participant diagnosis, type of training, and control treatment. As can be seen in **Table 1**, there were large differences between studies on all listed variables. The pretest–posttest ESs for all studies, both for the training group and the training group minus control group, can be found in **Table 2**.

The overall ES for the training group was 0.42, 95% CI (0.24,0.59), $p < 0.001$. When subtracting the ES from the control group (i.e., the placebo effect), the remaining effect was.24, 95% CI (0.06,0.43), $p < 0.01$. These ESs correspond to a medium and

[1]www.mendeley.com

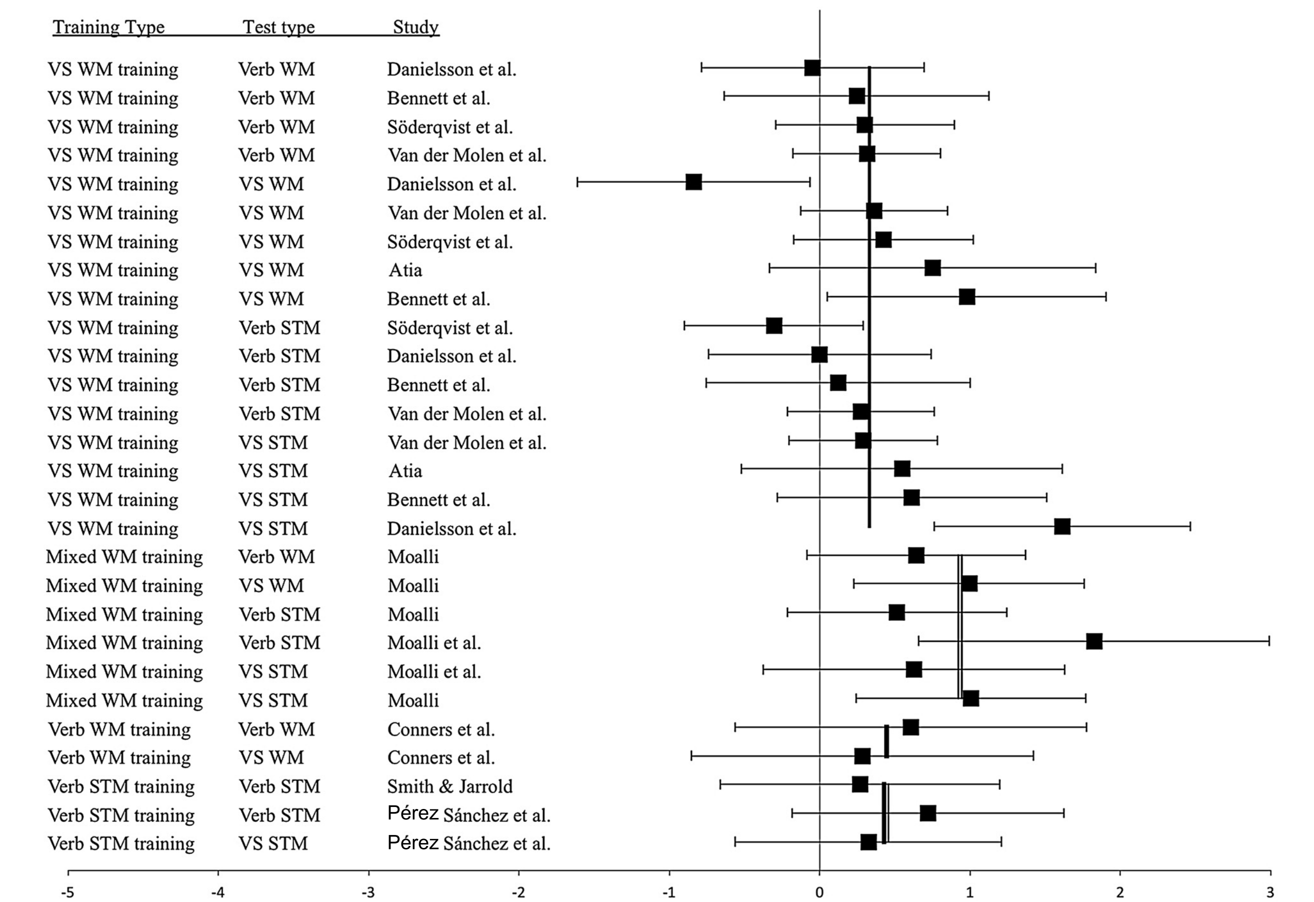

FIGURE 2 | Forrest plot for training group post-test minus pre-test effect sizes (ESs) sorted by type of training and test type. The overall ES for each training type is displayed by a line. Type of training and type of test are listed in the two left columns.

a small ES (Cohen, 1962) respectively. The ESs have been broken down on the two main variables, type of training and type of memory test. **Table 3** shows the results of these analyses. For the training group, there was a significant effect of visuo-spatial WM training [0.29, 95% CI (0.07,0.26), $p < 0.001$], which was driven by the significant effect on visuo-spatial STM [0.69, 95% CI (0.22,0.67), $p < 0.05$], whereas the effects on the other tests were non-significant. However, both these effects were non-significant and close to zero when subtracting the control groups ES.

In the training group, there was a significant overall effect of mixed WM training [0.88, 95% CI (0.37,0.99), $p < 0.001$], which was driven by a significant effect on verbal STM [1.01, 95% CI (0.11,0.67), $p < 0.05$]. The effects on the other test types were large, but not significant. In the training group minus control group analysis, the overall effect was still significant [0.74, 95% CI (0.45, 1.02), $p < 0.001$]. The effects on all test types were non-significant, but for all test types, except verbal WM, the ES was large.

The ESs for all studies are shown in **Figure 2** for the training group and in **Figure 3** for the training group minus control group. The studies are sorted by type of training and then by the magnitude of the ES. As can be seen, there were large variations in ESs and large confidence intervals in many cases. There were even studies where the confidence interval does not cover the overall ES for that type of training. This indicates that the included articles indeed have different characteristics, or that some studies could have low quality.

Discussion

The results show overall effects on WM training for individuals with ID. This was true for pretest–posttest ESs for both the training group (medium ES) and the training group minus control group analyses (small ES). Several different types of WM training have been used but only mixed WM training, with both verbal and visuo-spatial components, showed significant training effects. A breakdown of the training effects on verbal and visuo-spatial WM and STM tests indicated somewhat larger ESs for the STM tests compared to the WM tests.

Taken together these results suggest that different types of WM training can lead to different outputs on STM and WM in individuals with ID, and that depending on the type of activities the training can be more or less effective.

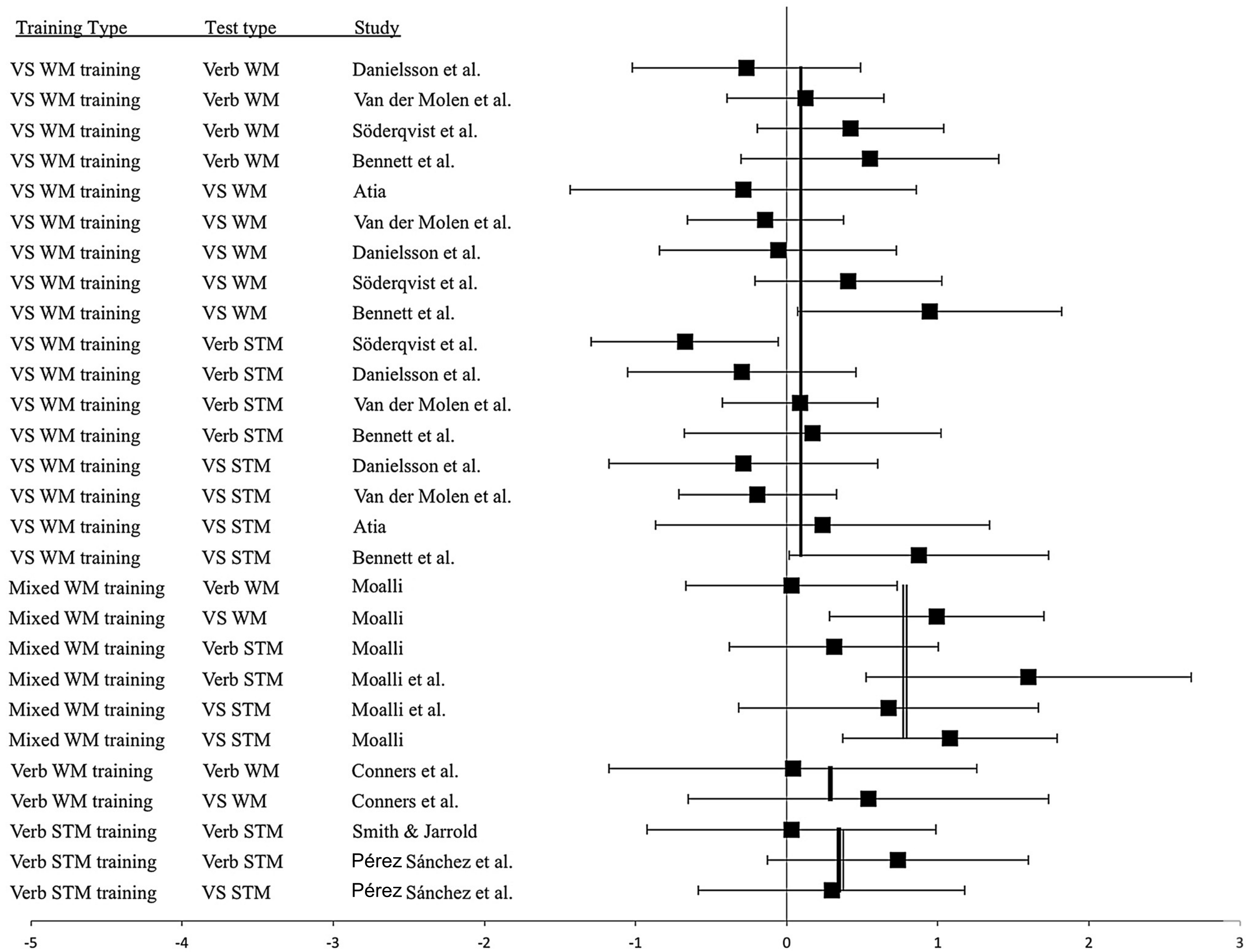

FIGURE 3 | Forrest plot for training group minus control group ESs sorted by type of training and test type. The overall ES for each training type is displayed by a line. Type of training and type of test are listed in the two left columns.

From the data analyzed in this study a mixed memory training seems to be the more effective in improving WM in individuals with ID, leading to greater improvements on verbal and visuo-spatial STM, than on WM. Only two studies (Moalli et al., 2004 and Moalli, 2006) used a mixed training program and the training activities used in both studies were similar. The training was focused on helping the child learn different strategies to improve verbal STM and WM, and to understand when and how to use them in verbal and visuo-spatial STM and WM tasks. The training focused on a variety of STM and WM tasks in order to exercise the use of the newly learned strategies. From a theoretical point of view the results of this meta-analysis suggest that, if we consider individuals with ID as one group, a mixed training approach works better than training focusing only on one particular WM aspect. This could be due to that individuals with ID show deficits in both verbal and visuo-spatial STM/WM (e.g., Lanfranchi et al., 2002; Danielsson et al., 2012). Moreover, one hypothesis is that working in a "metacognitive way" helps the person to acquire new strategies and to learn when and how to use them, which produces better results than just exercising STM/WM.

From a statistical point of view it is more probable that interventions that target multiple components of WM are more effective given the individual differences in strengths and weaknesses for different components of WM. This is in line with a meta-analysis on WM training for children and adolescents with ADHD (Cortese et al., 2014) where interventions targeting multiple neuropsychological deficits had large effects on ADHD symptoms.

That the effect for visuo-spatial WM training was close to zero in the training minus control group analysis makes the interpretation problematic, since this type of training accounts for 60% of the included comparisons.

However, at least half of the studies (Moalli et al., 2004; Moalli, 2006; Van der Molen et al., 2010; Söderqvist et al., 2012;

Smith and Jarrold, 2014) used a control group where the given memory training was supposed to be less effective than the target training. In Van der Molen et al. (2010) and Söderqvist et al. (2012) the control group was given a non-adaptive version of the target training. In Moalli et al. (2004) and Moalli (2006), the control group worked on the knowledge of how memory functions, and in Smith and Jarrold (2014) the control group worked on a visual activity that also involves memory. Although we agree with Melby-Lervåg and Hulme (2012), that an untreated control group might overestimate the effect due to the training, a control group that engage in activities that, in some way, involve memory, could have reduced the ES of the difference between the training and control group.

This meta-analysis highlights the lack of studies on WM training in individuals with ID. Although a number of studies have highlighted STM/WM deficit in individuals with ID (e.g., Lanfranchi et al., 2002; Danielsson et al., 2012), only few studies have explored the possibility to improve this important cognitive aspect in this population. Moreover, some of these few studies had to be excluded due to the methodological problems highlighted by Melby-Lervåg and Hulme (2012), such as the lack of a control group or lack of a pretest–posttest design. Therefore, we believe that future research should better explore the possibility to train WM in a population with ID, with a pretest–posttest design and an adequate control group.

Limitations of the Current Study

This meta-analysis has several limitations. Since there were few studies in this area, there were several important differences between the studies. If there had been more studies, these could have been analyzed as moderator variables (for example, one study allowed for an IQ up to 85, which is outside the traditional definition of intellectual disability). There are groups with different causes to their ID, for example individuals with Down syndrome as well as individuals with intellectual disability for unknown cause. Even though the control group in each study always had the same participant characteristics as the training group, the control groups differed between studies since the training groups had different causes to their ID. The controls also differed in terms of what they did between pre- and posttest. Some were active controls, who did other types of training with different levels of similarity to the training of the training group and some were passive controls. In an effort to acknowledge the control group issues in this meta-analysis the results are reported both with and without subtraction of the control group. The pattern of results are relatively similar for both analyses, which indicates that the control groups have small, or at least relatively equally distributed, effects in the different analyses.

The meta-analysis was also limited to only close transfer effects, i.e., on WM and STM, since most studies did not include tests of far transfer and those who did had very different types of tests.

Conclusion

This study shows that there was an overall significant effect of WM training for individuals with ID. An analysis of different types of training showed that only a mixed WM training approach, with both verbal and visuo-spatial components, had a significant ES. The effects were largest on STM tests. Even if the results are promising, they should be interpreted with caution since there were few studies included in the meta-analysis, the studies were relatively different with regard to type of intellectual disability, type of control groups and type of control group training.

The training effects analyzed are limited to effects to WM and STM test. The transfer to everyday activities and clinically relevant tasks have not been analyzed here due to very few of those measures in the studies. Meta-analysis on WM training for children with ADHD typically show an effect on WM, but limited transfer to clinically relevant tasks (e.g., Melby-Lervåg and Hulme, 2012; Rapport et al., 2013; Cortese et al., 2014). However, one meta-analysis (Spencer-Smith and Klingberg, 2015) actually found transfer to one activity, inattention in daily life. These results indicate that even if there are short-term effects on WM and STM for individuals with ID, these effects do not necessarily generalize to long-term effects or everyday life activities. More studies are needed to better understand how to design an effective WM intervention for this group and to understand if, and how these effects transfer to everyday activities.

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Benefits of extending and adjusting the level of difficulty on computerized cognitive training for children with intellectual disabilities

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Training on working memory (WM) improves attention and WM in children with attention-deficit hyperactivity disorder and memory impairments. However, for children with intellectual disabilities (ID), the results have been less encouraging. In this preliminary study it was hypothesized that children with ID would benefit from an extended amount of training and that the level of difficulty during training would affect the outcome. We included 21 children with mild or moderate ID aged 8–13 years. They went through between 37 and 50 training sessions with an adaptive computerized program on WM and non-verbal reasoning (NVR). The children were divided into two subgroups with different difficulty levels during training. The transfer to untrained cognitive tests was compared to the results of 22 children with ID training only 25 sessions, and to a control group. We found that the training group with the extended training program improved significantly on a block design task measuring NVR and on a WM task compared to the control group. There was also a significantly larger improvement on block design relative to the training group with the shorter training time. The children that received easier training tasks also improved significantly more on a verbal WM task compared to children with more demanding tasks. In conclusion, these preliminary data suggest that children with ID might benefit from cognitive training with longer training periods and less demanding tasks, compared to children without disabilities.

Keywords: intellectual disabilities, working memory, cognitive training, adaptive training, rate of failure, training amount, motivation, training intensity

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Introduction

Working memory (WM) refers to the retention of information over a brief period of time (Klingberg, 2010). It is of major importance for a wide range of cognitive tasks and for academic achievement (Alloway and Alloway, 2010). Numerous scientific articles have concluded that cognitive functions, such as WM, can be positively influenced to higher levels by different kinds of training (Klingberg, 2010; Diamond and Lee, 2011; Hötting and Röder, 2013; Bergman-Nutley et al., 2014). Computerized WM training programs has been shown to improve WM performance in healthy groups of children and adults (Olesen et al., 2004; Jaeggi et al., 2008; Bergman-Nutley et al., 2011) and in clinical groups, such as children with attention-deficit hyperactivity disorders (Klingberg et al., 2005; Beck et al., 2010; Holmes et al., 2010; Mezzacappa and Buckner, 2010), children born preterm (Løhaugen et al., 2011) and, although sparse, children with intellectual disabilities (ID; Van der Molen et al., 2010; Söderqvist et al., 2012; Bennett et al., 2013; Delavarian et al., 2015). The training has also been shown to have far transfer effects to reduce daily life inattention (Spencer-Smith and Klingberg, 2015). Recently, a better understanding of the neural basis for cognitive development during childhood and training-induced plasticity of the brain has emerged (Klingberg, 2014), which supports the assumption that cognitive training has a positive effect.

There are different kinds of computerized programs on WM training (Klingberg, 2010). Visuospatial WM-training programs focus on retaining visuospatial information, while *n*-back training presents sequences of stimuli demanding matching of stimuli to the ones at a defined number of steps earlier in the sequence. All the programs consist of training tasks at ascending levels, and a crucial element of the training is to adjust the tasks to a challenging level of difficulty for each of the trainees all through the training in order to give optimal training progress.

Söderqvist et al. (2012) trained children aged 6–12 years with mild or moderate ID on visuospatial WM and non-verbal reasoning (NVR). The training program had been developed for a former study by Bergman-Nutley et al. (2011). The results indicated that there might be some transfer effect from training NVR to non-trained WM tasks, and Söderqvist therefore decided to utilize a program version with both WM and NVR training. The test group trained on an adaptive computerized training program ascending to more demanding levels as a result of the trainees' right answers on the given tasks. The control group used a program with the same kind of tasks, but stayed on the easiest level throughout the entire training period. Both groups trained for 5 weeks, 5 days a week. Before training, they were tested with a battery of cognitive tests and their parents rated their behavior on a questionnaire. Their academic skills in reading, writing, number perception, and calculation was assessed by their teachers. During training, there was a large variance in progress within the test group. After training, the children were re-assessed with the same cognitive tests and their behavior was rated by their parents. One year after training, they were again tested on cognitive tests, their behavior was rated by their parents, and their academic skills were assessed at school. Comparing the results of the tests and assessments for the test group and the control group showed little difference, which indicated that the transfer effects of the adaptive training to untrained abilities were sparse. The results were compared to the study by Bergman-Nutley et al. (2011) on training 4-year-olds without special needs. It seemed like the 4-year-olds showed better transfer effects than the children in the Söderqvist et al. (2012) study, even if their cognitive capacity before training seemed to be at the same level. Söderqvist suggested that children with ID might require an alternative method of training, either by lengthening the training period or by a slower progress that allows more practice on every level.

Another important aspect that has to be taken into account for the adaptation of training is that persons with ID seem to be vulnerable in any demanding educational situation. It has been documented that children with ID report a greater frequency and intensity of fears than similar-age peers without ID (Ramirez and Kratochwill, 1997; Li and Morris, 2007). Another study showed that boys with mild levels of ID reported high levels of fear related to failure and criticism (Li et al., 2008). A high level of expectancy of failure has been a well-known phenomenon for persons with ID, probably as a result of numerous experiences of lack of success (Stancliffe et al., 2002). This expectancy can affect their motivation in such a way that task performance will be below what might be anticipated from the individual's capabilities (Balla and Zigler, 1979; Lecavalier and Tasse, 2002). Perrig et al. (2009) stated that one of the requirements for efficient WM training for children with ID would be to ensure that the tasks are easy enough to allow success in solving the problems and to keep alive the motivation to continue training.

The authors of this article were involved in the study by Söderqvist et al. (2012). The project left a number of unanswered questions waiting to be clarified. It was therefore decided to organize an extension of the study. We chose to focus on the mechanisms involved in the training and the immediate and relatively near transfer to untrained skills and not on the longitudinal effects and the far transfer to academic and everyday skills.

Defining the aims of the study, we were inspired by Jaeggi et al. (2011) who concluded that, in addition to the amount of training, individual differences in training performance play a major role for the transfer effects. They therefore suggested that future research should pay attention to factors that moderate transfer and to find how these factors can be manipulated to make training more effective.

The main goal of the extended study was to detect possible changes in the training procedures for children with ID that could give significantly better transfer effects to non-trained tasks than what was found in the Söderqvist et al. (2012) study.

Söderqvist et al. (2012) suggested that children with ID might benefit from lengthening the training period. We had also noticed that the proportion of incorrect responses during training was relatively high in order to make the tasks sufficiently challenging for the participants. We were aware of that the participants' experience of success and failure during training would affect their motivation on training. It would therefore be crucial to find a suitable level of difficulty on the training tasks to ensure a sufficiently high level of motivation.

For the current study the following two main hypotheses were developed:

Hypothesis 1: Children with ID will attain better transfer results on non-trained cognitive tests by extending the training period.

Hypothesis 2: The level of difficulty on the training tasks will affect training results and transfer to untrained tasks for children with ID.

The results from the present study were compared with the training group and the control group from the Söderqvist et al. (2012) study.

The participants of our group were separated into two subgroups who trained programs with different levels of difficulty.

Because of the low number of participants and its dependency on making comparisons to a former study, the present study should be considered a preliminary study.

Materials and Methods

Participants

E-mails were sent to every elementary school in the Oslo and Drammen regions to recruit 23 children and young adolescents. The participants all attended special education programs for children with ID and had been diagnosed with a mild or moderate mental retardation according to ICD 10 (World Health Organization, 1993). Two of the male children did not complete the training: one because of a long vacation abroad, and the other because he refused to continue training after 13 training sessions. The study included 21 participants: 10 female and 11 male, aged 8–13 years ($m = 10.18$ years, SD = 1.51).

Of the 21 participants, 10 were reported to have additional diagnoses: three with Down syndrome, two with Cerebral Palsy (with mild motor problems), two with ADHD, one with Kabuki syndrome, one with Dravet syndrome and one with William syndrome.

Ethical approvals were received from the regional ethics committee of the Norwegian south–east health region. Special information had been prepared for the children, and informed consents were obtained from the parents/caregivers and the children before participation.

Exclusion criteria were diagnosis of autism, or severe motor or sensory problems, as these were considered to affect assessments and/or training ability.

In the Söderqvist et al. (2012) study, all the children were pseudo-randomized into an intervention group or an active control group, after controlling for gender and chronological age by independent personnel. The control group trained on a non-adaptive version and the intervention group received an adaptive training program. The study had a double-blind design, with participants and the cognitive assessors unaware of group membership.

Neither the Söderqvist study nor this present study included data of parents' socioeconomic status or educational level.

Training Method

The participants trained on the same computerized program that was utilized in the studies by Bergman-Nutley et al. (2011) and Söderqvist et al. (2012). The program included two types of training exercises: one focused on WM training and the other on NVR training. The WM tasks are developed by Cogmed and the NVR tasks were specifically developed for the study by Bergman-Nutley et al. (2011). The level of difficulty was individually adapted by an algorithm. In this study, the number of training sessions had been extended according to the conclusions of the Söderqvist study. Because the number of training sessions had been increased from 25 to a maximum of 50, it was considered that the training could be better performed at the children's schools. The schools were asked to implement all the 50 sessions, but if this high number would cause difficulties, 40 sessions would be sufficient. The schools were also asked to facilitate frequent training, preferably as much as five times a week. At every training session there had to be a teacher or teacher's assistant accompanying the child.

Because of limited school resources, it was hard to recruit participants and many of the schools in this study were not able to give as much as 50 training sessions. Five children completed 37–39 training sessions, four completed 40–44, five completed 45–49, and seven completed 50. The mean number of training sessions was 44.76 (SD = 4.95). The sparse time for one-to-one teaching also resulted in that most of the participants having fewer training sessions each week, and the training was stretched out over a longer period than initially planned. The training length for our group ranged from 10 to 23 weeks.

The program had a clear structure and contained several systems of reward to keep the children motivated. During the workout, the teachers registered the children's motivation and their way of working.

The program for NVR consisted of three alternative types of tasks. In the Classification tasks, cards with figures were to be matched on the basis of shapes, colors, and numbers. Sequential Order demanded identification of a logical progression; for instance, in position, size, or brightness. Repeated Pattern required the completion of a repeated pattern of altering shapes. Training in all the three types of tasks started at an easy level and escalated to a higher level of difficulty as a result of a given number of correct responses. Each training session started at the final level of the previous training.

The WM training consisted of seven types of tasks. Colorful figures were displayed in different settings and some of the figures made sounds and movements in a serial order. The task consisted of clicking on the figures in the same order. The number of figures to be remembered increased for each level. Each training session started at a somewhat lower level than the results at the end of the previous training session and escalated to a higher level of difficulty as a result of a given number of correct responses.

After the first 13 participants had completed their training, we changed the program. The initial program algorithm led to a task level that was considered too difficult and the high number of incorrect responses seemed to demotivate the participants.

On the NVR tasks the initial program algorithm demanded only a few correct responses on each level to escalate to the next. It seemed like the children did not acquire a real understanding of the tasks on one level before being presented to a different and more difficult set of tasks. Therefore the program used for subgroup 2 was changed to demand a higher number of correct responses to escalate to a more difficult level. The aim was to secure a better understanding and higher motivation for the participants.

On the WM tasks the number of right responses demanded to escalate was not changed, but subgroup 2, unlike subgroup 1, started each session at a level considerably lower than the final level of the previous training. The aim was to secure a feeling of mastery and success at the beginning of each session leading to a higher motivation to solve the more challenging tasks as the level of difficulty escalates.

Except for the level of difficulty, the two program versions were identical. They consisted of the same number of training sessions and the same types of tasks.

Assessment Methods

The participants were tested at their schools by the authors of this article, before and after training, with a battery of cognitive tests. We chose to use the tests that we considered to be most suitable from the Söderqvist et al. (2012) study, supplemented with alternative tests on the same cognitive domains. The cognitive tests had been carefully selected. They had to fulfill the requirement of having indexes sufficiently fine-grained to show even little improvements, and difficulty levels adapted to ensure a feeling of success to keep the motivation steady throughout all the tests. To create a situation of predictability, the children were shown a setup with one picture for every test, and they were promised a little gift as a reward for completing the tests in order to keep them concentrated and motivated. The same procedure was followed on the pre- and post-tests.

For assessing the near transfer domain visual WM, Odd-One-Out from Automated Working Memory Assessment (AWMA; Alloway, 2007) was chosen, and for NVR, Block Design and Matrix Reasoning from Wechsler Preschool and Primary Scale of Intelligence, WPSSI-III (Wechsler, 2004a) was chosen. The domains of far transfer were considered to be verbal short-term memory and WM, and verbal reasoning. For these domains Word Span (Thorell and Wahlstedt, 2006), Comprehension of Instructions from A Developmental NEuroPSYchological Assessment, NEPSY II (Brooks et al., 2009) and Word Reasoning from WPPSI-III were chosen. In addition, Cancelation from Wechsler Intelligence Scale for Children, WISC-IV (Wechsler, 2004b) was administered in order to see if there would be a correlation between processing speed and training outcome.

After completing the training, the teachers filled out an in-house questionnaire with eight questions on a five-point scale. The questions concerned the children's motivation during training and the teachers' impression of the program.

Statistical Methods

For the statistical analyses, the SPSS 21 was utilized. To test the effect of training we performed ANOVA, comparing the differences of the means of the cognitive tests before training (T1) and after training (T2) for our groups and the training- and control groups of the Söderqvist et al. (2012) study. In order to investigate correlations between the training effect and the proportion of correct and incorrect responses during training, and the number of training sessions and training intensity, we used Pearson's r. To examine possible correlations between training effects (the difference between T1 and T2 scores) and the participants' age and T1 scores, Pearson's r was used.

Subgroups

Subgroup 1 had 13 participants, five female and eight male, aged 8–13 years ($m = 10.03$ years, SD $= 1.65$). Subgroup 2 had eight participants, six female and two male, aged 8.5–11.5 years ($m = 10.42$ years, SD $= 1.27$).

The results of the cognitive tests before training (T1; **Table 1**) showed no significant differences between the subgroups.

We found it justifiable to merge the two subgroups on the analyses concerning training extension because both groups had trained on programs with extended number of training sessions, the two subgroups were relatively identical on age and baseline cognitive functioning and the contribution of gender was more balanced by merging the groups.

Results

Comparisons of Groups

The distribution of gender, the mean age and the mean results of the cognitive tests before training (T1) of the participants of this study were compared on the same variables to the test and control group of the Söderqvist et al. (2012) study. A comparison of the groups is presented in **Table 1**.

Except for the gender distribution on the subgroups, the groups were relatively similar on these variables. There were no significant differences on the age between any of the five groups. On the T1 cognitive tests there were no significant differences, but there was a trend for difference on the T1 results on Block Design between short training and long training total ($p = 0.060$) and between short training and subgroup 1 ($p = 0.069$).

Training Progress

As we had expected, the change of the task algorithm led to an apparent reduction in the participants' failure rates. On the NVR tasks, the participants in subgroup 1 in total had 58.7% incorrect responses, while the participants in subgroup 2 had 39.3%. On the WM tasks, subgroup 1 had 49.8% incorrrect responses, and subgroup 2 had 38.8%.

All the participants showed an overall apparent training progress, but there were large differences regarding how much they improved. Looking at the long training group as a whole, there seemed to be a steady and stable progress within both the WM and the NVR training.

But there was a marked difference between the subgroups in the patterns of progress during training. In the WM training the level of difficulty is escalated by increasing the number of presented figures to be remembered. Subgroup 2 started every session on lower levels, but still reached higher difficulty ratings than subgroup 1 (**Figure 1**). It seemed like subgroup 2 started each exercise at a sufficiently low level to ensure the participants' success by easily finding the correct answer. It appeared that this adaption was beneficial, leading to higher levels of achievement.

In the NVR training the tasks are organized on subsequent levels according to the task complexity. After mastering a certain number of the tasks at one level, the participant escalates to the next level. The mean levels on the NVR training sessions 35 to 37 (where all the participants were still training) was 16.55 (SD $= 7.70$) for subgroup 1 and 11.65 (SD $= 6.31$) for subgroup 2. Subgroup 1 reached higher levels than subgroup 2, but it seemed like many of the participants had not achieved a real understanding of the nature of the task, resulting in many

TABLE 1 | Comparisons before training of the groups from our project (Long training) and the Söderqvist study (Short training and Control) on contribution of genders, means of age (years) and means of results on cognitive tests (T1).

		Long training			Short training ($n = 22$)	Control ($n = 19$)
		Total ($n = 21$)	Subgroup 1 ($n = 13$)	Subgroup 2 ($n = 8$)		
Gender	M (No.)	10	8	2	12	10
	F (No.)	11	5	6	10	9
Age		10.18 (1.51)	10.03 (1.65)	10.42 (1.27)	9.82 (1.62)	9.53 (1.56)
T1 Block Design		21.43 (5.37)	21.23 (5.26)	21.75 (5.90)	24.27 (4.23)	23.06 (4.32)
T1 Word Span		5.19 (2.42)	5.15 (2.79)	5.25 (1.83)	5.95 (2.18)	5.26 (2.60)
T1 Odd-One-Out Memory		8.00 (6.40)	7.62 (7.97)	8.62 (2.67)	9.59 (4.29)	9.47 (4.77)
T1 Comprehension of Instructions		14.00 (4.35)	14.08 (5.25)	13.88 (2.59)	14.70 (4.97)	13.58 (4.75)

F, female; M, male.

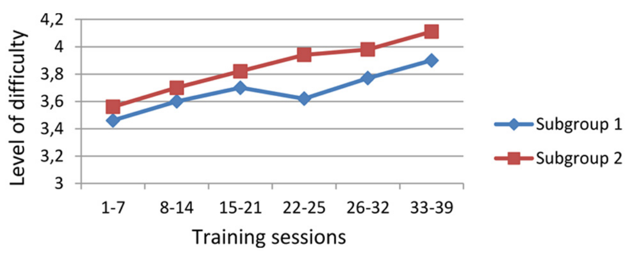

FIGURE 1 | The means of the highest levels in working memory (WM) training for the two subgroups at different stages of the training. *Y*-axis: level of difficulty refers to the number of figures being detected and remembered. *X*-axis: training session numbers are grouped in order to contain the same variety of training tasks for each cluster.

incorrect responses. Subgroup 2 did not reach as high levels as subgroup 1, resulting in a higher proportion of correct responses, and presumably a better understanding.

Teachers' Reports

In order to assess the children's motivation and the teachers' impression of the program, the teachers were asked to complete an in-house questionnaire using scales from 1 to 5. The mean score on motivation for the whole group was 3.78. For subgroup 1 the mean score was 3.58 and for subgroup 2 it was 4.50.

The second part of the questionnaire focused on the teachers' judgment of the program. On the question of whether the teachers regarded the program to be too difficult, on a scale where one was "Totally disagree" and five was "Totally agree," the mean score for the whole group was 2.56. For subgroup 1, the mean score was 3.08; for subgroup 2, it was 1.50, showing that there was a lower level of consent that the tasks were too difficult among the teachers in subgroup 2.

Transfer to Untrained Tasks

The purpose of the cognitive tests was to detect differences in transfer of trained skills to untrained tasks between the long training groups, the short training group and the control group, as would be expected from hypothesis 1.

The mean scores and standard deviations for the groups of our study (long training) and the groups from the Söderqvist et al. (2012) study (short training and control) are presented in **Table 2**.

The difference between T1 and T2 results shows the skills gained during the training period. By comparing the differences of our group (long training total, merged by subgroup 1 and subgroup 2) and the Söderqvist et al. (2012) training group (short training), we were able to get a picture of the difference in the effect of the two training extensions. In addition, by comparing the differences between the group of long training total and the Söderqvist control group, we got an indication of the total strength of the training variable despite other variables like maturation, training effect from the pre-test, and effects of other academic training (**Table 3**).

The Söderqvist et al. (2012) study did not find any significant differences between T1 and T2 for the short-training group and the control group. Comparing our long training group with the Söderqvist short-training group we found a significant difference on Block Design ($p = 0.037$) and in addition apparent positive differences on Odd-One-Out and Comprehension of Instructions. The comparison with the Söderqvist control group showed a significant difference on Block Design ($p = 0.006$) and also on Odd-One-Out Memory ($p = 0.028$). But on the Word Span tests the long training group showed less progress than the Söderqvist groups, mainly because of the negative differences of subgroup 1 who performed poorer on T2 than on T1.

The best over-all results we found in subgroup 2. The differences of the mean scores between T1 and T2 were larger for subgroup 2 than for subgroup 1 on all the cognitive tests except for cancelation, which was only included in the battery in order to investigate possible correlations between T1 scores and training effects. The most apparent differences between the subgroups were found on the WM tests, showing significant differences for Word Span Forward ($p = 0.039$) and Word Span Total ($p = 0.050$) and a trend of significance on Comprehension of Instructions ($p = 0.082$).

Level of Difficulty

Hypothesis 2 focuses on the impact of the training task level of difficulty on the training effects. **Table 3** shows an overall better transfer to untrained tasks for subgroup 2, which indicates

TABLE 2 | Mean test scores and SD before training (T1) and after training (T2) for the groups of the present study (Long Training) and the Söderqvist et al. (2012) study (Short training and Control).

Tests	Long training						Short training ($n = 22$)		Control ($n = 19$)	
	Total ($n = 21$)		Subgroup 1 ($n = 13$)		Subgroup 2 ($n = 8$)					
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
Block Design	21.43 (5.37)	24.86 (4.83)	21.23 (5.26)	24.23 (4.51)	21.75 (5.90)	25.88 (5.46)	24.27 (4.23)	25.09 (5.04)	23.06 (4.32)	22.50 (4.76)
Word Span Forward	4.00 (1.30)	4.10 (1.51)	3.85 (1.46)	3.77 (1.79)	4.25 (1.04)	4.62 (.74)	3.92 (1.94)	4.43 (1.16)	3.64 (1.62)	4.14 (1.52)
Word Span Backward	1.19 (1.57)	1.24 (1.55)	1.31 (1.70)	1.00 (1.35)	1.00 (1.41)	1.62 (1.85)	1.46 (1.32)	2.00 (1.84)	1.55 (1.77)	1.59 (1.68)
Word Span Total	5.19 (2.42)	5.33 (2.58)	5.15 (2.79)	4.77 (2.74)	5.25 (1.83)	6.25 (2.12)	5.25 (2.47)	6.43 (2.62)	5.18 (2.81)	5.73 (2.83)
Odd-One-Out Memory	8.00 (6.40)	10.81 (4.33)	7.62 (7.97)	9.77 (4.85)	8.62 (2.67)	12.50 (2.83)				
Matrix Reasoning	11.33 (5.93)	14.29 (5.07)	10.31 (6.37)	12.54 (4.88)	13.00 (5.07)	17.12 (4.22)				
Word Reasoning	9.81 (7.43)	13.62 (8.30)	9.54 (8.28)	12.54 (9.28)	10.25 (6.30)	15.38 (6.59)				
Comprehension of Instructions	14.00 (4.35)	16.33 (3.71)	14.08 (5.25)	15.69 (3.21)	13.88 (2.59)	17.38 (2.33)	14.70 (4.98)	16.20 (4.65)	14.06 (4.80)	15.12 (4.96)
Cancelation	38.33 (21.31)	45.00 (22.44)	32.77 (22.61)	40.15 (4.31)	47.38 (16.41)	52.88 (20.95)				

TABLE 3 | Presenting and comparing (ANOVA) test score differences from our study (long training) and the Söderqvist et al. (2012) study (short training and control).

Tests	Test score differences between T1 and T2. Means (SD)					Comparing score differences. *F* (p)		
	Long training			Short training ($n = 22$)	Control ($n = 19$)	Long training total ($n = 21$) vs. control ($n = 19$)	Long training total ($n = 21$) vs. short training ($n = 22$)	Subgroup 1 ($n = 13$) vs. subgroup 2 ($n = 8$)
	Total ($n = 21$)	Subgroup 1 ($n = 13$)	Subgroup 2 ($n = 8$)					
Block Design	3.43 (4.00)	3.00 (4.86)	4.13 (2.03)	0.82 (3.95)	0.53 (4.11)	8.57 (0.006)**	4.64 (0.037)*	0.38 (0.545)
Word Span Forward	0.10 (1.00)	−0.08 (0.86)	0.38 (1.19)	0.41 (0.85)	0.58 (1.02)	2.71 (0.137)	0.60 (0.445)	1.01 (0.325)
Word Span Backward	0.05 (1.02)	−0.31 (0.75)	0.63 (1.19)	0.18 (1.37)	0.00 (0.75)	0.12 (0.734)	1.34 (0.225)	4.92 (0.039)*
Word Span Total	0.14 (1.59)	−0.38 (1.39)	1.00 (1.60)	0.59 (1.56)	0.58 (1.07)	0.76 (0.389)	0.87 (0.357)	4.39 (0.050)*
Odd-One-Out Memory	2.81 (4.19)	2.15 (5.19)	3.88 (1.36)	1.86 (2.83)	0.21 (2.80)	5.20 (0.028)*	0.76 (0.389)	0.83 (0.374)
Matrix Reasoning	2.95 (3.37)	2.23 (3.09)	4.13 (3.68)					1.61 (0.219)
Word Reasoning	3.81 (2.91)	3.00 (2.74)	5.13 (2.85)					2.89 (0.105)
Comprehension of Instructions	2.33 (2.41)	1.62 (2.33)	3.50 (2.20)	1.36 (2.74)	1.00 (2.79)	2.63 (0.113)	1.51 (0.226)	3.37 (0.082)
Cancellation	6.67 (14.13)	7.38 (11.28)	5.50 (18.71)					0.08 (0.775)

*$p < 0.05$, **$p < 0.01$.

the benefit of the easier tasks. In addition, we computed the correlations between the results of the cognitive tests and the proportion of success and failures on training for the whole group. We found a significant negative correlation between the results of the Word Span test and the number and percentage of errors (incorrect responses) on the WM tasks. There was a trend of negative correlation between Word Span and the number and percentage of incorrect responses on the NVR tasks. Also, there was a trend for negative correlation between the results on the Comprehension of Instructions and the number of errors both on the WM and NVR tasks **(Table 4)**.

For the other cognitive tests, we found no significant correlations to the proportion of failure. Likewise, we found no significant correlations between any of the T1 and T2 differences on the cognitive tests and the number of correct responses or the total amount of training.

Training Intensity

The project data also provides opportunity to investigate some additional themes, like whether training intensity affected training outcome. The number of training sessions and the number of days from training start to completion will give a picture of the intensity of the training.

There was no significant correlation between any of the results on the cognitive tests and the total amount of training. However, there was a pattern of mostly negative correlations (Block Design: $r = 0.114$; Word Span Total: $r = -0.364$; Odd-One-Out Memory: $r = -0.248$; Matrix Reasoning: $r = -0.073$; Word Reasoning: $r = 0.000$; Comprehension of Instructions: $r = -0.340$).

Likewise, there was no significant correlation between any of the results on the cognitive tests and the number of days from the start to the completion of training, measuring training intensity. (Block Design: $r = 0.024$; Word Span Total: $r = 0.164$; Odd-One-Out Memory: $r = 0.174$; Matrix Reasoning: $r = -0.038$; Word Reasoning: $r = 0.093$; Comprehension of Instructions: $r = 0.246$).

Individual Training Benefits

It was also considered of interest to investigate whether all or just some of the participants seemed to benefit from the training. There were obvious individual differences on how many test points they improved from T1 to T2. Calculating the rank order (1–21) on the size of differences between the score results on the T1 and T2 cognitive tests (Block Design, Word Span Total, Odd-One-Out Memory, Matrix Reasoning, Word Reasoning, and Comprehension of Instructions) showed that the best mean rank order was 4.33 (SD = 2.58) and the poorest was 15.50 (SD = 6.41). For the five participants with the poorest rank order, the SD varied from 5.37 to 7.27, showing that none of them had a pervasive pattern of having the poorest improvement. This indicates that none of the participants clearly did not benefit from the training.

In order to gain information on what participants who benefited best from this particular kind of training, the transfer effects were compared to age, gender and results on the cognitive tests before training. We did not find any significant correlations between the transfer effects and the age of the participants or the T1 results. Likewise there were no significant differences comparing the mean transfer effects for the two genders.

Discussion

Summary of Findings

The findings showed that:

- Extended training leads to better results on non-trained tasks;
- The level of difficulty affects motivation and transfer to non-trained tasks, especially verbal WM tasks;
- Training intensity was not essential for the outcome;
- Neither age, gender nor test results before training was essential for the outcome.

Extended Training

In the present study, we evaluated the effect of two factors: extended length of training and lower difficulty of training. On investigating hypothesis 1, results from the extended training were compared to both the training group with shorter training and the control group from the Söderqvist et al. (2012) study. We found that extended training leads to a larger improvement in non-trained tasks.

It was considered prudent to make comparisons of the results from the two studies. They had been conducted with similar procedures by the same staff. We used many of the same cognitive tests. The groups were relatively similar regarding gender, age, and cognitive abilities before training. The only apparent difference was found on Block Design. The T1 results of the short training group showed a trend of significantly better results than the long training group. However, when the long training group was compared to the Söderqvist control group, the T1 Block Design difference was not so apparent. As we found an even more promising transfer effect comparing the long training to the Söderqvist control than comparing the long training to the short training, it seems like the T1 difference on Block Design was not of major importance.

On average, our group also had a somewhat longer training period than the Söderqvist control group. Therefore, it can be argued that other kinds of learning or maturation in this extra time can positively affect the differences between T1 and T2 for our group. However, in the 14 months from the start of training to the post-tests 1 year after the completion of training, the Söderqvist control group improved the results with an average of only 0.47 points on Block Design and 1.26 points on Odd-One-Out Memory. This comparison suggests that maturation and other learning during the extra weeks of training for our group had not been of major importance for the results.

The 4-year-olds without special needs at the Bergman-Nutley et al. (2011) study gained significant transfer effects on both WM tests [Grid Task (Bergman-Nutley et al. (2010) and Odd-One-Out Memory] and on a NVR test [Leiter (Roid and Miller, 1997)]. As the participants in the current study also gained significant transfer on a WM test (Odd-One-Out Memory) and a NVR

TABLE 4 | Correlation between training failure (number and percentage of errors) and the differences of the T1 and T2 test results (Pearson's *r*).

Difference pre- and post-test		Working memory tasks		Non-verbal reasoning tasks	
		No. of errors	Percent errors	No. of errors	Percent errors
Word Span Total	Pearson Correlation	−0.577**	−0.617**	−0.420	−0.396
	Sig. (two-tailed)	0.006	0.003	0.058	0.076
	No.	21	21	21	21
Comprehension of Instructions	Pearson Correlation	−0.406	−0.312	−0.379	−0.302
	Sig. (two-tailed)	0.068	0.169	0.091	0.184
	No.	21	21	21	21

**$p < 0.01$.

test (Block Design), it seems like children with ID can benefit from utilizing this particular training program in somewhat the same way as children on the same level of cognitive development without special needs.

We therefore find it appropriate to imply that our results suggest that extended training is beneficial to children with ID according to our first hypothesis. This assumption is supported by the fact that developmental delay is one of the main diagnostic criteria for ID, indicating a slow acquisition of new skills and a need for more repetitive trials for children with ID.

What can be considered as an optimal training length? There was also some variation as to the number of training sessions for each participant. However, those who trained in all 50 sessions did not seem to get more benefits of training and transfer than those who trained under 40 sessions. The comparisons of our results and the results from the Söderqvist groups show that the transfer effects increased by extending the number of training sessions beyond 25. Therefore, it seems that 40 training sessions would be sufficient for most of the participants. Our experience suggests that this amount of training makes it easier for the schools to fit the training into their regular program.

But children with ID constitute a heterogeneous group with obvious diversity in the patterns of cognitive functions. The differences in the relative strength and weakness of the verbal and visual skills seem to be apparent (Fletcher et al., 2004; Nuovo and Buono, 2009). Children with ID and Down syndrome generally show better skills on visual than verbal memory tasks (Van der Molen et al., 2009). This relative visual strength may explain why children with Down syndrome seem to benefit from training 25 sessions with the same WM training program from Cogmed, which was utilized in the present study (Bennett et al., 2013).

There seems to be some individual differences in cognitive profiles that need to be further investigated in order to find the best program facilitation for an optimal training efficiency.

Levels of Difficulty

The significant transfer differences between short and long training are found on tests assessing the domains of near transfer, namely Odd-One-Out Memory on visual WM and Block Design on NVR. This is in accordance with the scientific literature that reports difficulties in transfer of skills as being one of the main characteristics of persons with ID (Beirne-Smith et al., 2006). On this basis, transfer difficulties could be considered to cause poorer transfer to distant domains with less similar elements. However, if this was the main reason, we would expect to find the same pattern in both long training subgroups. The relatively poor results on far transfer domains, like Word Span and Comprehension of Instructions on verbal WM, were found only in subgroup 1. Subgroup 2 showed a relatively even improvement on all the cognitive tests.

On the other hand, we found more promising evidence concerning the rates of failure. Subgroup 2 had a considerably lower level of difficulty than subgroup 1 (and thereby a lower percentage of incorrect responses) and better transfer to untrained tasks, indicating benefits of a lower level of difficulty. It had been considered prudent to compare the results of the two subgroups as there were no significant differences on age, training length and T1 results. There was an apparent difference on distribution of gender, but comparing the transfer effects of male and female participants showed no significant differences. There was also an apparent negative correlation between the amount of incorrect responses and the outcome results on Word Span and Comprehension of Instructions.

These results indicate support for our second hypothesis. It might be reasonable to assume that there is a connection between low motivation and/or possibly anxiety for some of the participants in our group, and the lack of improvements on the verbal WM functions. Research on WM training and motivation (Bengtsson et al., 2009; Jaeggi et al., 2014) and on WM and anxiety (Shackman et al., 2006; Visu-Petra et al., 2011; Vytal et al., 2013) can be considered to support such an assumption.

It seems like the adaptation of levels of difficulty for subgroup 1 resulted in too many incorrect responses, especially on the WM tasks. Subgroup 2, which showed the overall best transfer effects, had slightly below 40% incorrect responses on both WM and NVR training. In the first six training sessions, the error was 30.1%, and on training session 32–37 it was 40.76%. This may give an indication of an appropriate proportion of success and failure to keep motivation sufficiently high.

Training Intensity

There was a considerable variation in the timespan from the start to the end of training and, thereby, the training intensity for our group. However, as the computations of correlation between training length and transfer effect to the cognitive tests did not show any significant values, it may be assumed that variations in training intensity did not make a great difference. This was surprising as high training intensity is recommended by the developer of the WM program (Ralph, 2014).

Individual Training Benefits

There was no apparent pattern on the correlations between the T1 results and the transfer effects to non-trained tasks, indicating that even the participants with the lowest test scores could benefit from the training. On a preliminary basis it therefore may be considered favorable for children with ID and a cognitive developmental level approximately corresponding to an average child of 4–6 years, to perform this kind of training.

Strengths and Limitations

Our study did not follow the ideal approach: a randomized, blinded, controlled study design, using an active control group (Klingberg, 2010). It was apparent for both the assessors, the teachers and the children that all the participants belonged to the test group, which made blinding and randomization impossible. Our results were compared to the Söderqvist control group which fulfilled the requirements of an active control group, but the accuracy of comparisons between groups from two different studies can obviously be questioned. Therefore, our results have to be considered as preliminary estimates.

The adjustments of the procedures for the cognitive testings could not be utilized for diagnostic purposes, but in this way it was possible to undertake the demanding cognitive testing of the children and thereby get credible and valid data for our project. The same procedure was also used in the Söderqvist et al. (2012) study, which made it possible to compare the results of the two projects.

The limited resources at the schools made it difficult to recruit participants. It also resulted in fewer training sessions and longer training periods than was initially planned. But these variations made it possible to do analyses of the impact of training length and intensity, which would not have been possible if the original plan had been followed.

In spite of these limitations, we consider our preliminary findings to be of importance. In a way that is different from preceding studies, we have pointed at some variables that possibly can affect the training outcome. Children with ID have strong needs for special facilitation of any educational process (Beirne-Smith et al., 2006). Therefore, it is of great importance to investigate which adaptations of cognitive training are necessary. The purpose of this study has been to focus directly on this matter.

Ethics

The training occupies valuable time, which could have been applied for teaching other important subjects. This can only be justified if there is a compelling probability that the training has a positive effect on daily life and academic skills of the participants. At the moment, there is still a lack of evidence on long term and far transfer effects. The parents/caregivers were informed beforehand that there was uncertainty as to the effect of the training. Their motivation to consent for participation seemed to be a mixture of a hope that their children would benefit from the training and an idealistic desire to contribute to the development of new knowledge on the education of children with ID.

The majority of the teachers gave positive feedback on the program except that the tasks became too difficult for subgroup 1. The training was canceled for only one of the participants due to lack of motivation. During the testing after training, most of the children reported that even if the training sometimes had been boring, it was mainly challenging, thrilling, and enjoyable. It therefore may seem like this form of training is feasible for children with ID provided that the basic requirement of an appropriate adaptation of the degree of difficulty is taken into account. So, on a short perspective, the training seems to have been a positive experience for most of the participants. Further research is needed to answer the question of whether this kind of training should be prioritized because of the transfer effects to important functional skills.

Conclusion

Even if there are many limitations connected to this study, the preliminary estimates show a clear tendency of better transfer results compared to the Söderqvist study, supporting our two hypotheses.

Our hope is that the results in the present study can contribute to the development of a more precise understanding of how cognitive functions can be trained to higher levels for children with ID. The results suggests that children with ID might benefit from adapted computerized training on WM and NVR in the same way as children without disabilities, provided that the training is extended and has less demanding tasks.

There are still many questions waiting for answers; therefore, there is an urgent need for more research. There is an open question of whether our results are specific only for this program. For the program that was utilized in this study, our project may be considered a pilot project, waiting for a blinded and randomized study with a higher number of participants focusing on the impact of adapting the amount of training and the level of difficulty. Furthermore there is a need for more evidence-based knowledge on long-term and far transfer effects, such as academic and everyday skills.

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Improving spatial-simultaneous working memory in Down syndrome: effect of a training program led by parents instead of an expert

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Recent studies have suggested that the visuospatial component of working memory (WM) is selectively impaired in individuals with Down syndrome (DS), the deficit relating specifically to the spatial-simultaneous component, which is involved when stimuli are presented simultaneously. The present study aimed to analyze the effects of a computer-based program for training the spatial-simultaneous component of WM in terms of: specific effects (on spatial-simultaneous WM tasks); near and far transfer effects (on spatial-sequential and visuospatial abilities, and everyday memory tasks); and maintenance effects (1 month after the training). A comparison was drawn between the results obtained when the training was led by parents at home as opposed to an expert in psychology. Thirty-nine children and adolescents with DS were allocated to one of two groups: the training was administered by an expert in one, and by appropriately instructed parents in the other. The training was administered individually twice a week for a month, in eight sessions lasting approximately 30 min each. Our participants' performance improved after the training, and these results were maintained a month later in both groups. Overall, our findings suggest that spatial-simultaneous WM performance can be improved, obtaining specific and transfer gains; above all, it seems that, with adequate support, parents could effectively administer a WM training to their child.

Keywords: Down syndrome, visuospatial working memory, computer-based training, intellectual disability, memory improvement

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Introduction

Down syndrome (DS), or trisomy 21, is the most common cause of intellectual disability of genetic origin, affecting about 1 in 700–1000 live births (e.g., McGrowther and Marshall, 1990; Sherman et al., 2007). The vast majority of individuals with DS have some degree of intellectual impairment. Despite a marked variability in terms of the severity of specific impairments (Dykens et al., 2000; Silverman, 2007), individuals with DS essentially have a profile featuring particular strengths and weaknesses. Their cognitive functioning is characterized by speech and language impairments (Chapman and Hesketh, 2000), and they often have more difficulty with expressive language than with language comprehension. Their non-verbal skills are usually less severely impaired, although recent studies have shown a variable picture that depends on which aspect of visuospatial cognition is considered (Yang et al., 2014). Several researchers have focused on working memory (WM) because of its crucial role in many everyday situations, such as learning, orientation, reasoning, and comprehension (Baddeley, 1986).

On the basis of Baddeley and Hitch's (1974) and Baddeley's (1986) multicomponent model, WM can be seen as a system comprising several different components. The central executive is seen as an attention-controlling system responsible for managing resources and monitoring information processing. Two slave systems are responsible for the storage of information, i.e., the phonological loop and the visuospatial sketchpad. The former is for temporarily storing and rehearsing speech-based verbal information, while the latter is for storing visuospatial information for brief periods of time.

Some researchers have analyzed WM functioning in DS, reporting impairments in executive processing (e.g., Lanfranchi et al., 2010) and the verbal component (e.g., Hulme and Mackenzie, 1992; Jarrold and Baddeley, 1997; Kittler et al., 2004), while findings on visuospatial WM are inconsistent. In fact, previous studies found participants with DS less impaired in visuospatial than in verbal WM, but more recent results suggest that individuals with DS may have difficulties in the visuospatial domain too (see Yang et al., 2014, for a review), depending on which specific aspect of this ability is considered. For instance, Lanfranchi et al. (2009) found that participants with DS performed worse than controls (children matched for mental age) in spatial-simultaneous WM tasks, but not in spatial-sequential ones. This finding can be explained in the light of the hypothesis advanced by Pazzaglia and Cornoldi (1999; see also Cornoldi and Vecchi, 2003; Mammarella et al., 2008) that sees the visuospatial sketchpad divided into three components: a visual component, involved in the recall of an object's features; a spatial-sequential component, implicated in memory for sequentially presented information; and a spatial-simultaneous component, responsible for recalling configurations that describe simultaneously presented spatial locations.

Using this distinction, Lanfranchi et al. (2009) observed a specific deficit in DS individuals' spatial-simultaneous WM, irrespective of the level of control required (see Cornoldi and Vecchi, 2003[1]). This result was supported by later research conducted to explore impairments in spatial-simultaneous WM more closely. Carretti and Lanfranchi (2010) found, for example, that when children with DS aged from 5 to 12 years performed spatial-simultaneous WM tasks, they did not take advantage of structured materials (in which the positions to remember formed a pattern) as effectively as a control group with typically developing (TD) children matched for mental age. To see if the DS individuals had a general problem with using structured material to memorize information, or if this problem related specifically to spatial-simultaneous WM tasks, Carretti et al. (2013) subsequently compared the advantage associated with the use of structured material in both spatial-simultaneous and spatial-sequential tasks in individuals with DS matched for mental age with TD children. Their results showed a marked difference between the two groups in the former but not in the latter tasks, confirming specific impairments in spatial-simultaneous WM in DS.

In the light of the above-mentioned findings on the particular weakness in spatial-simultaneous WM identified in individuals with DS, the aim of the present study was to investigate the feasibility of improving visuospatial WM in children and adolescents with DS. Previous studies investigating the efficacy of WM training programs in individuals with DS focused on the verbal component of WM. For example, some authors found improvements in auditory and/or visual span measures after using rehearsal training (e.g., Broadley and MacDonald, 1993; Comblain, 1994; Laws et al., 1996; Conners et al., 2001, 2008). These improvements were often limited to the skills directly treated, however. As for visuospatial WM, Bennett et al. (2013) assessed the effectiveness of a computer-based training program in reducing the memory difficulties of children with DS aged between 7 and 12 years. After approximately 3 months of training with the preschool version of the Cogmed Working Memory Training (which includes different visuospatial memory training tasks), the authors found improvements in both trained and untrained short-term visuospatial memory tasks, with no transfer to short-term verbal memory or WM skills.

In the present study, the feasibility of enhancing spatial-simultaneous WM in individuals with DS was tested using a training administered either by an expert in psychology or by parents at home. Earlier research had already demonstrated the efficacy of the training program adopted in terms of its specific effects on spatial-simultaneous WM, transfer effects on spatial-sequential WM, and maintenance effects after 1 month (Lanfranchi et al., 2014). In the present work, we focus on the person conducting the training activities because one of the problems of training administered by an expert concerns the burden on the families having to bring their child to a specialized center. With a view to the training's applicability, it therefore seemed worthwhile to see whether giving parents guidance on how to train specific aspects of cognition (such as WM) could produce similar results to those achievable by an expert.

The training activities were conducted using a computer, partly for its motivational value, and also because previous studies had shown that it can be used effectively with DS children (e.g., Ortega-Tudela and Gómez-Ariza, 2006; Bennett et al., 2013). The final version of the training (based on Mammarella et al., 2010) consisted of activities in which memory load and attentional control were manipulated. The activities were structured to suit the cognitive profile of DS. For instance, the training involved: little verbal information and only very simple verbal instructions because DS is known to be associated with impaired verbal abilities (e.g., Rondal, 1996); practical activities because of their difficulties with abstract reasoning (e.g., Rowe et al., 2006); or simple images because they have trouble with perceptual analysis (e.g., Bellugi et al., 2000), and may have visual impairments (e.g., Dykens et al., 2000).

[1]The Cornoldi and Vecchi (2003) model is based on the hypothesis that both verbal and visuospatial WM tasks can be described on two continuous dimensions: a horizontal continuum that refers to the type of stimulus (verbal, visual, spatial-simultaneous, and spatial-sequential); and a vertical continuum referring to the level of control, some (active) tasks requiring a higher level of WM control than others (passive tasks).

The present study therefore investigated whether WM training completed under the supervision of a parent could have positive effects. Conners et al. (2008) found that rehearsal training administered at home by parents was effective in improving memory span in children with DS. Although parent-implemented intervention may entail intervening variables, we agree with Conners et al. (2008) that training provided by parents can have a greater ecological validity and, if successful, improvements could be maintained by means of regular maintenance exercises.

Materials and Methods

Participants

Thirty-nine children and adolescents with DS (16 males and 23 females) took part in the study. Their mean chronological age was 12 years and 5 months (SD: 3 years; range: 7 years and 8 months to 19 years and 1 month). Participants were recruited from several regions in Italy through associations of parents who have children with DS, schools, pediatricians, or rehabilitation centers for people with intellectual disabilities. All participants were enrolled in mainstream school with the support of an assistant teacher. Selection criteria were: age; no severe behavioral problems; a minimum of expressive vocabulary; and the skills needed to complete the baseline assessment.

Parents' informed written consent was obtained for all children and adolescents participating in the study.

Participants were allocated to one of two conditions: in one (Group 1 – Expert) the training was administered by an expert in psychology; in the other (Group 2 – Parent), parents were given instruction on how to administer the training at home, and they were supervised when they did so. The training activities were the same for the two groups, which were matched on a measure of non-verbal ability – Raven's Colored Progressive Matrices (CPM; Raven et al., 1998), and on a measure of verbal ability – the Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn and Dunn, 1997). As shown in **Table 1**, non-verbal abilities are greater than verbal ones in both groups, as typically seen in individuals with DS.

Materials

To obtain measures of specific, near and far transfer, and maintenance effects, the following tasks were administered to participants at pre-test, post-test and follow-up (after 1 month).

Specific Effects: Spatial-Simultaneous Working Memory Tasks (Lanfranchi et al., 2004)

Each child was administered two simultaneous WM tasks, one passive and the other active.

Passive spatial-simultaneous task

Participants were shown for 8 s a 2 × 2, 3 × 3, or 4 × 4 square matrix where two or three squares were colored green. Immediately after the matrix was removed, they were asked to recall the positions of the green squares by pointing to the same positions on a blank matrix. This task had four levels of difficulty depending on the number of squares to be remembered (two or three) and the size of the matrix, 2 × 2 on the first level (with two green squares), 3 × 3 on the second and third (with two and three green squares, respectively), and 4 × 4 on the fourth (with two green squares). Two trials were run for each level of difficulty. A score of 1 was given for every pattern of positions recalled correctly. The final score was the sum of the scores obtained (minimum score = 0; maximum score = 8).

Active spatial-simultaneous task

Participants were shown for 8 s a 2 × 2, 3 × 3, or 4 × 4 matrix containing two or three red squares, and some boards also contained a blue square. Participants were then asked to remember the positions of the red squares, pointing to their locations on a blank matrix. They also had to tap on the table when a matrix containing a blue square was presented. The task had four levels of complexity, depending on the number of red squares to be remembered (two or three) and the size of the matrix: 2 × 2 on the first level (with two red squares), 3 × 3 on the second and third (with two and three red squares, respectively), and 4 × 4 on the fourth (with three red squares). Two trials were run for each level of difficulty. A score of 1 was given for every trial performed correctly, i.e., when the child remembered the position of the red squares and tapped on the table, where applicable. The final score was the sum of the scores obtained (minimum score = 0; maximum score = 8).

All the tasks were administered with a self-terminating procedure, i.e., when the child failed both trials on the same level of difficulty, the task was abandoned to avoid making participants frustrated.

Near Transfer Effects: Passive Spatial-Sequential Task (Lanfranchi et al., 2004)

Participants were asked to recall a path taken by a small frog on a 3 × 3 or 4 × 4 matrix, immediately after they had seen it.

TABLE 1 | Participants' characteristics.

	Group 1		Group 2		*P*	η_p^2
	M	**SD**	***M***	**SD**		
Chronological age	146.20	36.11	151.05	37.64	0.68	0.005
Colored Progressive Matrices (CPM) raw score	16.35	4.78	16.42	3.92	0.96	0.000
CPM mental age	79.05	14.35	79.26	11.76	0.96	0.000
Peabody Picture Vocabulary Test-Revised (PPVT-R) raw score	65.80	18.36	65.37	21.09	0.95	0.000
PPVT-R mental age	69.50	18.16	69.89	23.16	0.95	0.000

This task was presented with four levels of difficulty, depending on the number of steps along the frog's path and the size of the matrix (3 × 3 for the first level with two steps, and 4 × 4 for the second, third, and fourth levels, with two, three, and four steps, respectively). The frog's steps were presented at approximately 2-s intervals. Two trials were run for each level of difficulty. A score of 1 was given for every path recalled correctly. The final score was the sum of the scores for each trial (minimum score = 0; maximum score = 8).

Far Transfer Effects: Visuospatial Abilities (Geometric Puzzles) and Everyday Life (Everyday Memory Questionnaire)

Geometric puzzles (subtest of NEPSY battery; Korkman et al., 2007)

In this task, participants were shown a picture with a large grid containing six shapes, plus two shapes outside the grid. For each trial, the children were asked to match two shapes outside the grid with two shapes inside the grid; and they were allowed 45 s to do so. The task included 12 trials, and for each trial a score of 2 was awarded if the child correctly matched two shapes inside the grid with two outside the grid within 45 s. A score of 1 was given if a child correctly matched only one shape. The minimum score was 0 and the maximum score was 24.

Everyday memory questionnaire (adapted from Cornoldi et al., 2003)

Parents were asked to answer 16 questions about their child's functioning in everyday life (e.g., Can your child remember short songs or rhymes? When he/she looks at a picture, is he/she able to remember the details?). Each item was scored using a four-point Likert-type scale (1: never or almost never, 2: sometimes, 3: often, 4: always or almost always).

Procedure

Before parents began to administer the WM training, they met as a group and individually with a program coordinator who gave them instructions on how to conduct the training program, and explained how they should work with their child. The coordinator of this part of the project demonstrated the procedure and talked with parents about how to use strategies to sustain their children's motivation. Parents were shown videos or PowerPoint presentations to facilitate their understanding, and they were advised to work with their child in a quiet room to minimize distractions. Parents were supervised weekly throughout the study by means of telephone calls to answer any queries about the tasks and monitor the progress of the training program. During these phone calls, the program coordinator gave parents feedback about how the activities had been carried out. If they met with any problems, parents could also contact the coordinator at any time. Finally, to check whether parents had administered the training to their child correctly, after completing the training sessions parents gave the coordinator a file with records of the training activities conducted and any progress their child had made, in terms of the activities completed correctly.

The present study was approved by the Ethical Committee of the School of Psychology at Padova University.

An ABA design was used to judge the efficacy of the training, and a follow-up assessment was performed 1 month after the post-test to identify any maintenance effects. Children in both groups first completed a pre-test assessment, when the tasks were administered over the course of 2 days during the same week. All participants started the training program within one week after the pre-test session. The training lasted 4 weeks, with two sessions a week, each session lasting about 30 min.

All participants attended a post-test session within a week after completing the training and, a month later, a follow-up assessment was conducted to check whether any improvements recorded after completing the training program had been maintained.

Description of the Training Activities

As mentioned earlier, a computer-based training program was preferred because it seems to be effective for individuals with DS (e.g., Ortega-Tudela and Gómez-Ariza, 2006). The starting point was a training program for TD children designed to improve their visuospatial WM (Mammarella et al., 2010). This software considers two aspects of visuospatial WM: the nature of the stimulus (visual, spatial-sequential, and spatial-simultaneous; only spatial-simultaneous tasks were used in the present study); and the level of attentional control, with tasks demanding a low, medium or high level of control. Individuals with DS are weak in spatial-simultaneous WM, so our training focused exclusively on activities engaging this area. Moreover the activities were selected and adapted to the DS cognitive profile.

In particular, given these individuals' deficit in verbal abilities (e.g., Rondal, 1996), the tasks contained little verbal information and we used very simple verbal instructions (and parents administering the training were advised to do likewise). We also used simple, concrete tasks because of DS individuals' deficit in abstract reasoning (e.g., Rowe et al., 2006), and performing complex activities (e.g., Lanfranchi et al., 2010).

The training sessions focused alternatively on immediate attention and memory (recognition tasks), recollection (passive tasks), and active memory (active tasks that involve maintaining and processing information). In the immediate attention and memory sessions, the tasks mainly involved recognizing target stimuli; in the recollection sessions, the tasks were more complex than in the recognition tasks, and involved retrieving previously presented locations from memory; in the active memory sessions, participants were asked not only to analyze the spatial-simultaneous target stimuli, but also to maintain and process spatial-simultaneous information.

In all, there were 16 different activities. Each training session lasted approximately 30 min, and was administered twice a week. The activities proposed during the training sessions were identical for each participant in both groups.

Results

A preliminary analysis – one-way ANOVA – revealed no significant differences between the two groups at the pre-test session for any of the measures considered (all $p > 0.05$). **Table 2** shows descriptive statistics for the measures administered.

A 3 × 2 repeated measures ANOVA, with Session (pre-test, post-test, and follow-up) as within-group factors and Group (expert- and parent-delivered training) as the between-group variables, was run on the raw scores obtained on each measure to identify specific (on spatial-simultaneous WM), near (on spatial-sequential WM) and far (on visuospatial abilities and everyday memory) transfer, and maintenance effects[2]. Interactions were analyzed using *post hoc* analyses, applying Bonferroni's adjustment for multiple comparisons. The α-value was set at 0.05 for all statistical tests and at 0.004[3] for interactions.

Specific Effects. Spatial-Simultaneous Working Memory Tasks

Passive Spatial-Simultaneous Working Memory Task

The main effect of Session was significant ($F_{2,74} = 57.74$, $p < 0.001$, $\eta_p^2 = 0.609$), while the main effect of Group was not ($F_{1,37} = 0.12$, $p = 0.73$). Participants' performance improved from the pre-test to the post-test and follow-up sessions (*MDiff.* = –1.67, $p < 0.001$; *MDiff.* = –2.11, $p < 0.001$, respectively), while the latter two did not differ.

The Session × Group interaction was also significant ($F_{2,74} = 9.62$, $p < 0.001$, $\eta_p^2 = 0.206$). Subsequent *post hoc* comparisons showed that participants in the "Expert" group performed significantly better in the post-test and follow-up sessions than in the pre-test session (*MDiff.* = –2.55, $p < 0.001$; *MDiff.* = –2.75, $p < 0.001$, respectively), with no significant differences between post-test and follow-up, indicating a maintenance effect. The "Parent" group showed significant improvements only from pre-test to follow-up (*MDiff.* = –1.47, $p < 0.001$). The two groups' performance did not differ at pre-test, post-test, or follow-up.

Active Spatial-Simultaneous Working Memory Task

The main effect of Session was significant ($F_{2,74} = 61.16$, $p < 0.001$, $\eta_p^2 = 0.623$). Generally speaking, participants' performance improved from the pre-test to the post-test and follow-up sessions (*MDiff.* = −1.83, $p < 0.001$; *MDiff.* = −2.49, $p < 0.001$), but did not improve significantly from the post-test to the follow-up session. Neither the effect of Group ($F_{1,37} = 0.28$, $p = 0.867$, $\eta_p^2 = 0.001$) nor the Session × Group interaction ($F_{2,74} = 2.89$, $p = 0.062$, $\eta_p^2 = 0.073$) were significant.

Near Transfer Effect

Passive Spatial-Sequential Working Memory Task

The main effect of Session was significant ($F_{2,74} = 14.35$, $p < 0.001$, $\eta_p^2 = 0.279$). Participants' performance generally improved from pre-test to post-test, and from pre-test to follow-up (*MDiff.* = −0.69, $p = 0.002$; *MDiff.* = −0.89, $p < 0.001$; respectively), with no significant differences between post-test and follow-up. The effect of Group was not significant ($F_{1,37} = 1.44$, $p = 0.237$, $\eta_p^2 = 0.038$), nor was the Session × Group interaction ($F_{2,74} = 0.44$, $p = 0.644$, $\eta_p^2 = 0.012$).

Far Transfer Effect

Visuospatial Abilities (Geometric Puzzles)

The main effect of Session was significant ($F_{2,74} = 51.23$, $p < 0.001$, $\eta_p^2 = 0.581$). Participants' performance improved from the pre-test to the post-test and follow-up sessions (*MDiff.* = −2.57, $p < 0.001$; *MDiff.* = −2.94, $p < 0.001$; respectively), which did not differ. The effect of Group ($F_{1,37} = 0.22$, $p = 0.641$, $\eta_p^2 = 0.006$) and the Session × Group interaction ($F_{2,74} = 2.59$, $p = 0.082$, $\eta_p^2 = 0.065$) were not significant.

Everyday Memory Questionnaire

The main effect of Session was significant ($F_{2,74} = 4.70$, $p = 0.012$, $\eta_p^2 = 0.113$). No main effects of Group emerged ($F_{1,37} = 2.88$, $p = 0.098$, $\eta_p^2 = 0.072$). Participants' performance generally improved from pre-test to follow-up (*MDiff.* = −1.71, $p = 0.004$), with no significant differences between the pre-test and the post-test sessions, or between the post-test and

[2] All the analyses were also run with chronological age as a covariate, and the results remained substantially the same

[3] For the interactions, the alpha value for *post hoc* comparisons was set at 0.004 because 12 comparisons were conducted (0.05/12 = 0.004).

TABLE 2 | Outcome measures at pre-test, post-test, and follow-up for both groups.

	Group	Pre-test		Post-test		Follow-up	
		M	SD	*M*	SD	*M*	SD
Passive spatial-simultaneous working memory (WM) task	Expert	3.10	1.71	5.65	2.08	5.85	1.95
	Parent	3.89	2.33	4.68	2.29	5.37	2.11
Active spatial-simultaneous WM task	Expert	2.40	2.11	4.70	2.00	4.85	1.69
	Parent	2.79	2.32	4.16	2.41	5.32	2.06
Passive spatial-sequential task	Expert	5.55	1.93	6.40	1.43	6.50	1.57
	Parent	5.11	1.76	5.63	1.61	5.95	1.58
Geometric puzzle	Expert	14.25	5.87	16.65	5.17	16.50	5.18
	Parent	13.00	3.59	15.74	3.56	16.63	3.76
Everyday memory questionnaire	Expert	47.90	6.03	50.25	6.33	50.95	5.71
	Parent	46.84	5.69	45.79	6.31	47.21	6.09

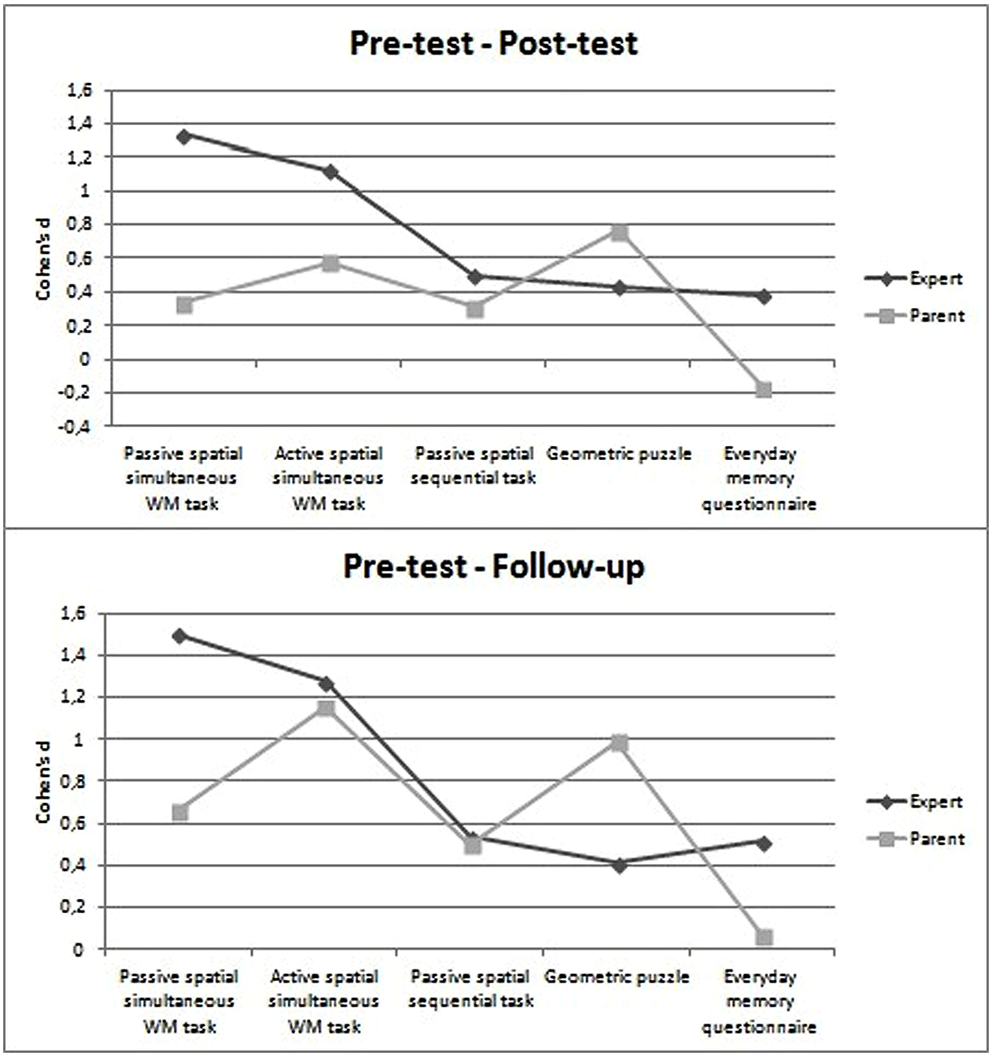

FIGURE 1 | Comparison between pre-test and post-test sessions (Upper), and between pre-test and follow-up sessions (Lower) by group, using Cohen's *d*.

follow-up. The Session × Group interaction was significant, however ($F_{2,74} = 5.07$, $p = 0.009$, $\eta_p^2 = 0.121$). Subsequent *post hoc* comparisons showed that the participants in the "Expert" group performed significantly better at the follow-up session than at the pre-test session (*MDiff.* $= -3.05$, $p < 0.001$), but there were no significant differences between the pre-test and post-test sessions ($p = 0.022$), or between the post-test and follow-up sessions ($p = 1.00$). The participants in the "Parent" group showed no significant improvement, neither from pre-test to post-test, nor from pre-test to follow-up.

Cohen's (1988) *d*-values were calculated to analyze the effect size of improvements from the pre-test to the post-test and follow-up sessions within each group. **Figure 1** shows the *d*-values obtained for the specific and transfer effects.

In the comparison between pre- and post-test results in the Expert group, the effect sizes were large for the passive and active spatial-simultaneous WM tasks, while they were medium for the passive spatial-sequential task, and small for the geometric puzzles and everyday memory questionnaire. In the comparison between pre-test and follow-up, the same pattern of effect sizes was apparent, with the exception of the everyday memory questionnaire for which a medium effect size was found.

In the Parent group the comparison between pre- and post-test sessions yielded medium effect sizes for the tasks testing visuospatial abilities (geometric puzzles), and active spatial-simultaneous WM, while small effect sizes emerged for the passive spatial-simultaneous and spatial-sequential WM tasks. In the comparison between pre-test and follow-up sessions, large effect sizes were found for the active spatial-simultaneous WM tasks and geometric puzzles, and medium effect sizes for the passive spatial-simultaneous and spatial-sequential WM tasks.

Discussion

The main goal of the present study was to analyze the feasibility of improving spatial-simultaneous WM in individuals with DS by means of a computer-based training administered by parents at home. As mentioned previously, we had already tested the efficacy of the training program adopted in a previous study (Lanfranchi et al., 2014). Here, specific effects on spatial-simultaneous tasks, near transfer effects on spatial-sequential tasks, and far transfer effects on visuospatial abilities and everyday life were tested immediately after completing the training and again at a follow-up session a month later.

Judging from our results, the performance of both groups (i.e., individuals with DS trained by an expert psychologist or by their parents) improved after the training in both spatial-simultaneous WM tasks. In both cases their improvement was greater than the one seen in a passive control group in a previous preliminary study on the efficacy of our training program (Cohen's *d* was 0.16 for the passive spatial-simultaneous task, and −0.05 for the active spatial-simultaneous task; Lanfranchi et al., 2014). The time it took for the improvement to become apparent differed between the two groups, however.

Our most important finding lies in that parents were able to administer the training to their children, who benefited from the intervention: participants in the "Parent" group showed significant improvements in performing the passive spatial-simultaneous task. This was only true, however, for the comparison between the pre-test and the follow-up, whereas no improvement emerged immediately after completing the training. In contrast, participants in the "Expert" group performed better already at the post-test stage, and maintained this gain a month later. In other words, participants in the "Parent" group seemed to improve more gradually. The benefits of the training, in terms of specific effects, only became evident with time. The different rate of improvement in the two groups might mean that the expert was more effective in promoting changes in performance; parents would probably need more time to become familiar with the training activities. The improvement in the "Parent group" that emerged at the follow-up session might be related to changes in the way parents interacted with their children, producing "pervasive" effects on their performance that became apparent at the follow-up assessment. In other words, parents may have helped their children learn to pay more attention to details, or to use more appropriate strategies – even outside the context of the training activities.

In contrast, no differences emerged between the two groups in the active spatial-simultaneous task: both groups performed better at post-test then at pre-test, and their improvement was maintained a month after completing the training.

In addition to the specific effects, the training also induced near and far transfer effects in both groups. Concerning the near transfer effects, there was some improvement in a WM component that was not treated specifically, i.e., spatial-sequential WM. Participants performed better at the post-test than at the pre-test session and this improvement was also maintained a month later. Similar findings emerged for the geometric puzzles task. Here again, the two groups improved from the pre-test to the post-test session, and maintained their better performance after 1 month. Taken together, these results confirm that the type of training considered here could be administered by parents just as effectively as by an expert.

On the whole, the specific and transfer effects identified here can be explained in terms of strategy acquisition: during the training activities, participants were stimulated to adopt appropriate strategies to solve the tasks, and to generalize them to other tasks.

Concerning the everyday memory questionnaire, our findings differed between the two groups: the "Expert" group improved from the pre-test to the follow-up, indicating that parents' opinions of their children's everyday functioning became more positive after the training. In the "Parent" group, on the other hand, participants' scores in the questionnaire showed no significant differences between the three sessions; they dropped slightly from pre-test to post-test, then returned to the same level as at the pre-test in the follow-up session. A possible explanation for these results lies in that, having received specific instruction, the parents concerned were more aware of their child's abilities and difficulties, and were consequently more severe in the opinions they expressed. In other words, the lower scores would indicate not a worse everyday functioning of the participants, but a change in their parents' awareness of their memory ability.

In general, our study demonstrated the feasibility of improving WM performance in children and adolescents with DS, even with a relatively short training program and when the training is administered by parents. The effects of the training were not limited to the specific area of WM treated, but were also generalized to other skills, as demonstrated by near and far transfer effects. To our knowledge, this is one of the few studies to have attempted an analysis on the effect of visuospatial WM training in DS. In a recent study, for instance, Bennett et al. (2013) tested the efficacy of a computer-based training (that involved different visuospatial memory tasks) in reducing memory difficulties in children with DS. They reported improvements in both trained and untrained short-term visuospatial memory tasks and, in some children, also in tasks measuring executive functions, as indicated by parents' responses to the BRIEF-P (Gioia et al., 2003). In contrast, they reported finding no transfer effects on verbal short-term memory and verbal WM skills. The findings obtained by Bennett et al. (2013) and our own results reported here support the feasibility of computer-based training programs enhancing visuospatial WM in individuals with DS, and also obtaining transfer effects.

In our opinion, the results of the present study are important for several reasons. For a start, having demonstrated the effectiveness of this training even when it is administered by parents show that it could be used more frequently and/or periodically in order to maintain the effects of the training. The other point of interest concerns the confirmation of its efficacy in everyday life functioning (such as learning activities, reasoning, orientation, etc.), the training program could prove useful in clinical and rehabilitation settings.

Beyond the results obtained here, it could be interesting in future studies to analyze the nature of the effects, and particularly of the transfer effects, more systematically. For example, it would be important to examine the effects on verbal WM or other domains of cognitive functioning, especially those related to everyday life. Further research could shed more light on this issue, which is a source of debate in the literature (e.g., Melby-Lervag and Hulme, 2013).

Conclusion

In line with the results reported by Conners et al. (2008), who found that training led by parents could produce positive effects on memory performance, our findings suggest that – with adequate support and instruction – parents of individuals with DS can administer their offspring effective WM training programs. In our research, we identified the same specific improvements in spatial-simultaneous WM, and the same transfer and maintenance effects, as when the training activities were administered by an expert psychologist.

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Improving working memory abilities in individuals with Down syndrome: a treatment case study

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Working memory (WM) skills of individuals with Down's syndrome (DS) tend to be very poor compared to typically developing children of similar mental age. In particular, research has found that in individuals with DS visuo-spatial WM is better preserved than verbal WM. This study investigated whether it is possible to train short-term memory (STM) and WM abilities in individuals with DS. The cases of two teenage children are reported: EH, 17 years and 3 months, and AS, 15 years and 11 months. A school-based treatment targeting visuo-spatial WM was given to EH and AS for six weeks. Both prior to and after the treatment, they completed a set of assessments to measure WM abilities and their performance was compared with younger typically developing non-verbal mental age controls. The results showed that the trained participants improved their performance in some of the trained and non-trained WM tasks proposed, especially with regard to the tasks assessing visuo-spatial WM abilities. These findings are discussed on the basis of their theoretical, educational, and clinical implications.

Keywords: working memory, short term memory, Down syndrome, training, cognitive intervention

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Introduction

Down syndrome (DS) is a pervasive developmental disorder caused by abnormalities of chromosome 21. It is one of the most common causes of intellectual disability (ID), affecting about 1 in 700/1000 live births (Steele, 1996; Sherman et al., 2007; Parker et al., 2010). IQ generally ranges between 25 and 70 and the cognitive development of individuals with DS is characterized by significant delays and difficulties in working memory (WM) and short-term memory (STM) abilities. WM plays a key role in everyday life (e.g., reading, writing, arithmetic, learning, language-processing, orientation, and imagination) for typically developing (TD) children as much as for individuals with cognitive disabilities. Given this link between WM performance and classroom and daily life functioning, it is of substantial interest to investigate the effectiveness of interventions designed to reduce WM and STM difficulties in order to provide effective evidence-based training programs for young people with DS. Indeed, the enhancement of memory skills would be expected to promote skill development (e.g., Gathercole and Alloway, 2006) and independence of individuals with DS, minimizing the impact of the WM deficit on their lives.

DS and WM Abilities

Working memory has been defined as a mental system that temporarily stores information while allowing that information to processed or manipulated (e.g., Baddeley, 1986). There are many different models of the structure of WM, but the investigation of WM abilities in DS has been largely conducted within the framework of the multi-component model of WM initially proposed by Baddeley and Hitch (1974; see also Baddeley, 1986, 2000). This model is composed of three main components. Two of these are the phonological loop and visual-spatial sketchpad, which are modality-specific systems dedicated to the passive storage of verbal and visuo-spatial information, respectively. The central executive, which in contrast is domain-general, controls the transfer of information to and from the two slave systems and it has been associated with a broad range of processing functions, such as inhibiting irrelevant information, shifting attention, and updating information. WM is considered an active system, involving both storage and processing, whereas STM involves only storage and no processing, as required in forward span tasks (Cornoldi and Vecchi, 2003; Swanson and Beebe-Frankenberger, 2004).

Working memory in DS has been investigated using a range of experimental approaches, providing substantial evidence of a dissociation between verbal and visuo-spatial abilities (Jarrold and Baddeley, 1997; Laws, 2002; Brock and Jarrold, 2005). Compared with children with ID or younger TD children matched for mental age, it has been found that there is a large deficit for those with DS in several verbal STM measures (Kay-Raining Bird and Chapman, 1994; Buckley et al., 1995; Laws, 1998; Jarrold et al., 1999). The current best explanation for the deficit in the phonological loop component of WM in individuals with DS is that they have a problem in storage itself, rather than in the encoding or rehearsal of information (Jarrold et al., 2002; Purser and Jarrold, 2005; Baddeley and Jarrold, 2007) Within Baddeley's (1986) WM framework, DS seems to be associated with a reduction in phonological store capacity (Baddeley and Jarrold, 2007).

On the other hand, the visuo-spatial sketchpad abilities of individuals with DS are found to be in line with what one would expect given individuals' general level of ability (Jarrold and Baddeley, 1997; Baddeley and Jarrold, 2007; Lanfranchi et al., 2012). Compared to TD children of the same mental age, DS children obtain largely equivalent scores (Lanfranchi et al., 2004). However, some studies showed that even if visuo-spatial STM was less impaired in DS than verbal STM, some differences emerged when the visuo-spatial component of WM was broken down into separate spatial and visual components (Ellis et al., 1989; Laws, 2002). Indeed, individuals with DS appear to show an unimpaired spatial memory (e.g., memory of spatial positions), but an impaired visual memory (memory of objects and their visual properties, such as colors, surfaces, etc.). Although visuo-spatial STM abilities seem to be better preserved if compared with phonological STM abilities, it is important to remember that both verbal and visuo-spatial WM skills are usually impaired if compared to chronological age-matched individuals (Kay-Raining Bird and Chapman, 1994).

The studies that examined the central executive component of WM suggested that there is a central executive limitation in DS. Children with DS have difficulties with executive load WM on both verbal and visuo-spatial measures, compared to mental age matched TD children (e.g., Lanfranchi et al., 2004). In particular, the results of a recent study of Lanfranchi et al. (2012) suggest that individuals with DS have a general executive deficit resulting in disproportionate deficits when two tasks are coordinated. These results are consistent with those of previous studies that also demonstrated such executive deficits in individuals with DS (Rowe et al., 2006; Lanfranchi et al., 2010) in addition to general difficulties in performing a variety of dual tasks (Lanfranchi et al., 2004).

WM and Learning

A variety of studies have found that both verbal and visuo-spatial WM are strongly associated with a range of measures of learning (Gathercole and Baddeley, 1993; Jarvis and Gathercole, 2003; Gathercole and Alloway, 2006). Moreover, WM deficits are characteristic of children with learning difficulties both in literacy and in mathematics (Passolunghi and Siegel, 2001; Geary et al., 2004; Pickering, 2006; Schuchardt et al., 2008). Compared to WM abilities, STM skills are much more weakly associated with general academic attainment (Gathercole and Alloway, 2006). However, verbal STM skills are linked to reading progress and an accurate phonological representation within STM is required for new word learning (Service and Kohonen, 1995; Gathercole et al., 1997; Jarrold et al., 2009).

In the field of ID, some studies have suggested that the learning difficulties associated with DS might be underlain by difficulties in WM and STM. DS is characterized by generalized difficulties in performing number and calculation tasks (Marotta et al., 2006). In particular, individuals with DS exhibit several mathematical difficulties compared to TD individuals (Brigstocke et al., 2008). They obtain lower scores in a wide range of tests assessing basic mathematical knowledge, arithmetic abilities, and counting skills (Buckley and Sacks, 1986; Carr, 1988; Porter, 1999). Recently it has been suggested that visual WM memory difficulties in DS could lead to deficits in some early numerical abilities that are thought to be foundational to mathematical learning (Sella et al., 2013).

On the other hand, weak verbal WM and STM abilities make processing verbal information and learning from listening difficult for children with DS. Indeed, the marked phonological STM deficit seems to underlie the characteristic profile of language difficulties seen in individuals with DS (e.g., deficits in phonology, speech intelligibility, language production, syntax, reading; Dodd and Thompson, 2001; Byrne et al., 2002; Lanfranchi et al., 2009).

WM Intervention

The results described above provide evidence that DS is characterized by significant delays and difficulties in WM and STM abilities that are associated with general learning disabilities and language impairment. Therefore, it is clearly of some importance to investigate the effectiveness of interventions designed to reduce the WM and STM difficulties, in order to provide effective evidence-based training programs for children with DS. However, WM has traditionally been considered a genetically fixed cognitive ability (Kremen et al., 2007). Therefore, it was not considered possible to enhance WM skills by acting on an individual's environmental experiences and opportunities. Recently, a growing set of studies with TD children and adults have shown that WM skills can be improved through training demonstrating that considerable cerebral plasticity exists and that WM capacity may potentially be improved (Olesen et al., 2004; Thorell et al., 2009). Some studies have even shown a transfer effect of WM training on school-related skills (Holmes et al., 2009; St Clair-Thompson et al., 2010; Alloway et al., 2013; Passolunghi and Costa, 2014). However, the debate is still open and some authors questioned the effectiveness of WM training, arguing that there is currently too little evidence to conclude that such training generalizes to other cognitive skills (Melby-Lervåg and Hulme, 2013; Redick et al., 2015). Moreover, it has been emphasized that many studies that have examined the effect of WM training have not always applied adequate methodological criteria (e.g., no-contact control groups, single measures of cognitive constructs, inconsistent use of valid WM tasks, subjective measurement of change; Shipstead et al., 2010, 2012).

Given that the WM system is important for language learning, intervention studies designed to target the memory difficulties associated with DS have typically focused on improving verbal STM skills, generally by training children to use rehearsal strategies (Broadley and MacDonald, 1993; Laws et al., 1996). These studies have focused on improving the ability to repeat items in the correct order. Training in an overt cumulative rehearsal strategy has been shown to improve recall in groups with DS: such training involves the rehearsal, spoken aloud, of increasing amounts of information over the course of an STM task (Broadley and MacDonald, 1993; Comblain, 1994; Laws et al., 1996). Some of the studies dealing with rehearsal training used picture supports (children used visual processing to aid their memory span), with mixed findings for auditory span measures but clear improvements for measures of visual span (Broadley and MacDonald, 1993; Laws et al., 1996). A further study (Comblain, 1994) found a clear improvement in auditory memory span, beginning with picture supports, but phasing them out over the course of the task, ending in auditory-only training. Using a somewhat different approach Conners et al. (2008) used purely auditory rehearsal training and the results showed verbal span improvements.

To our knowledge, Bennett et al. (2013) is the only study to have investigated the effects of visuo-spatial training in DS children. This training consisted of seven computerized STM and WM games: four of them involved only the storage of visual information, two of them involved both manipulating and storing visual information, and one incorporated the storage of information in both modalities. Results showed that performance on trained and non-trained visuo-spatial STM tasks was significantly enhanced for children in the intervention group and this improvement was sustained four months later. However, they failed to find any transfer effect of the training either to visuo-spatial WM or verbal STM and WM skills. Despite this lack of transfer, these results suggest that training the visuo-spatial component of WM in a school setting may be possible for children with DS.

The Present Study

The aim of the current study was to evaluate the efficacy of a school-based visuo-spatial WM training on STM and WM skills for two individuals with DS. Previous studies of memory training for individuals with DS have focused on the enhancement of verbal STM abilities by teaching rehearsal strategies, with positive results (Broadley and MacDonald, 1993; Comblain, 1994; Laws et al., 1996). Only one study has used WM training that taps both STM and WM skills (Bennett et al., 2013), in which a positive effect was found of training on visuo-spatial STM abilities (passive recall of information) but not on visuo-spatial WM abilities. However, several studies have demonstrated the effectiveness of WM training in both TD children and children with intellectual disabilities (Thorell et al., 2009; St Clair-Thompson et al., 2010; Van der Molen et al., 2010). Therefore, it was expected that the training, targeting visuo-spatial STM abilities (simple recall of information) and visuo-spatial WM abilities (ability to both simultaneously process and store information) would improve visuo-spatial WM and STM abilities. Moreover, it was expected that our training should improve not only the visuo-spatial component of WM, but also produce a transfer effect on the verbal component of WM. This hypothesis is in line with previous studies dealing with WM training in TD children and individuals with ID (Thorell et al., 2009; Van der Molen et al., 2010).

Materials and Methods

Participants

AS Case Report

AS is a boy with DS aged 15;11 at the time of the investigation. AS was selected from a database of participants, following on-going consent after recruitment for previous research studies by one of the authors (Harry R. M. Purser). After consent was provided by the schools, and prior to testing, parental consent was obtained. AS lives with his parents and attends a special secondary school for children with severe or moderate learning disabilities. AS was not on any medication at the time of the investigation. He received a diagnosis of DS 2 h after birth (confirmed trisomy 21, without mosaicism). He was born by cesarean section and his birth weight was 1.81 kg. AS has salivary gland malfunction and was hospitalized at 3 years old in order to receive surgical operation for the correction of umbilical hernia. Developmentally, sitting was normal at 0;7, though walking was late at 2;5. AS spoke his first words at 0;8 and did not start putting 2–3 words together until around 4–5 years. He received a diagnosis of dyspraxia at 5 years old and currently has some speech problems: he speaks in short, simplified sentences. AS attended a mainstream school from 2;6 to 12;0 when he moved to a school for children with learning disabilities. Before entering primary school, he never received any type of special education service or preschool support. AS was reported to enjoy school. He has problems with writing, but his general academic achievement is in line with what would be expected given his intellectual level. He was reported to be well behaved at school, and to have good relationships with both adults and peers. AS was also reported to enjoy sports, in particular swimming. Additionally, he enjoyed 2 years work experience in a garden center.

Non-verbal Intelligence was assessed at time of testing using Raven's Colored Progressive Matrices (RCPM; Raven et al., 1998). AS's RCPM raw score was 16, and his non-verbal mental age was 7. AS was also assessed on the British Picture Vocabulary Scale III (BPVS; Dunn et al., 2009), a measure of receptive vocabulary. AS BPVS raw score was 96, his vocabulary mental age was 6 years and 5 months.

EH Case Report

EH is a girl with DS aged 17;3 at the time of the investigation. Selection and consent were via the procedures described for AS. EH lives with her parents and attends a special secondary school for children with severe or moderate learning disabilities. EH was not on any medication at the time of the investigation except for hay fever tablets. She received a diagnosis of DS immediately after birth (confirmed trisomy 21, without mosaicism). She was born naturally and birth weight was 2.72 kg.

Developmental milestones were reportedly delayed: she started sitting at 0;10 and walking at 2;5. EH spoke her first words at 0;7 and did not start putting 2–3 words together until she was 3;0. Currently EH was not reported to have any speech problem. EH attended a mainstream school until 11;0 when she moved to a school for children with learning disabilities. Prior to entering primary school she never received any type of special education service or preschool support. She was reported to enjoy school with normal reading, spelling and arithmetic skills. EH was also reported to be well behaved at school, even if sometimes she does not want to do her homework. She gets on well both with both adults and peers. EH was reported to enjoy music and dance.

Non-verbal Intelligence was assessed at time of testing using RCPM (Raven et al., 1998). EH's RCPM raw score was 19, and her non-verbal mental age was 8. EH was also assessed on the BPVS III (Dunn et al., 2009), a measure of receptive vocabulary. AS BPVS raw score was 101, her vocabulary mental age was 7 years.

TD Control Group

The TD group was comprised of children randomly selected on the basis of date of birth from a mainstream primary school. Both school and parental consent were obtained prior to testing. The WM training used in this study targeted visuo-spatial WM, and AS and EH were therefore matched to TD controls on the basis of non-verbal intelligence assessed with the RCPM test. Given that the RCPM test is commonly used to estimate of IQ (Belacchi et al., 2010; Lanfranchi and Carretti, 2012; Kolkman et al., 2013; Xenidou-Dervou et al., 2014), this matching criteria ensured that performance differences prior and after the training were not due to any general intelligence differences. Children with a RCPM score below 15 and greater than 21 were excluded to ensure that AS and EH were compared to children with a comparable non-verbal intelligence. Children with statements of special educational need (as identified by local educational services) were excluded. There were 17 TD children (eight boys and nine girls) in the TD group. The mean age was 6 years, 1 (SD 0 years, 7 months), with a range of 5 years 7 months to 7 years 0 month.

Procedure

Participants were individually tested at school in two sessions separated by approximately 1 week. Testing sessions lasted approximately 30 min. For matching purposes, the participants with DS completed their testing session first. Then, based on the score reached at the RCPM test, the 17 TD children were selected and they completed their testing sessions.

The WM training undertaken by the participants with DS included eight of paper-and-pencil tasks that were designed to improve visuo-spatial WM abilities. Over six successive weeks, AS and EH participated in 12 training sessions (twice weekly). In each session, two games were played. Training duration was 40 min per session. After the training, AS and EH's WM abilities were assessed again. In all the assessment tasks the child was given an example of how to perform the trial before to start. Only when the child understood the instructions the task was recorded.

Assessments

Visuo-Spatial STM

Pathway recall (Lanfranchi et al., 2004). The child was shown a path taken by a small toy frog on a 3 × 3 or 4 × 4 grind. The child had to recall the pathway immediately after presentation by moving the frog from square to square, reproducing the experimenter's moves. The task is composed of eight trials and had four levels of difficulty, depending on the number of steps in the frog's path and dimensions of the chessboard (3 × 3 in the first level with two steps and 4 × 4 in the other levels, with two, three, and four steps, respectively). Two trials for each difficulty level were presented. A score of 1 was given for every trial performed correctly. The minimum score was 0 and the maximum was 8.

Visuo-Spatial WM

Pathway recall backward (Lanfranchi et al., 2004). The child was shown a path taken by a small toy frog on a 3 × 3 or 4 × 4 grind, in the same way as the pathway recall task. The child had to remember the path in the reverse order. There were four levels of difficulty, depending on the number of steps in the frog's path and the size of the chessboard (3 × 3 in the first and second levels, and 4 × 4 in the other levels). Two trials for each difficulty level were presented. A score of 1 was given for every trial performed correctly. The minimum score was 0 and the maximum was 8. Selective pathways task (Lanfranchi et al., 2004). The child was shown one or two small toy frog's paths taken by the frog on a 4 × 4 grind, as in earlier tasks. The child had to remember the frog's starting position(s). The task had four different levels of difficulty, depending on the number of pathways and the number of steps in each pathway. There were two trials for each difficulty level. At levels one and two, respectively, one pathway with two steps and one with three steps was presented. At levels three and four, two pathways of two and three steps, respectively, were presented. A score of 1 was given for every trial performed correctly. The minimum score was 0 and the maximum was 8. Visuo-spatial dual task (Lanfranchi et al., 2004). The child had to remember the frog's starting position on a path on a 4 × 4 grind, in which one of the 16 cells was red. The child also had to tap on the table when the frog jumped onto the red square. The task had four different levels of difficulty, depending on the number of steps in the path (i.e., two, three, four, and five steps, respectively). Two trials for each difficulty level were presented. The score of 1 was given for every trial performed correctly, with the child both remembering the first position of the pathway and performing the tapping task. Otherwise, a score of 0 was given. The minimum score was 0 and the maximum score was 8.

Verbal STM

Forward word recall (Lanfranchi et al., 2004). In this task lists of two to five words were presented to the child, who was required to repeat the list immediately and in the same order of presentation. Two trials for each difficulty level were presented. A score of 1 was given for every trial performed correctly. The minimum score was 0 and the maximum was 8.

Verbal WM

Backward word recall (Lanfranchi et al., 2004). Lists of two to five words were presented, and the child was asked to repeat each list in reverse order immediately after presentation. Two trials for each difficulty level were presented. A score of 1 was given for every trial performed correctly. The minimum score was 0 and the maximum was 8.

Selective word recall (Lanfranchi et al., 2004). One or two lists were presented to the child, who was required to repeat the first word of each list after the presentation of the entire series. There were four difficulty levels, depending on the number of lists (one or two) and the number of words (two or three) in each list. Two trials for each difficulty level were presented. At levels one and two, respectively, one list with two words and one with three words were presented. At levels three and four, two lists with two and three words, respectively, were presented. A score of 1 was given for every trial performed correctly. The minimum score was 0 and the maximum was 8.

Verbal dual task (Lanfranchi et al., 2004). The child was presented with a list of two to five two-syllable words and was asked to recall the first word on the list and tap on the table when the target word ("ball") was presented. The test is made up by eight trials, two for each of the four difficulty levels. A score of 1 was given for every trial performed correctly, when the initial word of the sequence was remembered correctly at the same time the dual task was performed. Otherwise, a score of 0 was given. The minimum score was 0 and the maximum was 8.

Visuo-Spatial WM Training

The visuo-spatial WM training used was an adapted version of a WM training used in a previous study (Passolunghi and Costa, 2014) and it included different tasks that were designed to enhance visuo-spatial STM and WM abilities. The training was implemented for six weeks, twice weekly, with each session lasting 40 min. The full training program consisted of eight different games grouped into two different categories: four visuo-spatial WM games, and four visuo-spatial STM games. In each session, two games were played: one mainly focused on the enhancement of visuo-spatial STM, one mainly focused on the enhancement of visuo-spatial WM.

The training was adaptive with the instructor adapting the tasks to the child's performance (e.g., if the child failed to remember three items, on the next occasion the instructor asked for two items and, after a successful repetition of two items, asked for three again). This procedure allows to individualize the intervention by constantly assessing children's performance and adapting the difficulty level of the task, thus maintaining each child in his or her zone of proximal development (Vygotsky, 1978). The instructor gave continuous feedback to the children during the training. The children participated in the activity one after the other.

Visuo-Spatial STM Games

The first category tapped visuo-spatial STM abilities. These games required the immediate serial recall of visuo-spatial information. For the game "Farmers," a 1.5 m × 1.5 m matrix with 25 elements positioned on the floor was used. The instructor presented paths of different lengths on the matrix. Steps were presented at the rate of approximately one step every 2 s. Children had to repeat the steps of the path in the presented order. In the game "Circles" 25 hula hoops were randomly positioned on the floor. The instructor presented paths of different lengths on the circles. Steps were presented at the rate of approximately one step every 2 s. Children had to repeat the steps in the presented order. In the "Game of cards," 7 × 10 cm cards with pictures (animals, fruit & vegetables, and objects) were presented, one at a time at the rate of a card per second, and the children had to recall the list in the correct order using cards with pictures to respond. In the "Game of numbers" 7 × 10 cm cards with numbers were presented, one at a time at the rate of a card per second, and the children had to recall the list in the correct order using cards with numbers to respond.

Visuo-Spatial WM Games

The second category of games tapped visuo-spatial WM abilities. These games required a dual task procedure ("Colors" and "Pairs") or a backward recall ("The farmers backward" and "Game of Cards Back").

For the game "Colors" A 1.5 m × 1.5 m matrix with 25 colored elements (blue, yellow, red, green, and black) was positioned on the floor. The instructor presented paths of different lengths on the matrix. Children had to name the color of each element during the presentation of the path and then recall the first step of the path after presentation. The game "Pairs" challenged the children to remember the locations of 7 × 10 cm cards with pictures (animals, fruit & vegetables, and objects) placed on a grid. On each turn, a player turns over two cards (one at a time) and keeps them if they match. For the game "Farmers backward," a 1.5 m × 1.5 m matrix with 25 elements positioned on the floor was used. The instructor presented paths of different lengths on the matrix. Steps were presented at the rate of approximately one step every 2 s. Children had to repeat the steps of the path in the reverse order after presentation. In the "Game of Cards Back," some 7 × 10 cm cards with pictures (animals, fruit & vegetables, and objects) were presented, one at a time at the rate of a card per second, and the children had to recall the list in the reverse order using pictures to respond.

Analysis

Crawford and Howell's (1998) modified t-test was used to test whether the difference between the single cases (AS and EH) and the control sample was statistically different. This method provides both significance tests and a point estimate of the percentage of the population that would obtain a more extreme score (or different score) and an interval estimate (i.e., confidence limits) on this percentage. The effect size (z_{cc}) and 95% confidence interval around the effect size were also calculated using the methods proposed by Crawford et al. (2010). Analyses were run using the program Singlims_ES.exe, an upgraded version of the program Singlims.exe (Crawford and Garthwaite, 2002). It implements classical methods for comparison of a single case's score to scores obtained in a control sample.

In agreement with Perneger (1998), Bonferroni adjustments were not applied. If using Bonferroni adjustments for small sample sizes, the interpretation of a finding becomes dependent upon the number of analysis performed so they automatically increase the likelihood of Type II errors and important performance differences may be missed (Perneger, 1998).

The focus of the current study was of individuals with DS. It was therefore expected that where performance differed to that of controls would be in the direction of impaired performance and one tailed t-test were used for the analysis (Crawford et al., 2003). However, literature shows how the WM memory deficit seems to be limited to the verbal rather than visuo-spatial domain (Jarrold and Baddeley, 1997; Laws, 2002). Indeed, the visuo-spatial sketchpad abilities of individuals with DS seems to be in line with what one would expect given individuals' general level of ability. (Jarrold and Baddeley, 1997; Baddeley and Jarrold, 2007; Lanfranchi et al., 2012). Therefore, for visuo-spatial STM measures two-tailed t-tests were used. For all t-tests, the 0.05 probability level for significance was used.

Results

Performance prior and after training is reported for EH and AS, two teenagers with DS, in comparison to matched TD controls (**Table 1**). In the first part of this section, results in visuo-spatial STM and WM abilities are reported. In the second part of the section, the results in verbal STM and WM are reported. Both parts are followed by a summary of the main findings (see also **Figure 1**).

Visuo-Spatial STM

Pathway Recall

EH's *Pathway recall* score did not differ significantly from the TD group either in the pre-test, $t = 1.67$, $p = 0.11$, or in the post-test, $t = 0.93$, $p = 0.37$. In both sessions her score was higher compared to the mean score of the control TD group and in the pre-test her performance was at ceiling. The estimated percentage of normal population falling below case's score was 94.33% (95% CI: 82.98%; 99.33%) before training and was 81.61% (95% CI: 64.29%; 93.59%) after the training.

TABLE 1 | Scores for the working memory (WM) and short-term memory (STM) measures.

	Task	TD group (n = 17)		AS				EH			
		Mean	(*SD*)	Pre	Z_{CC} (95% CI)	Post	Z_{CC} (95% CI)	Pre	Z_{CC} (95% CI)	Post	Z_{CC} (95% CI)
Verbal measures	Word span (STM)	5.18	1.38	0	−3.75 (−5.12 to −2.37)	4*	−0.85 (−1.40 to −0.29)	4	−0.85 (−1.40 to −0.29)	4	−0.85 (−1.40 to −0.29)
	Word span backward	3.00	0.87	0	−3.45 (−4.71 to −2.17)	0	−3.45 (−4.71 to −2.17)	3	0.00 (−0.47 to 0.47)	4	1.14 (0.52 to 1.76)
	Selective word recall	5.12	1.36	3	−1.56 (−2.26 to −0.83)	6	0.64 (0.11 to 1.16)	8	2.12 (1.24 to 2.98)	6	0.65 (0.11 to 1.16)
	Verbal dual task	4.71	2.42	0	−1.95 (−2.76 to −1.12)	2*	1.12 (−1.72 to −0.50)	7	0.95 (0.36 to 1.51)	5	0.12 (−0.36 to 0.59)
	Cumulative verbal WM	12.82	3.34	3	−2.94 (−4.05 to −1.82)	8*	−1.44 (−2.12 to −0.75)	18	1.55 (0.83 to 2.25)	15	0.65 (0.12 to 1.17)
Visuo-spatial measures	Pathway recall (STM)	5.76	1.30	3	−2.12 (−2.98 to −1.24)	5*	−0.58 (−1.09 to −0.06)	8	1.72 (0.95 to 2.47)	7	0.95 (0.37 to 1.52)
	Pathway recall backward	5.47	1.23	4	−1.19 (−1.81 to −0.56)	4	−1.19 (−1.81 to −0.56)	5	−0.38 (−0.87 to 0.12)	7	1.24 (0.59 to 1.87)
	Selective pathways	5.06	1.75	3	−1.18 (−1.79 to −0.54)	6	0.54 (0.02 to 1.04)	1	−2.32 (−3.24 to −1.38)	8*	1.68 (0.92 to 2.42)
	Visuo-spatial dual task	5.47	1.70	0	−3.22 (−4.41 to −2.01)	4*	−0.86 (−1.42 to −0.29)	3	−1.45 (−2.13 to −0.75)	7	0.90 (0.32 to 1.46)
	Cumulative visuo-spatial WM	16.00	3.28	7	−2.74 (−3.79 to −1.68)	14*	−0.61 (−1.12 to −0.08)	9	−2.13 (−3.00 to −1.25)	22*	1.83 (1.03 to 2.61)

*Improvement from a significantly impaired performance in the pre-test to a score that didn't differ significantly from the performance of TD group. Z_{CC} = effect size index for the difference between the case and controls.

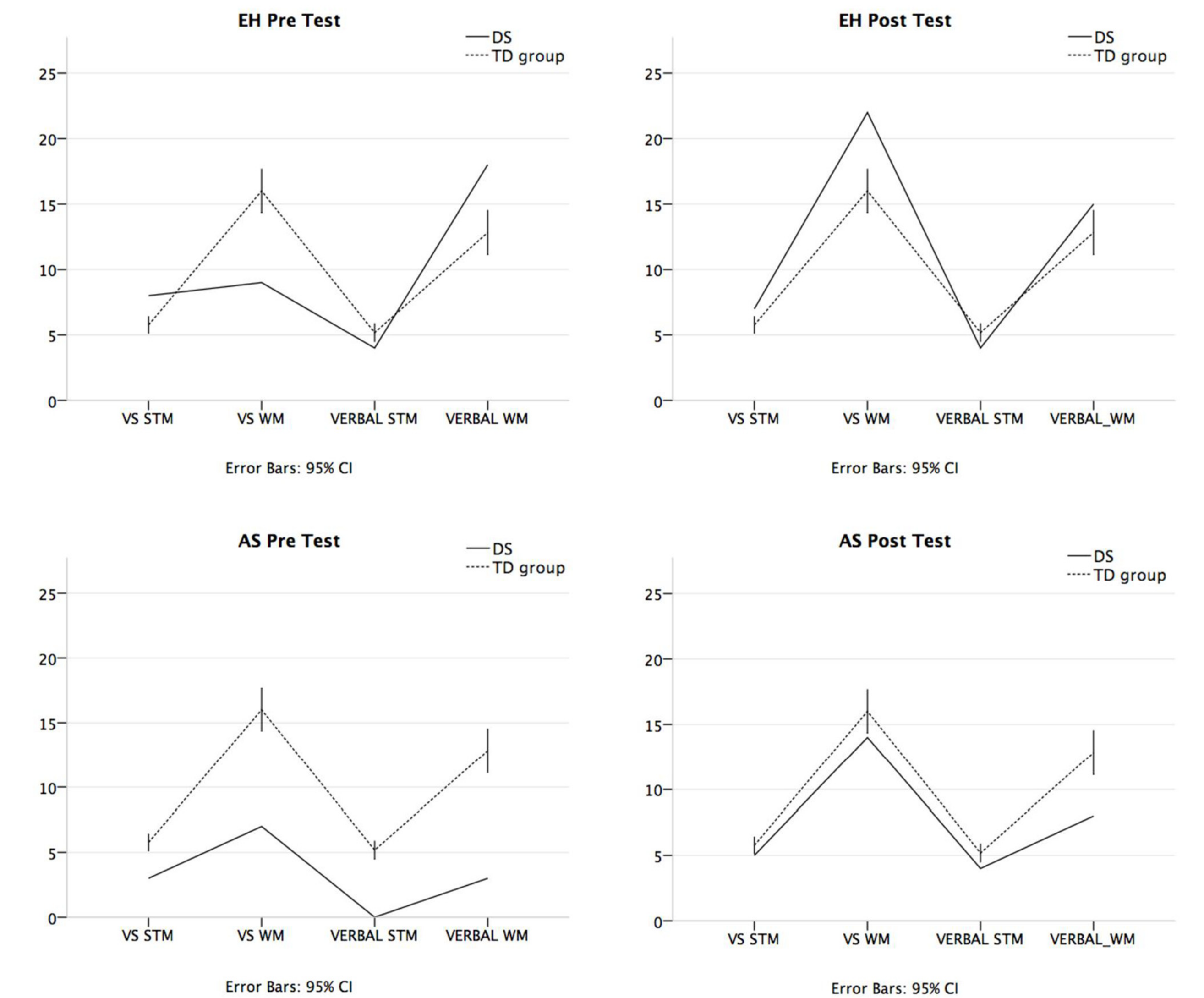

FIGURE 1 | Visuo-spatial STM and cumulative working memory (WM) scores, and verbal short-term memory (STM) and cumulative WM scores at pre-testing (for EH, AS, and TD group) and post-intervention (for EH and AS). VS STM, Visuo-spatial STM score; VS WM, Cumulative visuo-spatial WM score; VERBAL STM, Verbal STM score; VERBAL WM, Cumulative verbal WM score.

Prior to training, AS recalled significantly fewer paths than the control group, $t = 2.18$, $p = 0.04$. After training AS improved in performance on the *Pathway recall* and in the post-test session there was no longer a significant difference from the TD group, $t = 0.60$, $p = 0.56$. The estimated percentage of the normal population falling below the case's score was 2.78% (95% CI: 0.01%; 10.69%) before training and increased up to 28.89% (95% CI: 13.72%; 47.57%) after the training.

Visuo-Spatial WM

Pathway Recall Backward

EH's score in *Pathway recall backward* did not differ significantly from the TD group in the pre-test session, $t = 0.37$, $p = 0.36$, or the post-test session, $t = 1.2$, $p = 0.12$. However, the estimated percentage of the normal population falling below the case's score increased from 35.76% (95% CI: 19.22%; 54.64%) before training up to 87.79% (95% CI: 72.37%; 96.94%) after the training.

For AS, the score was the same prior and after the training and his performance did not differ significantly from the TD group, $t = 1.16$, $p = 0.13$. The estimated percentage of the normal population falling below the case's score was 13.12% (95% CI: 3.49%; 28.90%).

Selective Pathways

EH's *Selective pathways* performance in pre-test session was significantly impaired compared to the TD group, $t = 2.25$, $p = 0.02$. Her performance improved after the training with a post-test score at ceiling and higher than the mean score of the TD group, $t = 1.63$, $p = 0.06$. Strikingly, the estimated percentage of the normal population falling below the case's score was 1.92%

in the pre-test (95% CI: 0.06%; 8.3%) and 93.90% (95% CI: 82.17%; 99.22%) in the post-test.

AS's performance did not differ significantly from the TD group in the pre-test session, $t = 1.14$, $p = 0.13$, or the post-test session, $t = 0.52$, $p = 0.30$. The estimated percentage of the normal population falling below the case's score was 13.47% (95% CI: 3.67%; 29.38%) before training and was 65.56% (95% CI: 50.80%; 85.08%) after the training.

Visuo-Spatial Dual Task

In the *Visuo-spatial dual task,* EH's performance did not differ significantly from the TD group in the pre-test session, $t = 1.41$, $p = 0.09$, or the post-test session, $t = 0.87$, $p = 0.20$. However, the estimated percentage of the normal population falling below the case's score increased from 8.85% in the pretest (95% CI: 1.65%; 22.57%) to 80.26% (95% CI: 62.67%; 92.75%) in the post-test.

AS's *Visuo-spatial dual task* performance in the pre-test session was significantly impaired compared to the TD group, $t = 3.13$, $p = 0.003$, since he was not able to perform the double task. After training, AS's score did not differ significantly from the TD group, $t = 0.84$, $p = 0.21$. The estimated percentage of the normal population falling below the case's score was 0.32% (95% CI: 0.00%; 2.23%) before training and increased up to 20.65% (95% CI: 7.84%; 38.42%) after the training.

Cumulative Visuo-Spatial WM Score

In order to better understand the nature of EH and AS's WM improvements and for data reduction purposes, a *Cumulative visuo-spatial WM score* was created by summing the scores of the *Visuo-spatial dual task*, the *Selective pathways,* and *Pathway recall backward.*

EH's *Visuo-spatial WM cumulative score* prior to training was significantly impaired compared to the TD group, $t = 2.07$, $p = 0.03$. After training, EH's performance increased (EH = 22, control mean = 16, SD, 3.28) and she obtained a significantly higher score than the TD group, $t = 1.77$, $p = 0.047$. The estimated percentage of the normal population falling below the case's score was 2.73% (95% CI: 0.014%; 10.55%) before training. After the training, the results showed that the estimated percentage of the normal population falling below EH's score was 95.28% (95% CI: 84.87%; 99.54%).

AS's *Visuo-spatial WM cumulative* performance in the pre-test session was significantly impaired compared to the TD group, $t = 2.67$, $p = 0.008$. After the training, there was no longer a significant difference from the TD group, $t = 0.59$, $p = 0.28$. The estimated percentage of the normal population falling below the case's score was 0.84% (95% CI: 0.007%; 4.64%) before training and was 28.09% (95% CI: 13.11%; 46.71%) after the training.

Summary

EH's performance in visuo-spatial STM, assessed with the pathway recall task was higher compared to the mean score of the control TD group both in the pre-test and post-test. The results did not show an improvement of EH's visuo-spatial STM abilities after training. Her lower performance in the post-test session was probably be due to a regression to the mean effect.

Considering the tasks assessing visuo-spatial WM abilities, in the *Pathway recall backward* and in the *Visuo-spatial dual task* EH performance did not differ significantly from the TD group either in the pre-test or post-test sessions. However, in both tasks there was an improvement of performance after the training, as shown by the increased estimated percentage of the normal population falling below the case's score in the post-test session (from 35.76 to 87.78% for the *Pathway recall backward*; from 16.80 to 72.62% in the *Visuo-spatial dual task).* The third task used in order to assess visuo-spatial WM abilities was the *Selective pathways.* EH's performance in the pre-test session was significantly impaired compared to the control TD group. The results showed that her performance improved after the training and her score did not differ from the TD group.

If one considers the *Visuo-spatial WM cumulative score,* EH's performance prior to training was significantly impaired compared to the control group. The training led to an improvement of overall visuo-spatial WM abilities given that after the training EH obtained a significant higher score in comparison to the TD group.

AS's performance in visuo-spatial STM, assessed with the pathway recall, was significantly impaired compared to the control TD group in the pre-test session. The results showed that his performance improved after the training when the score did not differ from the TD group.

Considering the tasks assessing visuo-spatial WM abilities, AS's *Pathway recall backward* performance prior to training did not differ significantly from the TD group. Results showed no improvements in the post-test session. In the *Selective pathways* AS's performance did not differ significantly from the TD group either in the pre-test or post-test session. However, there was an improvement of performance after the training as shown by the increased estimated percentage of the normal population falling below the case's score in the post-test session (from 13.47 to 65.56%). Regarding the *Visuo-spatial dual task*, AS showed impaired performance in the pre-test session. The performance improved after the training, with no more significant difference from the average scores obtained by the TD group.

If one considers the *Visuo-spatial WM cumulative score,* AS's performance prior to training was significantly impaired compared to the control group. The training led to an improvement of overall visuo-spatial WM abilities, given that after the training there was no longer a significant difference from the TD group.

Verbal STM

Word Span

For EH, *word span* score was the same prior and after the training and her performance did not differ significantly from the TD group, $t = 0.83$, $p = 0.21$. The estimated percentage of normal population falling below case's score was 20.91% (95% CI: 8.01%; 38.72%).

AS's *word span* performance in pre-test session was significantly impaired compared to the TD group, $t = 3.65$, $p = 0.001$, since it was not able to perform the task. After training, AS's score did not differ significantly from the TD group, $t = 0.83$, $p = 0.21$. The estimated percentage of the normal population falling below the case's score was 0.11% (95% CI: 0%; 0.88%) before training and increased up to 20.21% (95% CI: 8.01%; 38.72%) after the training.

Verbal WM

Word Span Backward

EH's *Word span backward* score in the pre-test was equal to the average score obtained from the control TD group, $t = 0$, $p = 0.50$. In the post-test session again EH's performance did not differ significantly from the TD group, $t = 1.17$, $p = 0.14$. The estimated percentage of the normal population falling below the case's score was 50.00% (95% CI: 31.73%; 68.27%) before training and was 85.98% (95% CI: 69.87%; 96.05%) after the training.

AS was not able to perform the *Word span backward* either before or after the training. His performance was significantly poorer than the control group, $t = 3.35$, $p = 0.002$, and the estimated percentage of the normal population falling below AS's score was 0.20% (95% CI: 0%; 1.51%).

Selective Word Recall Task

EH's *Selective word recall* performance in the pre-test session was at ceiling and significantly higher than the TD group, $t = 2.06$, $p = 0.03$ while EH's post-test performance did not differ significantly from the TD group, $t = 0.63$, $p = 0.27$. The estimated percentage of the normal population falling below the case's score was 85.98% (95% CI: 69.87%; 96.05%) in the pre-test and was 73.08% (95% CI: 54.53%; 87.77%) in the post-test.

The difference between AS's *Selective word recall* performance and the TD group did not differ significantly from the mean score of the TD group either in the pre-test, $t = 1.51$, $p = 0.07$, or post-test, $t = 0.63$, $p = 0.26$. However, it can be seen that the effect size for the case's difference is quite large in the pre-test: the case's difference is over 1.5 SD from the mean difference in controls. After training, AS's *Selective word recall* score was higher compared to the mean score of the control TD group. The estimated percentage of the normal population falling below the case's score was 7.46% (95% CI: 1.18%; 20.27.77%) before training and increased up to 73.08% (95% CI: 54.54%; 87.77%) after the training.

Verbal Dual Task

EH's *Verbal dual task* score did not differ significantly from the mean score of the TD group either in the pre-test, $t = 0.92$, $p = 0.18$, or post-test, $t = 0.12$, $p = 0.45$. The estimated percentage of the normal population falling below EH's score was 81.43% (95% CI: 64.07%; 93.47%) in the pre-test and was 54.55% (95% CI: 35.97 %; 72.41%) in the post-test.

AS's *Verbal dual task* performance in the pre-test session was significantly impaired compared to the TD group, $t = 1.89$, $p = 0.038$, since he was not able to perform the double task. After training, AS's score did not differ significantly from the TD group, $t = 1.09$, $p = 0.15$. The estimated percentage of the normal population falling below the case's score was 3.84% (95% CI: 0.29%; 13.22%) before training and was 14.63% (95% CI: 4.26%; 30.93%) after the training.

Cumulative Verbal WM

To better understand the nature of EH and AS's WM abilities and for data reduction purposes a *Cumulative verbal WM score* was created by summing the scores of the *Verbal dual task*, the *Selective word recall,* and *Word span backward.*

EH's *Cumulative verbal* score in both sessions was higher compared to the mean score of the control TD group. Her score was higher compared to the TD group in the pre-test, but the difference was not significant, $t = 1.50$, $p = 0.07$. In the post-test, there was a decrease of performance but her score remained higher than the average score of the TD group. EH's post-test performance did not differ significantly from the TD group, $t = 0.63$, $p = 0.27$. The estimated percentage of the normal population falling below the case's score was 92.44% (95% CI: 79.56%; 98.79%) before training and was 73.26% (95% CI: 54.72%; 87.90%) after the training.

AS's *Cumulative verbal WM* score in the pre-test session was significantly impaired compared to the TD group, $t = 2.86$, $p = 0.006$. After the training, there was no longer a significant difference from the TD group, $t = 1.40$, $p = 0.09$. The estimated percentage of the normal population falling below the case's score was 0.56% (95% CI: 0.0073%; 3.46%) before training and was 8.99% (95% CI: 1.70%; 22.80%) after the training.

Summary

EH's performance in verbal STM, assessed with the *Word span*, did not differ significantly from the TD group prior to training. Results showed no improvements in the post-test session.

Considering the tasks assessing verbal WM abilities, the results showed no impairments in any verbal WM measure compared to the TD group in the pre-test session. After the training period the performance in all verbal WM tasks (*Word span backward, Selective word recall,* and *Verbal dual task*) remained within the range of the TD group. In *Selective word recall* and in the *Verbal dual task* there was a decrease of performance, but her score remained higher than the average score of the TD group both in the pre- and post-test sessions. Only in the *Word span backward task* was there an increased performance at post-test, as shown by the increased estimated percentage of the normal population falling below the case's score in the post-test session (from 50.00% in the pre-test to 85.98% in the post-test).

If one considers the *Verbal WM cumulative score,* EH's performance did not differ significantly from the TD group either in the pre-test or in the post-test. The results show a lower performance in the post-test but it should be noted that in both sessions her score was higher than the mean score of the control TD group.

EH lower performances in the the post-test session compared to the pre-test session in some of the tasks (*Selective word recall, Verbal dual task*, *and Verbak WM cumulative score*) could be due to a regression to the mean effect. Ideeed, she showed a high performance in the pre-test, and even if her performance decreased in the post-test, in both sessions was higher compared to the mean score of the control TD group.

AS's performance in all verbal STM and WM tasks was significantly impaired compared to the control TD group in the pre-test session, except for *Selective word recall* where the performance difference relative to the TD group was not significant. The results showed that AS's verbal STM performance improved after the training when his score did not differ from the TD group.

Considering the tasks assessing verbal WM abilities, the results showed an improvement in the post-test session in the *Selective word recall* and in the *Verbal dual task,* with no significant difference from the average scores obtained by the TD group. AS was not able to perform the *word span backward* either before or after the training.

If one considers the *Verbal WM cumulative score*, AS's performance prior to training was significantly impaired compared to the control group. The training lead to an improvement of overall Verbal WM abilities, given that after the training there was no longer a significant difference from the TD group.

Discussion

The aim of our study was to evaluate the impact of a school-based visuo-spatial WM training on the STM and WM skills of two individuals with DS. With regard to visuo-spatial abilities, both EH's and AS's visuo-spatial WM cumulative scores (created by summing the scores of the *Visuo-spatial dual task*, the *Selective pathways,* and *Pathway recall backward)* improved after the training. Indeed, while in the pre-test their performance was significantly impaired compared to the TD group, in the post-test session their scores did not differ significantly from the performance of TD group. EH's scores were improved in all visuo-spatial WM tasks after training. In particular, her performance in the *Selective pathways* was significantly impaired in the pre-test, while after training there was no longer significant difference from the TD group. AS improved his performance in all the visuo-spatial WM tasks after training except for the *Pathway recall backward* task that, in any case, remained within the range of the TD group. In particular, his performance in the *Visuo-spatial dual task* was significantly impaired in the pre-test while after the training there was no longer a significant difference from the TD group. Moreover, AS's Pathway recall performance (visuo-spatial STM) was significantly impaired in the pre-test while after the training there was no longer a significant difference from the TD group.

It should be noted that both EH and AS significantly improved their visuo-spatial scores after training, mostly on those tasks on which they were significantly impaired in the pre-test session. These results suggest that our training successfully enhanced visuo-spatial abilities, improving also those skills in which they were deficient in the pre-test compared to the TD group.

On the basis of the results of previous studies (Thorell et al., 2009; Van der Molen et al., 2010) and given that our visuo-spatial WM training included complex memory tasks involving the central executive component of WM, a transfer of improvements to the verbal domain was expected. The results showed that AS's verbal STM and WM skills were significantly impaired compared to the control TD group prior to training. After the training his performance improved and there was no longer a significant difference from the TD group, except for the *Word span backward* score. EH's performance did not differ significantly from the TD group in any verbal STM and WM task, either in the pre- or post-test session. There was no improvement from pre-test to post-test except for the *Word span backward*. Therefore, there was a transfer of the visuo-spatial WM training effects on verbal abilities for AS, while EH didn't showed any significant improvement in her verbal STM or WM performance. This result could be explained considering the different profiles of the participants, which reflect the wide variation in the effects of the chromosomal abnormality on the development in the DS. In the pre-test assessment, AS showed a generally weak profile, with most of the verbal and visuo-spatial scores significantly below the mean of the TD group. In contrast, EH showed a stronger profile with all the verbal scores and most of visuo-spatial scores within the range of the TD group. Moreover, EH's scores in all verbal WM measures (*Word span backward*, *Selective word recall*, *Verbal dual task*, *Verbal WM cumulative score*) both in the pre-test and in the post-test were equal or higher than the average scores of the TD control group. Taken together, these results indicate that the training had a beneficial effect, especially on those skills that were deficient (below expected standards), while it is more difficult to influence those skills that are already in line with what one would expect given individual's general level of ability.

To explain the stronger memory profile of EH, it can be hypothesized that her good education path/career and her good verbal abilities encouraged the development of WM skills. In particular, participation in school activities may have led to a familiarity in processing verbal information. On the other hand, AS's dyspraxia and speech problems could explain his general low WM and STM profile (Alloway and Archibald, 2008).

There are some limitations of the study. First, although we administered WM tasks used with individuals with Down syndrome (7–23 years) in previous studies (Lanfranchi et al., 2004, 2010, 2012) we found some ceiling performance levels with EH in the pre-test and in the post-test session. The ceilings for EH are probably connected to her stronger memory profile as explained above and may be prevented in future studies by using a more complex version of the same WM tasks. Second, only two single case treatments were studied. While the results are encouraging, extension with further data is required to better assess the effectiveness of the WM training outlined. A further limitation is that changes were only assessed immediately after the training so that there is no information about the longer-term stability of any training-related gains in performance. Previous studies reported an increased affects of WM training at follow-up compared with immediate effects in the post-test (Klingberg et al., 2005; Holmes et al., 2009; Van der Molen et al., 2010). It should be important in future studies to follow up post-intervention to see whether benefits of training last and to investigate the effectiveness of this kind of WM training with group studies.

The findings of the present study are promising and could have important practical implications for intervention. In fact, the training program successfully enhanced AS's and EH's WM, a central and important cognitive aspect for classroom and daily life functioning. Our results, in line with previous studies (Klingberg et al., 2002; Thorell et al., 2009; Van der Molen et al., 2010), provide further evidence that WM abilities can be improved and that school-based visuo-spatial memory training can be effective for children with DS, also without the support of a computer. Given the importance of WM abilities for the development of a broad range of learning achievement (e.g., Alloway and Alloway, 2010), further work is required to investigate possible transfer effects of visuo-spatial WM training on learning in individuals with DS.

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CLINICAL CASE STUDY
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Treating verbal working memory in a boy with intellectual disability

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The present case study investigates the effects of a cognitive training of verbal working memory that was proposed for Davide, a 14-year-old boy diagnosed with mild intellectual disability. The program stimulated attention, inhibition, switching, and the ability to engage either in verbal dual tasks or in producing inferences after the content of a short passage had been encoded in episodic memory. Key elements in our program included (1) core training of target cognitive mechanisms; (2) guided practice emphasizing concrete strategies to engage in exercises; and (3) a variable amount of adult support. The study explored whether such a complex program produced "near transfer" effects on an untrained dual task assessing verbal working memory and whether effects on this and other target cognitive mechanisms (i.e., attention, inhibition, and switching) were long-lasting and produced "far transfer" effects on cognitive flexibility. The effects of the intervention program were investigated with a research design consisting of four subsequent phases lasting 8 or 10 weeks, each preceded and followed by testing. There was a control condition (phase 1) in which the boy received, at home, a stimulation focused on the visuospatial domain. Subsequently, there were three experimental training phases, in which stimulation in the verbal domain was first focused on attention and inhibition (phase 2a), then on switching and simple working memory tasks (phase 2b), then on complex working memory tasks (phase 3). A battery of neuropsychological tests was administered before and after each training phase and 7 months after the conclusion of the intervention. The main finding was that Davide changed from being incapable of addressing the dual task request of the listening span test in the initial assessment to performing close to the normal limits of a 13-year-old boy in the follow-up assessment with this test, when he was 15 years old.

Keywords: intellectual disability, training, attention, inhibition, switching, verbal working memory

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Introduction

According to an influential multi-component model (Baddeley and Hitch, 1974; Baddeley, 2000, 2010), working memory consists of a central executive whose limited capacity attentional control is responsible for the active maintenance and processing of task-relevant information, which is temporarily held in domain-specific verbal and visuospatial stores or a multi-modal episodic buffer (Baddeley, 2000). Consistent with this model is the description of the central executive as a cluster of executive functions whose specific control process consists in updating the contents of working memory, switching between different tasks or procedures, inhibit irrelevant information or actions, coordinating multiple tasks (Baddeley, 1996; Miyake and Friedman, 2012).

The critical role that working memory plays in enhancing cognitive development is suggested by several studies that point to a strong relationship between executive functions, working memory, and fluid intelligence (see the recent review by Titz and Karbach, 2014) both in adults (Friedman et al., 2006; Wang et al., 2013) and children (Engel de Abreu et al., 2010; Giofre et al., 2013).

Learning is also promoted by working memory capacities and executive functioning, as suggested by a number of studies showing high correlations between working memory and measures of learning and academic achievement (Alloway and Passolunghi, 2011; Swanson and Alloway, 2012; Alloway et al., 2013). Working memory capacity is an effective predictor of performance in reading (de Jong, 1998; Gathercole and Pickering, 2000; Swanson, 2003; Gathercole et al., 2006) and mathematics (Gathercole and Pickering, 2000; Bull and Sherif, 2001; Geary et al., 2004). The executive processes of updating and shifting are also associated with scholastic attainment scores and performance on tests of reading and mathematics (St Clair-Thompson and Gathercole, 2006; Yeniad et al., 2013). Working memory and executive functions not only play a key role in learning but also affect a range of everyday life situations (e.g., following instructions or carrying out a sequence of actions) in which cognitive processing has to be complemented by short-term storage (see Gathercole and Alloway, 2006).

The strong association between working memory and executive functions on one hand and academic learning on the other hand is also shown by children with intellectual disabilities (ID) and borderline intellectual functioning (Numminen et al., 2000; Henry and Winfield, 2010; Poloczek et al., 2012).

Given the strong relationship that working memory and fluid intelligence have in typically developing individuals, we may ask whether working memory, especially when central-executive-loaded tasks are employed, is an area of weakness in the neuropsychological profile of children with ID. Most studies assessing working memory in children with ID analyzed their performance using age-expected norms and found deficits in all the subcomponents of working memory (Henry, 2001; Pickering and Gathercole, 2004; Van der Molen et al., 2007; Maehler and Schuchardt, 2009). Some studies have asked whether children with ID show lower performance compared to children of the same chronological age only (CA controls) or also to younger children with the same mental age (MA controls). This double comparison is assumed to distinguish the effects of a simple developmental delay from the effects of specific structural impairments in one of the components of the working memory system. Using this method, Van der Molen et al. (2009) assessed visual and verbal working memory in a group of children with mild intellectual disabilities (IQ 55–85) and found an unbalanced profile between the visuospatial and verbal components of the working memory system. Specifically, visuospatial working memory (tested with the *odd-one-out task*) was delayed compared to CA controls only, whereas performance in a verbal dual task involving central executive resources (i.e., listening span test), was lower compared to both the CA and MA controls. Other studies, however, found a reverse pattern in which non-verbal WM was delayed compared to the MA controls whereas verbal WM, always assessed with the listening span test, was lower only when compared to the CA controls (Danielsson et al., 2012).

As far as the verbal component of working memory is concerned, there is rich evidence that the phonological loop component of WM is weaker compared to mental age peers in most children with ID (Jarrold et al., 2000; Henry and MacLean, 2002; Van der Molen et al., 2009; Schuchardt et al., 2010, 2011) and even in children with borderline intellectual functioning (Henry, 2001; Henry and MacLean, 2002; Hasselhorn and Maehler, 2007).

Studies of executive functions in children with ID or borderline intellectual functioning are consistent in showing lower performance than chronological age comparisons (Conners et al., 1998; Levén et al., 2008; Alloway, 2010). A study assessing executive functioning with a comprehensive battery of tests (Danielsson et al., 2012) found that children with ID had lower performance than chronological age controls on all the executive function tests. Moreover, on the inhibition and planning tasks children with ID performed more poorly than the mental age comparison group. An inhibition deficit, mostly consisting in behavioral inhibition and interference control, emerged in a recent meta-analytic study (Bexkens et al., 2014) and generalized inhibitory difficulties were observed in a recent study on children with Down Syndrome (Borella et al., 2013).

In summary, children with ID or borderline intellectual functioning show heterogeneous domain-specific effects in performance with working memory tasks (Van der Molen et al., 2007). Such effects are likely to be related to disorder-specific "structural" impairments affecting a short-term storage of verbal, visual, or spatial information (Jarrold et al., 1999, 2006; Lanfranchi et al., 2004). Although working memory tasks may be more easily performed in one or the other domain, it is still an open question whether devoting attentional resources to processing current information, while simultaneously storing target items in memory to be retrieved later can be successfully treated in children with intellectual disabilities (see Perrig et al., 2009).

We review the evidence concerning such issue along with a discussion of the factors that generate relevant differences in WM training methods and their effects. Starting with the distinction between *strategy training* and *core* (Morrison and Chein, 2011) or process-based (Jolles and Crone, 2012) *training*, some programs teach strategies to facilitate the encoding and recall of more information, whereas other training approaches aim to induce changes in the target ability through extensive and repeated practice. Strategy training has been used to teach rehearsal in order to improve short-term memory (e.g., increases in digit span) in children with Down syndrome (Broadley and MacDonald, 1993; Comblain, 1994) or fetal alcohol spectrum disorder (Loomes et al., 2008). Rehearsal can prevent the quick decay of representations from the phonological loop in working memory and compensate for structural impairments of short-term storage. It is clear that children with intellectual disabilities can learn rehearsal and improve their memory span when they use such a strategy. However, the near transfer effects of this method—that is, the improvement that can be generated in similar but untrained tasks—have been little investigated; thus it is unclear, for instance, whether rehearsal can be used spontaneously in tasks that are similar but not identical to the trained task (e.g., from rehearsing digits to rehearsing words). Also unclear is whether rehearsal strategies can produce improvements in the parallel tasks of processing, memory encoding, and recalling that are involved in working memory.

Unlike strategy training, *core training* addresses the functionality of a mechanism through practice and repetition, as when cumulative rehearsal is intensively practiced to enlarge the storage capacity of the phonological buffer. When training Down syndrome children with overt cumulative rehearsal (e.g., if I said "car," and you said "ball," I have to say "car, ball") for one or two 3—month periods, Conners et al. (2008) found effects on the digit span task and an increased phonological similarity effect, suggesting a deeper phonological encoding of information in short-term memory. However, when the task required subjects to both process and store information, no transfer was observed.

This finding led us to another crucial question regarding the characteristics of training methods—whether they address the central executive or only the short-term storage components of the working memory system. Some studies used computerized adaptive training to involve participants in processing current spatial (Jaeggi et al., 2011) or visual-auditory stimuli (Redick et al., 2013) and to decide whether they are the same (and/or have identical locations) as the n-back ones. Focusing on the near transfer effects of adaptive n-back training to tasks deeply involving the central executive (e.g., reading span), Redick et al. (2013) found that such transfer did not occur, whereas training complex span (Chein and Morrison, 2010; Harrison et al., 2013) produced near transfer to other central-executive-loaded working memory tasks. Complex span tasks, for instance, ask participants to recall a sequence of digits or pictures when there is a background processing task, such as counting or analyzing the orientation of the presented pictures. Such complex tasks involve crucial characteristics of the working memory system: allocating attentional resources to maintaining the task goals, storing relevant information, processing the current stimuli, and recalling target information in a sequentially ordered fashion.

A dual task involving processing the current stimuli (i.e., identifying which figure is the odd one), and remembering a target location across increasingly longer spans has been used by Van der Molen et al. (2010), using computerized training. A large group of adolescents with mild-to-borderline intellectual disabilities participated in either an adaptive or a stable training regimen with the visual dual task; a control group was trained with a single task. Results showed that children trained with dual tasks (no matter whether adaptive or stable) improved their performance in verbal short-term memory between pre- and post-testing. Visual working memory significantly improved only at follow-up testing, whereas performance with verbal working memory was not affected by training in any testing phase.

Soderqvist et al. (2012) analyzed the effects of a training procedure combining working memory and non-verbal reasoning (NVR) tasks. A sample of 41 children with ID participated in two training groups that used the same NVR tasks but differed regarding their treatment with either adaptive or non-adaptive, computerized, visual, simple-span tasks. There was large individual variability in the children's responses to intervention, and only children who made remarkable progress in the training tasks showed improved performance in verbal or visual working memory at post-testing. However, as there was no control group, it is not clear whether post-testing WM improvements in the subgroup of children who showed progress in the training tasks were an outcome of training and/or an outcome of repeated testing. Despite such methodological weakness, the findings of the study show that training success is feasible in children with ID and depends on the individual's modifiability in response to the increasing difficulties of the training regimen.

Bennett et al. (2013) used a computerized WM training consisting of visuospatial simple and complex span tasks. Children with Down syndrome aged seven to 12 years were allocated to either the intervention program or a waiting list group. Children in the intervention group significantly improved for visuospatial WM both immediately after the training and at 4-month follow-up but the training showed no effects on verbal WM.

In summary, there is evidence that using dual tasks in the visual domain can successfully improve visual working memory. Some studies have even found that such progress produced near transfer effects to verbal short-term memory in children with ID (Van der Molen et al., 2010). However, evidence that verbal working memory can be improved in children with ID, enabling them to effectively engage in verbal dual tasks, is still scarce.

In this single-case study we explore whether verbal working memory, assessed through a dual task such as the listening span test, can be improved as an effect of training in a child with a mild intellectual disability.

As the study's main goal is applicative, we designed a cognitive intervention that could be effective in practice and took into account the severe attention, impulsivity, and working memory difficulties of Davide, a 14-year-old boy with a diagnosis of mild intellectual disability. Our study explores whether a complex intervention can produce near transfer to an untrained task assessing verbal working memory (i.e., the listening span test) and whether effects on this and other target cognitive mechanisms (i.e., attention, inhibition, and switching) are long-lasting and can produce "far transfer" effects to cognitive flexibility.

Background

Davide (a fictional name) was born in a middle-class family and started to show signs of motor delay before 1 year of age. The first formal assessment took place in a public neuropsychiatric unit when he was 3 years old, when he communicated mainly with gestures and showed a severe motor delay. As the child was very shy around peers and did not look people in the eye, the diagnosis at that time was global developmental disorder. After 2 years of treatment within a small group of children, his communication skills increased remarkably, and the diagnostic label was changed to that of a specific language impairment (evidenced in receptive language, verbal dyspraxia, and phonological disorder) associated with difficulties in emotion regulation and cognitive delay. Davide then attended speech therapy and entered primary school 1 year later than expected, assisted by a special educator who, according to Italian law, helps the children with special needs for a varying amount of time (according to the severity of their impairment) in regular classes. As the genetic analyses, the EEG and the functional magnetic resonance carried out by the family, never revealed any type of anomaly, Davide's parents have been swinging between believing that the child's cognitive weaknesses were generated by a learning disability that could be overcome in the future or considering the child's cognitive delay as a fixed characteristic. Davide seemed to have interiorized this latter conception and interpreted the difference in achievement between him and his peers at school as generated by insurmountable problems. He tended to present himself as a person "with problems" and was very prone to claiming his lack of intelligence whenever he realized to be incorrect.

Davide had received a diagnosis of mild intellectual disability of a non-specific etiology in three public neuropsychiatric units in Rome, showing an IQ ranging between 60 and 70 in different testing across the elementary and junior school years. The diagnosis was based not only on the intelligence quotient (IQ) level that was assessed with the WISC-III (Wechsler, 1991) but also on the level of adaptive functioning. Davide's social life was extremely poor. He had no relationships with school peers and did not have friends; although, he participated in activities at a Boy Scout center. Davide's life skills were also quite low as he had difficulties using money, traveling via metro or bus, planning his homework, and helping with simple works at home (e.g., setting the table). Academic learning had been assessed several times, with arithmetic skills and text comprehension corresponding to the level of an 8-year-old child in the last assessment when he was 13-year-old.

In our university clinical center, Davide was assessed when he was 14 years old and attending the third year of junior school. Turning to the results of our neuropsychological testing shown in **Table 1**, it is clear that language was still a core impairment, with performances in productive lexicon and receptive grammar below those of much younger children.

Verbal short-term memory was low but within normal limits, whereas complex dual tasks in both the spatial (see performances with the BVS battery by Mammarella et al., 2008 in **Table 1**) and the verbal domain of working memory could not be addressed in this initial assessment. In the listening span test (Pazzaglia et al., 2000), when he was asked to carry out the dual task of providing judgments of sentence plausibility and memory encoding of the last word of each sentence, Davide could not remember one word and only gave judgments of sentence plausibility; however, he made several errors. Such difficulties with dual tasks both in the verbal and visuo-spatial domains were likely to be related, on one hand, to the very low language and visuo-spatial processing skills (see the performances on sentence comprehension and with the visuo-spatial test ≪ Arrows ≫ in **Table 1**). On the other hand, the difficulties with attention, inhibition, and switching contributed to an impaired performance with executive-loaded working memory tasks. Selective attention (see **Table 1**) was, in fact, exceedingly slow, and among the executive processes there was a particularly low performance with inhibition, whereas the switching task had been addressed by Davide in a dysfunctional quick way that resulted in a huge number of errors (see **Table 1**).

Episodic memory (see **Table 1**) showed a different pattern of performance according to whether items to be recalled later were single words that could strengthen their representation through repetition (as in the test ≪ Selective Memory for Words ≫, Reynolds and Bigler, 1994) or were narrative contents to be recalled immediately after one single listening (as in ≪ Recall of Stories ≫, Reynolds and Bigler, 1994).

Davide's low processing speed emerged both in tests engaging executive control (see, for instance, the inhibition completion time) and in everyday life actions involving visual-motor coordination (e.g., exceedingly slow typing with the computer's keyboard) or discourse processing (e.g., long pauses before answering complex questions in conversation or following instructions).

Despite a poor social life and an extremely scarce experience of communicating with peers, Davide had a good performance on a theory-of-mind task (see **Table 1**), and his good ability of taking into account feelings and thoughts of other people was also clear from the conversations shared with him in the initial assessment (Fatigante et al., 2015).

Following ethical approval, informed written consent from the parents was obtained for Davide to include him in our experimental treatment. Davide was also involved in decisions concerning his participation in the training activities. When we proposed a treatment ("Would you like to exercise your attention and memory in our lab?"), Davide initially kindly declined our proposal: "Thank you. Everybody wants to give me some help, but I'm very busy with my studies and Boy Scout activities." We then suggested he could try to come only three times and then make a final decision. He eventually decided to accept our proposal because, he said, "You can perhaps change my life." We then clarified that we could not "change his life" but only teach him skills and give him support in his own attempts to change.

Discussion

Cognitive Training Program

Previous studies that have trained WM in children with ID used computerized tasks with structurally similar exercises that varied in terms of difficulty levels (Van der Molen et al., 2010; Soderqvist et al., 2012; Bennett et al., 2013). We assumed instead that cognitive enhancement may benefit more from training with varying tasks (Jolles and Crone, 2012) and that both progression from simple to complex tasks and change of stimuli could be important to boost the participants' motivation. Other key elements in our program included (1) core training of target cognitive mechanisms through repeated practice; (2) guided practice emphasizing concrete strategies to engage in exercises (e.g., verbalization to promote the task's goal maintenance); and (3) variable amount of the adult's support to adapt the task difficulty to the child's actual level of performance.

TABLE 1 | Davide's assessment before intervention (age: 14 years and 2 months).

Test		Performance (standard scores or percentiles*)
VMI—Developmental Test of Visual-Motor Integration (Beery and Butkenica, 1997)		
Visual test		In norm
Motor and visual-motor tests		5th percentile
Arrows—Nepsy II (Korkman et al., 2007)		−2
Boston naming test (Kaplan et al., 1983; Italian norms in Riva et al., 2000) (comparison with 10-year-old children, that is the highest age level of the test norms)		−1.78
Peabody picture vocabulary test (Dunn and Dunn, 1981; Italian norms in Stella et al., 2000)		−1
Test of grammatical comprehension for children (Chilosi et al., 1995) (comparison with 8-year-old children, that is the highest age level of the test norms)		Below the 10th percentile
BVS—Battery for assessment of visual and spatial memory (Mammarella et al., 2008)		
Simultaneous matrices (the child is asked to memorize the position of red circles in a matrix and reproduce it figuring out the position immediately below)		The task was too difficult and was not completed
Paths on a matrix (the child is asked to memorize the starting position of a symbol in a matrix and follow instructions to reproduce the arrival point)		−2.9
Battery for neuropsychological assessment in adolescence (Gugliotta et al., 2009)		
Direct digit span		In norm
Backward digit span		−1.26 (raw score: 3)
Word repetition (from Word list interference)—Nepsy II (Korkman et al., 2007)		−1.3
Listening span test (Pazzaglia et al., 2000) (comparison with children aged 11–13, that is the highest age level of the test norms)		
Number of words correctly recalled in order		Raw score: 0
Number of errors in judging sentences plausibility		−2.47
Number of intrusion errors (recalled words that do not occupy the sentence ending position)		Raw score: 0
Episodic memory—TOMAL (Reynolds and Bigler, 1994)		
Recall of stories—Number of recalled content units		1st percentile (raw score: 14)
Selective memory of words (immediate)		16th percentile
Attention (Di Nuovo, 2000)		
Alertness (*Simple reaction time*)		In norm
Selective attention (*Speed and accuracy*)—Errors		−0.66
Selective attention (*Speed and accuracy*)—Reaction time		−3.5
Bells (Italian norms of Biancardi and Stoppa, 1997)		
Selective attention		−1.5
Sustained attention		−4.5
Fluency—Nepsy II (Korkman et al., 2007)		
Phonological fluency		−0.33
Semantic fluency		−0.66
Stroop test, (Di Nuovo, 2000)		
Difference between baseline and condition with interference—Errors		−0.34
Difference between baseline and condition with interference—Reaction time		−2.4
Inhibition—Nepsy II (Korkman et al., 2007)		
Naming condition	Errors	In norm
	Completion time	1
Inhibition condition	Errors	Below the 2nd percentile (raw score = 7)
	Completion time	−2.6
Switching condition	Errors	Below the 2nd (raw score = 46);
	Completion time	1.33
Animal sorting Nepsy II (Korkman et al., 2007) Total correct sorts		−2.6
Theory of mind Nepsy II (Korkman et al., 2007)		In norm

**Comparison with chronological age norms unless specified otherwise in the table.*

Core training through repeated practice was thus complemented in our training by adults leading verbal interaction and promoting an attentional control on the task's goal maintenance and the strategies that may help task execution. For instance, the adult asked the child to rephrase instructions, select characteristics on which to focus attention, anticipate possible sources of confusion in the task, and rehearse or visualize contents for later recall.

As illustrated in **Table 2**, our experimental training (occurring after the phase 1 control treatment) started from attention, as attention is involved in working memory (Vandierendonck, 2014), and it is known that weak attention skills are often present in children with ID, with a strong negative impact on working memory (Kirk et al., 2015). There were then activities related to inhibition that asked participants to process negative sentences to accomplish selection of target items (e.g., "The thief does not have blond hair") or semantic categorization of pictures (e.g., "You cannot play cards with animals"). Processing of sentences with negation has been shown to involve the left inferior frontal gyrus (Bahlmann et al., 2011) that is also involved in tasks related to inhibition of irrelevant stimuli (Swick et al., 2008).

After the first 10-week unit, treatment was focused on both switching and simple working-memory tasks, with the former asking participants to practice different actions in the same exercise (e.g., looking at the picture and either saying something that was not true for that picture, or saying something that was true but different from the word that was written on the top of the picture). Phase 2b treatment also involved simple verbal working-memory tasks, asking participants to recall sequences of items belonging to a target semantic category or sequences of words starting with a target phoneme.

Phase 3 treatment engaged working memory with complex tasks that consisted either of verbal dual tasks where the participant is asked to recall information after having accomplished a different task (e.g., recalling a sentence after having judged whether that sentence was friendly or not) or tasks

TABLE 2 | Phases of the cognitive training program.

	First 10-week unit—Phase 2a		Second 10-week unit—Phase 2b	First and second 8-week units—Phase 3
	Attention	**Inhibition**	**Switching and simple verbal working memory**	**Complex working memory**
Adult's led interaction is focused on enhancing	Verbalization of stimuli Systematic visual exploration Sustained attention Selective attention	Maintenance of the task's goal Divided attention Selection of members of target categories	Rehearsal strategies Task planning and sequencing Focus on relevant information Semantic integration in sentence processing Summarizing the available information Anticipation of possible sources of difficulty Generalization of approach to different tasks	
Examples of computer-presented exercises and card games	• *Animal detective*: An incomplete picture appears on the computer screen and quickly disappears. The participant is asked to recognize the animal and then identify the lacking part of the picture, selecting it from four cards. • *Monsters*: An adult and child take turns in selecting one or more cards with monsters, describing their characteristics and communicating the precise location in which they put them. If the second player (who cannot see what the first is doing) makes the same choices as his/her companion does, the first player wins some points.	• *Characters detective*: A thief has been seen from people who describe his/her characteristics. Relying on each of such descriptions (e.g., "the thief was not a woman" or, "the thief did not wear glasses"), the participant removes images from a pool of suspects until the thief is identified. • *Category*: Each player has six cards and proceeds on a game of the goose board if he/she can play cards according to the category specified on the board box. Categories may be single or multiple (e.g., "food and furniture") and affirmative or negative (e.g., "no fruits, no clothes").	• *Guessing what*: The participant is asked to discover what the object hidden on the computer screen is by relying on the information provided by two types of characters. A wizard will say something that is opposite of the real characteristic (e.g., "if the wizard says that the thing is put on a lower part of the body, you have to think that it is put on an upper part of the body"). A pessimistic man will say something true but will add pessimistic evaluations that may distract you (e.g., "he will say that you wear this thing when it is hot, and he will add that if you do not do so, it may be very dangerous, and you can even die"). • *The dolphin game*: Players proceed with a game of the goose if they can repeat the sequence of words that has being said by the other player and add a new word according to the instruction specified on the board box. Boxes on the board ask for a fixed number of words (from 2 to 6) either starting with a given letter or belonging to a given category.	• *Stories*: Short narrative sequences are read by the adult and are also shown on the computer screen with the written text accompanied by a picture. For instance: "A hare was very proud of herself because she could run quickly. One day she said to all the other animals: - nobody is quicker than me; nobody has the courage to race with me-." After the last sentence is read, the short passage disappears from the computer screen, and the participant is asked to produce a pragmatic judgment (e.g., "is what the hare says friendly?") and then to recall the sentence. • *Take cards and remember*: Each player has three picture cards and can take one of four picture cards on the table, following the given rules (e.g., humans can take animals, animals can take plants or fruits, plants or fruits can take objects). At the end of the round, each player attempts to recall the word that was written on each of the taken cards (e.g., the word "surprise" written under the image of a birthday cake), and if he/she manages to do so, he/she wins the cards.

engaging inferential processes (e.g., guessing the place in which a short dialogue has occurred) after the content of a short passage had been encoded in episodic memory.

Each phase of the experimental training in our university lab consisted of 2-h weekly sessions that started with conversation and narrative talk to promote a close adult-child relationship and mitigate the shame feelings and self-undervaluation beliefs that are often present in children with ID. After such a warming stage, there was an exercise presented through PowerPoint and a card game that stimulated the target cognitive mechanisms of each phase (see **Table 2** for examples of exercises and games).

The Research Design

As our program combines core training (i.e., repeated practice involving target cognitive mechanisms) and strategy training, we started with a control condition that was only focused on strategy training and involved the visuo-spatial domain. As illustrated by **Figure 1**, in phase 1 Davide received home training based on the Feuerstein approach (Feuerstein et al., 2006) and centered on visuo-spatial activities (e.g., "Organization of dots"). Learning how to inhibit impulsiveness, develop visual strategies, maintain visual attention to details, work to reach precision, and analyze sources of facilitation in task execution were the main objectives pursued through the Feuerstein approach. As each activity of phase 1 stimulated both selective and sustained attention but there was no repeated practice related to inhibition of response or switching, we predicted an effect on attention but no effect on inhibition and switching after phase 1.

The home treatment started to be accompanied by our experimental cognitive training program in the university lab that first stimulated attention and inhibition (phase 2a), then switching and working memory with simple tasks (phase 2b). Thus, in phases 2a and 2b, there was a combination of two treatments, the first being the continuation of the home treatment and the second being the specific stimulation of inhibition and switching in the verbal domain. If training effects were affected by the specific core training introduced in phases 2a and 2b, we should observe a different trend of improvements between these two phases, with performance in inhibition and switching higher after phases 2a and 2b respectively.

In phase 3, Davide was only involved in our experimental cognitive training of working memory with complex tasks for two subsequent 8-week time units. Davide's performance with the listening span test was assessed at the beginning of this phase and then at the end of each treatment unit. Phase 3 allowed us to compare the effects of a specific stimulation of working memory with complex tasks (testings 6 and 7) with those generated by the preceding phases (testing 5). Eventually, after a 7-month delay in which Davide was involved in a treatment of academic learning (namely, arithmetic, and text comprehension) and social skills, a follow-up assessment was carried out to explore whether the effects observed immediately after our training units were long-lasting, independent from the experience of being repeatedly tested with the same tasks, and generalizable to a task-assessing cognitive flexibility that was completely different from the type of tasks used in the training.

Assessing the Immediate Effects of the Cognitive Training Program

Davide's assessment was carried out with Italian tests that either have been adapted from international tests (e.g., Nepsy II, Korkman et al., 2007) or have been designed in Italian (e.g.,

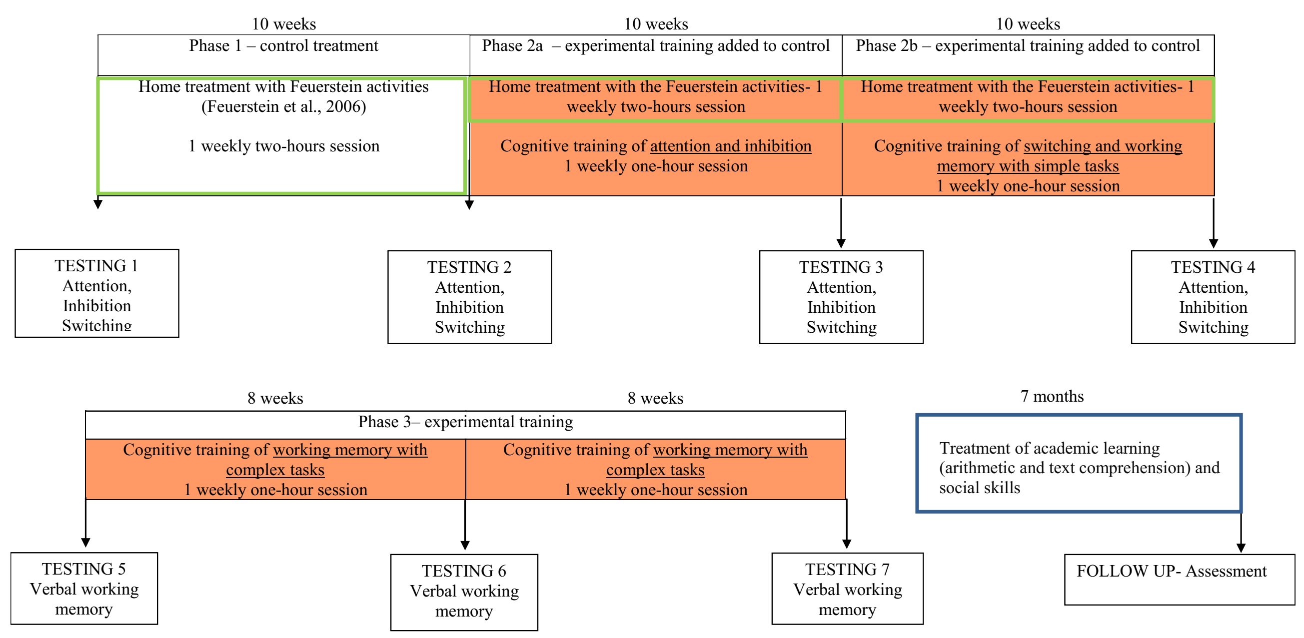

FIGURE 1 | The research design.

Attention by Di Nuovo, 2000). Each test used in our study has been validated with Italian participants and has good reliability.

Whereas Davide's initial assessment has been quite comprehensive, including different domains and abilities, the evaluation of the effects of our cognitive training program focused on attention, inhibition, switching, and verbal working memory.

Inhibition and Switching (Testings 1–4 and Follow-up)

In this timed test of the Nepsy II battery (Korkman et al., 2007), the ability to inhibit automatic responses in favor of novel responses and the ability to switch between response types is assessed. In the Naming phase of the task, the participant looks at a series of black and white shapes (circle and square) or arrows (pointing up and down) and names either the shape or the direction. In the Inhibition phase, the child names the same symbols but is asked to apply the non-target label (e.g., saying "square" for a circle or "up" for an arrow pointing down). In the Switching phase, the child is asked to say the correct name for black symbols but to apply the non-target label if the symbol is white (e.g., "down" for a white arrow pointing up or "circle" for a white square). The completion time and the total number of mistakes (including self-corrections) are evaluated for naming, inhibition, and switching.

Verbal Working Memory (Testings 5–7 and Follow-up)

Verbal WM was assessed with the Listening span test, an Italian adaptation (Pazzaglia et al., 2000) of the Daneman and Carpenter (1980) task consisting of sentences that are auditorily presented in blocks of increasing span (from two to six). The participant is asked (i) to judge the plausibility of each sentence (state whether it is true or false) and (ii) to recall the last word of each sentence, in the correct order, at the end of each block. The total number of words correctly recalled *in order* provides one type of score. For instance, if a subject is presented with a six-span block and recalls the last word of the third and fourth sentences in the right order, the score in this block would be 2. Further types of score are the number of errors with sentence judgements and the number of intrusion errors (recalling words that are not the last in the sentence).

Assessing the Long-term Effects of the Cognitive Training Program (Follow-up Testing)

Attention

Selective attention was evaluated using a task from a computerized battery (Di Nuovo, 2000). Participants are shown a sequence of numbers on the computer screen, and as soon as one of the numbers becomes surrounded by a red circle, they have to press the corresponding number on the computer keyboard; the reaction time and errors are evaluated.

Inhibition and Switching

Inhibition was evaluated with a test assessing interference control (Di Nuovo, 2000) through an adjustment of the classic Stroop test. The computerized test consists of two sequential tasks. The first is baseline condition—asking the participant to name colored squares—and the second is interference condition, asking the participant to name the ink color of the printed color words. The difference between the scores obtained in the first condition and second condition measures the subject's ability to overcome the distraction induced by irrelevant stimuli. Inhibition and Switching were also assessed with the Nepsy II test (see the description in the previous section).

Short-term Memory, Working Memory, and Episodic Memory in the Language Domain

A Forward digit span (Gugliotta et al., 2009), in which the examiner reads a list of numbers—a digit per second—and the participant must immediately repeat them back, was used to evaluate verbal short-term memory. The starting point in the task is a three-digit list, and the span is increased until the participant fails in all three lists of the same span. The score is the highest span in which the child manages to correctly repeat two out of three lists of that span. Verbal short-term memory was also tested with a word span using the first part of the test Word Interference from the Nepsy II. The child is auditorily presented with blocks of words increasing in span (from two to five) and is asked to repeat them in the same order. The number of blocks correctly repeated is the task score. Verbal working memory was assessed both with the Listening span test (see the description in the previous section) and a simple task, Backward digit span (Gugliotta et al., 2009), which is similar to a Forward digit span in the presentation of the items and score assignment, but at the end of each sequence, the child is asked to recall the presented digits in the reverse order.

Episodic memory was evaluated with Memory for Stories, a subtest of the Test of Memory and Learning (Reynolds and Bigler, 1994). Participants are asked to recall three short-story passages that were read by the examiner. Credit is given for each element of the story repeated correctly, irrespective of whether recall is verbatim or in a sequence that is different from the heard story. Only immediate memory was assessed.

Cognitive Flexibility

The test Animal Sorting from the Nepsy II (Korkman et al., 2007) was used to assess concept formation and the ability to shift from one concept to another. The child sorts pictures cards as quickly as possible into two groups of four cards each, using self-initiated criteria.

Results

Table 3A shows the results on selective and sustained attention assessed through the Bells test (Biancardi and Stoppa, 1997). Davide made a noticeable progress (almost one standard deviation on selective and about three standard deviations on sustained attention) after the home treatment with the Feuerstein activities (testing 2). As such activities promoted a systematic exploration of visual stimuli and a top-down search for characteristics (e.g., four equidistant dots) that can identify target shapes (e.g., a square), it is understandable that such activities enhanced attention. Davide's performance with selective and sustained attention continued to improve from testings 2–4 (see sustained attention improving of about one standard deviation in testing 3).

TABLE 3A | Effects of treatment on attention, inhibition, and switching.

	Testing 1	Testing 2*	Testing 3**	Testing 4***
Selective and sustained attention (*Bells*, Italian norms in Biancardi and Stoppa, 1997) analyzed with standard scores (chronological age norms)				
Number of targets identified in the first 30 s	−1.5	−0.46	−0.52	0.46
Number of targets identified in 240 s	−4.5	−1.59	−0.15	−0.31
Inhibition (Korkman et al., 2007) analyzed with percentile ranks and standard scores (chronological age norms)				
Errors—Percentile ranks	<2 (raw score: 7)	<2 (raw score: 8)	>75 (raw score: 0)	>75 (raw score: 0)
Completion time—Standard scores	−2.6 (raw score: 106)	−2 (raw score: 81)	−1.33 (raw score: 70)	−1.33 (raw score: 69)
Switching (Korkman et al., 2007) analyzed with percentile ranks and standard scores (chronological age norms)				
Errors—Percentile ranks	<2 (raw score: 46)	<2 (raw score: 26)	<2 (raw score: 13)	Between the 11th and the 25th percentile rank (raw score: 9)
Completion time—Standardized scores	1.33 (raw score: 59)	−2 (raw score: 118)	−2.6 (raw score: 175)	−2.6 (raw score: 157)

After 10 weeks of home treatment with Feuerstein activities; **after 10 weeks of the cognitive training program added to the home treatment; * after further 10 weeks of the cognitive training added to the home treatment.*

Turning to Davide's performance with inhibition, **Table 3A** shows that there was a remarkable change after the first 10 weeks of our cognitive training program (testing 3). Davide changed from being under the second percentile rank for correctness in testing 2, to being in norm in testing 3, whereas his completion time was still high but within normal limits in the same phase. Thus, only when a specific stimulation of inhibition was added to the Feuerstein treatment did Davide improve on a test assessing this type of executive function.

Results on switching are again suggestive of an effect of specific stimulation. Focusing on the initial assessment, Davide not only failed to maintain the task rules but also underestimated the task difficulty as he tried to be very quick. After the home treatment with the Feuerstein activities (testing 2), he still made an extremely high number of errors but seemed to realize that the switching task was difficult and required slowness. Only after the second phase of our cognitive training program, when switching had been specifically stimulated (testing 4), did Davide's performance on switching improve for correctness, whereas the completion time was still much higher than chronological age norms.

Turning to the findings concerning verbal working memory in **Table 3B**, an improvement occurred after the 30 weeks of treatment. Davide's performance with the listening span test shifted from being only focused on providing judgments of sentences' plausibility in the initial assessment to accommodating the dual task request in testing 5. Despite such progress, Davide's performance was still extremely low in terms of number of words correctly recalled in order, and the intrusion errors were exceedingly numerous. However, after only 8 weeks of training that stimulated verbal working memory with complex tasks (see testing 6 in **Table 3B**), Davide's improvement increased by more than one standard deviation from the previous testing. In terms of raw scores, whereas Davide had changed from recalling 0 words to correctly recall 7 words after the first 30 weeks of treatment, he improved on 8 more words (from 7 to 15 words correctly recalled in order) after 8 weeks of specific training. After a further 8 weeks of training, the number of words correctly recalled slightly decreased (see testing 7), whereas performance with both intrusion errors and sentence judgments further improved in this last assessment.

Despite the noticeable improvements, difficulties in carrying out a dual task asking to semantically process sentences and to memory-encode some target information were still present. We should remember that Davide was 15 years old in testing 7, whereas the highest age level in the Italian listening span test is 11–13. More than fifty percent of the subjects in the test's normative sample made 0–1 intrusion errors (Pazzaglia et al., 2000). As such types of errors consist in recalling words that do not occupy the sentence ending position (e.g., recalling "football" instead of "mountain" for the sentence *Football is a sport that you can only practice in a high mountain*), it is clear that the high number of intrusion errors still produced by Davide in testing 7 was an indicator of difficulties in inhibiting irrelevant information.

Listed in **Table 4** are the scores that are more than two standard deviations below mean, or at the fifth percentile, before and after the control treatment (testing 2), the training stimulating attention, inhibition and switching (testings 3–5), and the training stimulating WM with complex tasks (testings 6–7). We applied to this list of performances evaluated with standard scores or percentile ranks the line of reasoning that Parker et al. (2007) considered for raw scores when they defined the "percent of all non-overlapping data" (PAND) as the percent of all data remaining after removing the number of data points that overlap between a baseline and an intervention phase. Applying this same argument, we asked how many "deficit" scores on tests assessing the cognitive mechanisms that were the target of our training did not overlap before and after intervention. Only sustained attention improved above the criteria level after the control treatment (testing 2); there were three out of eight overlapping data after experimental training of attention, inhibition, switching, and working memory with simple tasks. The switching completion time, and two scores of the listening span test, remained in fact below the criterial level in testings 3–5. After experimental training of working memory with complex tasks (testing 6–7) the number of words correctly recalled in order in the listening span test improved above the criteria level in the first treatment

TABLE 3B | Effects of treatment on verbal working memory analyzed with standardized and raw scores (listening span test, Pazzaglia et al., 2000).

	Testing 1	Testing 5*	Testing 6**	Testing 7***
Number of words correctly recalled in order	^^	−3.12 (raw score: 7)	−1.57 (raw score: 15)	−2.28 (raw score: 12)
Number of errors in judging sentences plausibility	−2.47 (raw score: 8)	−0.89 (raw score: 4)	−1.29 (raw score: 5)	−0.10 (raw score: 2)
Number of intrusion errors	^^	−9.17 (raw score:13)	−6.90 (raw score:10)	−4.90 (raw score: 7)

*After 30 weeks of treatment focused both on Feuerstein activities and training of inhibition, switching and working memory with simple tasks; ** after 8 weeks of training with complex memory tasks; *** after further 8 weeks of training with complex memory tasks.

^^The test asks to recall the last word of each sentence in blocks of increasing length (from 2 to 6 sentences) but Davide did not try to recall one word and for this reason he did not make intrusion errors either.

TABLE 4 | List of Davide's performances before and after different phases of treatment.

	Initial assessment	Control treatment (Testing 2)	Experimental training added to the control treatment (testings 3–4, 5)	Experimental training only (testings 6–7)
Scores that are 2 standard deviations below mean (or below the 5th percentile)	• Sustained attention • Inhibition errors • Inhibition completion time • Switching errors • Switching completion time • Number of words correctly recalled in sequence * • Errors in judging sentence plausibility* • Intrusion errors**	• Inhibition errors • Inhibition completion time • Switching errors • Switching completion time	• Switching completion time • Number of words correctly recalled in sequence • Intrusion errors	• Intrusion errors
Scores that are within normal limits (less than 2 standard deviations below chronological age mean or above the 10th percentile)		• Sustained attention	• Inhibition errors • Inhibition completion time • Switching errors • Errors in judging sentence plausibility	• Number of words correctly recalled in sequence

*These performances were evaluated in the initial assessment and then in testings 5–7.

**We infer that these errors would correspond to the deficit range in the initial assessment, as Davide was only able to judge sentence plausibility but did not recall any word in the listening span test.

unit (testing 6), whereas intrusion errors remained below the criterial level. Pooling together the number of scores improving after the different phases of experimental training, there were six out of eight non-overlapping data. Percentage of non-overlapping data (PAND) for our experimental training was therefore 75%.

Turning to the results of the follow-up testing that was run when Davide was 15 years old, it can be observed in **Table 5** that after 7 months in which there was no specific exercise of attention, inhibition, switching, and verbal working memory, a number of training effects were still observable even when they could be assessed through tasks that were different from the ones used throughout the treatment phases. Selective attention was tested with a computerized task and was in norm; interference control was also tested with a computerized Stroop test and was in norm for both errors and reaction times. Inhibition and switching were again tested with the Nepsy II tasks and were in norms in terms of correctness, but below norms for completion times.

Performance with the listening span test was within the norms of junior school children (age range: 11–13) in terms of a number of words that were correctly recalled in sequence and correct sentence judgments, whereas intrusion errors were still much above the mean of the same age range.

The long-term sustainment of improved performances in the listening span test were not accompanied either by an improvement of verbal short-term memory (see standard scores of direct digit span and word repetition in **Table 5**), nor by a better episodic memory.

The follow-up testing showed an improvement in Davide's cognitive flexibility. His performance in Animal Sorting test (Korkman et al., 2007) shifted from 2.6 to 1.6 standard deviations below the chronological age mean. This test asks participants to sort pictures into two groups of four using various self-initiated sorting criteria and engages both concept formation and shifting.

Recapitulating the Findings of Different Testing Phases

In the current study, we assumed that attentional control and executive functions of inhibition and switching are all involved in verbal working memory, and for this reason we structured a complex treatment that stimulated such functions

TABLE 5 | The initial and follow-up assessments analyzed with standard scores or percentile ranks (comparison with chronological age norms unless specified otherwise in the table).

		Initial assessment (age: 14 years and 2 months)	Follow-up assessment (age: 15 years and 10 months)
ATTENTION			
Selective attention (Di Nuovo, 2000)			
Errors		−0.66	−0.66
Reaction times		−3.5	−1.42
INHIBITION AND SWITCHING			
Interference control (Stroop Test, Di Nuovo, 2000)			
Difference between baseline and condition with interference—Errors		−0.34	−0.34
Difference between baseline and condition with interference—Reaction time		−2.4	0
Inhibition—Nepsy II (Korkman et al., 2007)			
Errors		Below the 2nd percentile rank (raw score = 7)	Between the 51st—75th percentile rank (raw score: 1)
Completion time		−2.6	−2
Switching—Nepsy II (Korkman et al., 2007)			
Errors		Below the 2nd percentile (raw score: 46)	Above the 75th percentile rank
Completion time		1.33	−2.33
SHORT-TERM MEMORY, WORKING MEMORY, AND EPISODIC MEMORY IN THE LANGUAGE DOMAIN			
Short-term memory			
Direct digit span (Gugliotta et al., 2009)		−0.1 (raw score: 5)	−1.7 (raw score: 4)
Word repetition (from Word list interference)—*Nepsy II* (Korkman et al. 2007)		−1.3 (raw score: 14)	−0.66 (raw score: 16)
Working memory			
Backward digit span (Gugliotta et al., 2009)		−1.26 (raw score: 3)	−1.13 (raw score: 3)
Listening span test (Pazzaglia et al., 2000)*	Number of words correctly recalled in order	^^(raw score: 0)	−0.76 (raw score: 21)
	Number of errors in judging sentences plausibility	−2.47 (raw score: 8)	−0.10 (raw score: 2)
	Number of intrusion errors (recalled words that do not occupy the sentence ending position)	^^	−3.89 (raw score: 6)
Episodic memory			
Recall of stories (Reynolds and Bigler, 1994)	Number of recalled content units	1st percentile (raw score: 14)	9th percentile (raw score: 29)
COGNITIVE FLEXIBILITY			
Animal sorting—Nepsy II (Korkman et al., 2007)	Total Correct Sorts	−2.6 (raw score: 2)	−1.6 (raw score: 4)

^^*The test asks to recall the last word of each sentence in blocks of increasing length (from 2 to 6 sentences) but Davide did not try to recall one word and for this reason he did not make intrusion errors either.*
**Comparison with children aged 11–13, that is the highest age level of the test norms.*

before engaging the ability to address verbal dual tasks. Davide's training started with a control condition based on the Feuerstein approach (Feuerstein et al., 2006) and centered on visuo-spatial activities. As learning how to inhibit impulsiveness, maintaining visual attention to details, and working to reach precision were pursued in these activities, Davide showed a remarkable increase in sustained visual attention after this control treatment phase, but did not show improvements in his severely impaired performances with the inhibition and switching tests. After our experimental cognitive training program focusing on attention and inhibition was added to the treatment with the Feuerstein activities, Davide's performance with sustained attention continued to improve in about one standard deviation—whereas performance with inhibition changed from being under the second percentile rank for correctness and two standard deviations below norms for completion time—to being in the norm for correctness and still low but within normal limits for completion time.

Again, only after our experimental cognitive training program stimulated switching in the subsequent phase did Davide's performance on switching changed from being severely incorrect to being within normal limits for correctness, whereas his completion time was still much below chronological age norms.

When verbal working memory was assessed again after this combined treatment phases, Davide's performance was still severely impaired; although, he managed to accommodate the dual task request. After the first 8-week unit of training with complex working memory tasks, Davide was evaluated again with the listening span test. The number of words that were correctly recalled in sequence was low but close to normal limits, the number of errors in judging the sentences' plausibility was within normal limits whereas intrusion errors were still very high. In the second 8-week unit of training, Davide's performance slightly decreased for the number of words correctly recalled but improved for the other two parameters.

Overall, there were six out of eight scores that shifted from being more than two standard deviations below the chronological age mean (or below the fifth percentile rank) in the initial assessment to being either within or close to normal limits after the specific stimulation of target cognitive mechanisms introduced in each phase of Davide's experimental treatment.

Effects of Training or Repeated Testing?

Although these findings are very encouraging, how can we rule out that increasing exposure to tests, rather than training, was the factor generating changes of target cognitive mechanisms?

First, the findings described in the previous section suggest that a predicted change in the dependent variable covaries with manipulation of the independent variable (Kratochwill et al., 2010). In other words, improvements of specific cognitive functions were observed only after a phase in which a specific stimulation of that function had been introduced. Second, most of the observed improvements were maintained in the follow-up assessment, after 7 months in which attention, inhibition, switching, and verbal working memory had not been tested anymore. Third, the same experimental cognitive training program in which Davide was involved produced similar effects in a multiple case study in which such training was implemented in a more intensive way and contrasted with a control training (Orsolini et al., 2014). In such a study, six children with ID or "borderline intellectual functioning" were tested before and after a 10-week treatment, consisting of either our experimental program or a control training focused on narrative skills. Each child in this study was tested twice, and we found that each of the three children involved in the experimental program improved by at least one standard deviation in the listening span test, whereas only one of the three children participating in the control group showed a similar improvement.

Thus, the findings of the current study suggest that a combined intervention, in which a core training of specific cognitive mechanisms interacted with teaching a strategic approach to task execution, was effective in improving Davide's cognitive performances. Although our research design did not allow us to assess which of the different training components was responsible of the observed effects, it seems to us that the applicative goal of designing an effective intervention was attained.

Near Transfer Effects

Turning to the findings concerning "transfer effects," our experimental cognitive training program, unlike most other types of working memory treatments, consisted of highly varied activities never involving the same type of verbal processing (i.e., judging semantic plausibility) or to-be-memorized-units (i.e., the last word of each sentence) required by the listening span test. Thus, Davide's improved performance with the listening span test was a reflection of "near" transfer to an untrained task.

We should also emphasize some absence of near transfer effects emerging from the follow-up assessment, the first consisting of a lack of improvements with backward digit span and the second of a very low increase of episodic memory. Lack of training effects on performance with backward digit span may be explained by taking into account that Davide did not practice at all the specific type of processing (i.e., repeating items in the reverse order) involved in backward digit span in our cognitive training program. As such, lack of practice had a negative impact on his post-test performance. This suggests that working memory ability, though improved, was not sufficient to prevent the child's difficulty with a type of verbal processing that he had not been practicing.

Turning to episodic memory, the very low improvement of performance in a narrative memory task may suggest that the episodic buffer—although the target of some complex working memory activities in our program—was not affected by training. According to Baddeley (2000), this particular working memory component depends on executive processing, but is primarily concerned with the storage of information rather than with attentional control. It is not clear yet to what extent binding together information from different sources into chunks or episodes depends on activation of concepts and schemas from long-term memory or from a fluent coordinated working of executive processing, as well as visual and verbal short-term storage. The results of a study by Hambrick and Engle (2002)—which showed that knowledge of the topic influenced performance on retention of narrative passages much more than working memory—should be considered in interpreting Davide's performance on narrative memory. Such performance might have been more related to lack of expert knowledge on the stories' topics than to verbal working memory. Alternatively, the low modifiability of Davide's narrative memory may suggest that binding together information from different sources is a structural impairment for some individuals with intellectual disability, and is therefore very resistant to intervention. A deficit in binding together information may not impair performance when the instructions enforce both attentional control and explicit memory encoding, which occurs in the listening span test. Such a deficit is likely to generate an extremely poor episodic memory when the task does not have these characteristics, as when the instructions ask participants to listen to a story for later recall. This point deserves further exploration in future research as the binding of information into chunks or episodes is of the greatest importance in learning, and a deficit in this area may shed a less optimistic light on the transfer effects that can be generated by a more effective working memory in individuals with intellectual disability.

Far Transfer Effects

Our study also explored whether "far transfer" effects of our combined treatment can be generated on cognitive flexibility that was assessed with a task engaging both concept formation and shifting (i.e., Animal Sorting from the Nepsy II). We found that Davide's performance in this task increased of one standard deviation in the follow-up testing. Thus, there was a slight far transfer effect to more flexible processes of concept formation

TABLE 6 | A dialogue between Davide and the therapist (MO).

The excerpt is from a conversation focused on choosing a new professional high school after a first year in which Davide attended a professional school that he did not like. The doubt has to do with whether to move to the first-year class or second-year class of the new school.

- Therapist: Beh, se ricominci dal primo anno avresti due anni di più dei tuoi compagni (Davide è andato a scuola un anno più tardi).

Well…if you start again from the first class you will find mates that are 2 years younger (Davide started primary school 1 year later than his peers did.)

- Davide: Tanto non-importa, tanto anche se c'ho due anni in più, gli altri sono sempre più intelligenti.

Well…It does not matter, even if I'm 2 years older…the others are always more intelligent.

- Therapist: Che cosa? Che hai detto? (scherzando, marcando esageratamente le espressioni del viso)

What? What did you say? (joking and with marked visual expressions)

- Davide: Che anche se c'ho due anni in più, gli altri sono sempre più intelligenti.

That even if I am 2 years older than my mates they are always more intelligent.

- Therapist: Tu pensi questo? Pensi questo?

Are you really thinking this? Do you think this?

- Davide: (sorride)

(he smiles)

- Therapist: Sono più intelligenti in tutto?

Are they more intelligent in everything?

- Davide: Sì. (sorride)

Yes. (smiling)

- Therapist: (Abbassa la testa e fa un lungo sospiro.) Ma io vorrei sapere perché…noi lavoriamo tanto e tu però pensi sempre queste cose negative, Davide.

(She lowers the head and sighs.) Davide, I would like to know why…we are working so much and you are still thinking such negative things of yourself.

- Davide: Non lo so. (sorride)

I do not know. (smiling)

- Therapist: Ma tu spiegami una cosa, non c'è una cosa in cui ti senti intelligente?

But tell me, is there a thing in which you feel you are intelligent?

- Davide: Quando faccio le cose da solo mi sento intelligente.

When I do things by myself I feel I am intelligent.

- Therapist: Ah…e come mai allora?

Ah, and why then?

- Davide: Quando non so le cose non mi sento.

When I do not know things I do not feel so.

- Therapist: Ah, quando non sai le cose pensi "non sono intelligente." Invece non è che pensi "non so le cose perché le devo ancora imparare." Non è che pensi che puoi imparare, non lo pensi mai questo, che puoi imparare?

Ah, when you do not know things you think "I'm not intelligent." But you do not think "I do not know things because I still have to learn them." You do not think you can learn, do you? Do you ever think that you can learn?

- Davide: Non l'ho mai pensato. (sorride)

I never thought this. (smiling)

and shifting. Moreover, as the scores in the Animal Sorting test correlate most highly with Matrix Reasoning (0.49, as reported in Korkman et al., 2007, p. 89), an increased capability of addressing problem-solving tasks may complement the increase in cognitive flexibility.

In our opinion, Davide's improvement in concept formation and shifting should be interpreted as related not only to the enhanced cognitive mechanisms but also to the more benevolent beliefs about himself that started to emerge in the conversations occurring in the initial stage of our cognitive training sessions (Fatigante et al., 2015). It is well known that holding either a fixed or an acquirable view of intelligence deeply affects a student's performance on learning tasks (Mangels et al., 2006). Individuals with fixed view of intelligence are more likely to avoid learning situations where they anticipate a high risk of errors. In tasks such as Animal Sorting, in which participants are asked to think of different possible ways for grouping images that are quite dense in visual details, individuals who do not trust their own thinking and problem-solving abilities are likely to have a poor performance.

Although Davide still tended to present himself as a non-intelligent person after almost 2 years of intervention, he could smile while saying "I'm not intelligent," and somehow waited for the therapist's questioning of such "old" belief (see the dialogue reported in **Table 6**). Contrary to this, in the initial dialogues, he positioned himself as hostile, helpless, or discouraged toward his reasoning abilities. Davide has been constantly reminded of the idea that intelligence is a kind of power that is within every human being and that manifests itself thanks to the help of a wide range of more-specific abilities, such as attention, language, and memory.

Concluding Remarks

This study explored the effects of training in which attention, inhibition, switching, and the ability to engage in elaborate processing and memory encoding with verbal tasks were stimulated. The main finding was that Davide, a 14-year-old boy with a mild intellectual disability, shifted from being incapable of addressing a verbal dual task such as the listening span test to having a performance close to the normal limits of a 13-year-old boy in the follow-up assessment with this test, when he was 15 years old. It should be emphasized that Davide's initial verbal short-term memory was low but within normal limits, whereas his ability to carry out dual working memory tasks was completely absent. Thus, our study shows on one hand a very encouraging finding, as deficits in verbal WM are often deeper than visuo-spatial deficits in children with intellectual disabilities (Henry and MacLean, 2002; Van der Molen et al., 2009; Soderqvist et al., 2012). On the other hand, such a good response to intervention on verbal working memory is likely to be also related to a specific individual characteristic: that of a verbal short-term memory that was not severely impaired.

The findings of our study induce an optimistic view of the cognitive modifiability of verbal working memory in children with intellectual disability, but more evidence is needed on the individual characteristics that may predict a good response to intervention. Further investigation is also required to analyze the far transfer effects of improved verbal working memory, clarifying whether or not a range of cognitive processes—from concept formation to discourse comprehension and verbal reasoning—can be positively affected.

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Effect of training focused on executive functions (attention, inhibition, and working memory) in preschoolers exhibiting ADHD symptoms

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The development of early intervention strategies for children with symptoms of Attention Deficit Hyperactivity Disorder (ADHD) is important because it provides an opportunity to prevent severe problems in the future. The main purpose of this investigation was to determine the efficacy of a group training for the control of attention, working memory and impulsive behaviors, involving 5-year-old children with ADHD symptoms. Twenty-six children with ADHD symptoms and 26 with typical development were randomly divided in two conditions. Thirteen children in each group were assigned to the training condition and the other to the business as usual condition (normal class activity). Children who participated in the intervention showed an improvement in the tasks measuring their control of attention, impulsive behavior, and working memory. Moreover, children with typical development who attended the training also improved their competencies. The results confirm the importance of an early intervention for preschool-age children with ADHD symptoms.

Keywords: ADHD, preschool children, training, executive function, attention, impulsive behavior, working memory

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Introduction

Although it is well-known that ADHD symptoms are linked to a biological predisposition and are often evident during a child's first few years, the assessment procedures and the subsequent treatment are usually administered when children are well along in the primary grades and have probably been exposed to negative experiences. As a consequence, their ADHD symptoms could have been emphasized by school, failures, and social exclusion. These considerations can make the disorder more resistant to psychological treatment. It is therefore important to consider children younger than six who show ADHD symptoms helping them with an early intervention, as also suggested by previous research showing the impact of the early presence of ADHD symptoms (Sonuga-Barke et al., 2006) and of early intervention (Young and Amarasinghe, 2010) on subsequent growth.

The present study is focused on the effects of an early intervention on executive functions (EFs). EFs are a set of general-purpose control processes that regulate one's thoughts and behaviors (Miyake and Friedman, 2012), inside of this set we have different skills and abilities like working memory, capacity to suppress inappropriate responses or behaviors, and to shift between different activities. As it is well known from literature, ADHD children have weaknesses in their EFs like attentional control, working memory, and inhibition. In particular important meta-analyses showed impairment of ADHD children in several EFs (e.g., Reid et al., 2005; Willcutt et al., 2005). For example, the meta-analysis of Martinussen et al. (2005) highlighted an ADHD impairment in working memory that was greater in visuo-spatial working memory than in the verbal one. In particular, some studies have found weaknesses in executive functions also in pre-school children who exhibit symptoms of ADHD (Mariani and Barkley, 1997; Schoemaker et al., 2012; Sinzig et al., 2014).

Sonuga-Barke et al. (2002) examined a large sample of pre-schoolers with ADHD and found specific difficulties in the inhibition capacity, planning, and working memory. More recently Re et al. (2010) compared a group of 23 kindergarten children characterized by the presence of ADHD symptoms, and one group of 23 children matched for gender, age, and socioeconomic status, in a visuo-spatial working memory task which required the selective recall of information. Authors found that children with ADHD symptoms performed more poorly than controls and were affected to a particularly high extent by intrusion errors (i.e., recalling of information initially encoded but that needed to be consequently suppressed during the task). In sum, from literature we can argue that executive functions are already impaired in pre-schoolers with symptoms of ADHD and are crucial in the children's development as they may offer the basis for the self-regulation requests present in later years (Diamond, 2012), suggesting that they could be the object of an early treatment devoted to reduce the presence of ADHD symptoms.

Despite the potential advantages of an early intervention on young children who exhibit ADHD symptoms, intervention studies on children with ADHD symptoms who are younger than six are few. A first reason of this concerns their identification, as symptoms of ADHD at young ages may be unclear, reflect other problems, or simply be due to maturation variations and delays. A second problem concerns the practical and social limitations that interventions on young children with ADHD may meet.

In general, it seems important to devise intervention projects that support young children with ADHD symptoms by possibly involving not only the children but also their schools and families (Sonuga-Barke et al., 2001; Young and Amarasinghe, 2010; DuPaul and Kern, 2011). A recent meta-analysis (Rajwan et al., 2012) found 29 intervention studies on young children, but they mainly concerned parent training (10), teacher training (3), diets (2), nutritional supplements (1), and acupuncture (1). Only four studies considered a direct psychological intervention for the children. This confirms the need of evidence on interventions directly involving children that is also evident at older ages (Evans et al., 2013).

Interventions, that aim directly to teach children some skills to regulate their behavior, are mainly focused on cognitive-behavioral strategies, either starting from external verbal prompts given from an adult trainer and moving towards an internal self-statement made by child, or using contingence analyses and reinforcement techniques without deeply considering the associated neuropsychological problems.

However, there are a few studies on pre-school children involving intervention on EFs (Bergman Nutley et al., 2011; Röthlisberger et al., 2012). In particular, Re and Cornoldi (2007) conducted a pilot study on 5-year-old children with ADHD symptoms and they found that an intervention on attentive control and working memory improved their executive functions and reduced the presence of ADHD symptoms. These results were substantially replicated by another pilot study carried out with first-graders with symptoms of ADHD (Salvaguardia et al., 2009). However, these two studies were preliminary and could not control for a series of intervening variables and for the possibility of carrying out an intervention in the context of everyday school activities. Thorell et al. (2009) investigated the effects of two different trainings, one specific for working memory and the other one for inhibition. Preschool children received computerized training of either visuo-spatial working memory or inhibition for 5 weeks and were then compared with an active control group that had played commercially available computer games, and a passive control group. The results of the study suggested that working memory training can have significant effects also with preschool children and be more effective than inhibition training. Finally, a study with an intervention program on EFs with ADHD children aged between 4 and 5 years was carried out by Halperin et al. (2013). Children and their parents participated in separate group sessions where they played games designed to enhance inhibitory control, working memory, attention, visuo-spatial abilities, planning, and motor skills. Parents were also encouraged to play these games with their children at least 30–45 min/day. It was found that parents and teachers ratings about severity of ADHD symptoms decreased significantly from the pre to the post test.

In sum, studies on cognitive intervention on children's EFs are showing good improvements. However, but more evidence is needed on specific programs and condition following a protocol that permits repeatable results (Rapport et al., 2013), and on psycho-educational interventions for young children may be carried out at schools, possibly in groups, and in the context of everyday activities. The preliminary available evidence (DuPaul and Kern, 2011) seems promising and shows the long-term effects on the prevention of associated behavioral disruptive problems (Kern et al., 2007).

The present study intends to examine more systematically the effects of the training of executive functions, in particular attentive control, inhibition and working memory, carried out in the context of school activities with groups of preschoolers, including not only children with ADHD symptoms but also typically developing children (TD children). In fact, schools typically require that interventions are carried out during the everyday activities and potentially interest all children. In this way we had the advantage of testing the efficacy of an intervention deeply rooted in the schools settings and immediately replicable, but also the disadvantages of necessarily accepting the requests present in schools: in this case the information and involvement of teachers and the adoption of an inclusion model where children in difficulty work together with children without problems. We hypothesized that a group training of executive functions (in particular impulse control, controlled attention, and working memory) carried out within the routine day activities of a kindergarten and interesting at the same time children with ADHD symptoms and TD children could be well accepted by children, school, and parents and could improve children's executive functions, possibly also reducing ADHD symptoms.

Materials and Methods

Participants

Children Exhibiting ADHD Symptoms

The sample consisted of 26 children attending their last year of pre-school (kindergarten) and who exhibited ADHD symptoms but without a diagnosis, due to the fact the Italian guidelines on ADHD suggest to avoid the complete assessment and the diagnosis before six. Children were considered as exhibiting ADHD symptoms on the basis of information collected from teachers and a validated rating scale for teachers, the IPPDAI "Identificazione Precoce del Disturbo da Deficit di Attenzione/iperattività per Insegnanti" ("Early Identification of ADHD for Teachers," Re and Cornoldi, 2009), and on the basis of information collected from parents through interviews and another rating scale whenever possible (IPDDAG, Re and Cornoldi, 2009).

The IPDDAI includes 14 items referring to symptoms described both by DSM-IV and DSM-5 (American Psychiatric Association, 1994, 2013) identified as the most predictive of ADHD in preschoolers, seven concerning inattention (items 1, 2, 4, 5, 12, 13, and 14), seven concerning hyperactivity/impulsivity (items 3, 6, 7, 8, 9, 10, and 11), and four additional items (15, 16, 17, and 18) concerning risk factors, i.e., the fact of "coming from a disadvantaged family" (item 15), "having problematic situations at home" (item 16), "having poor cognitive abilities" (item 17), and "having emotional and relational problems" (item 18). The IPDDAI scale has been validated and standardized for the Italian population. Test–retest information is only available for the version for older children ($r = 0.80$) but, in a study correlating the IPDDAI scores given by kindergarten teachers with the identification of ADHD symptoms 1 year later by primary school teachers, Marcotto et al. (2002) identified a positive correlation of $r = 0.56$. Moreover, IPDDAI scores appear to be highly correlated with the ADHD score obtained with the Conners' scale for both inattention ($r = 0.88$) and hyperactivity ($r = 0.84$; Trevisi and Re, 2008). The IPDDAG scale has the same structure of IPDDAI but refers to home situation.

Teachers and parents indicated the presence of each behavior by using a 4-point Likert scale, ranging from 0 to 3 (0 = behavior never present/not at all, 1 = behavior sometimes present, 2 = behavior often present, 3 = behavior always/very much present). After combining the values of the seven ratings into two subscale scores, the children of the ADHD group had a score greater than 11 (corresponding to the 10° percentile) either in the attention or in the hyperactivity subscale of IPDDAI or both.

The children with ADHD symptoms were randomly assigned to two conditions as follows: 13 children (eight boys and five girls, mean age = 63.42, SD = 4.98) were included in the experimental training (hereafter referred to as the training condition) and 13 (nine boys and four girls, mean age = 63.03, SD = 4.40) in the non-training condition where children had business as usual or activities devoted to develop literacy. Children of both groups had similar scores on the IPPDAI rating scale: training group inattention, $M = 11.23$ (SD = 3.41); hyperactivity, $M = 10.57$ (SD = 5.35); control group inattention, $M = 11.04$ (SD = 4.83); and hyperactivity $M = 11.8$ (SD = 4.61).

Typically Developing Children

As schools required that children should be trained within an integration perspective that did not isolate the children with problems, children with ADHD symptoms were trained together with typically developing children (TD, with an IPPDAI score of below 3, i.e., $>50°$ percentile). Therefore, we individuated 26 TD children; of these 13 (five boys and eight girls, mean age = 65.15, SD = 4.498) were randomly assigned to the training condition and 13 to the non-training condition (six boys and seven girls, mean age = 65.61, SD = 4.21). In the selection of the TD children, who had to be included in the groups, we had to decide whether to maintain the same proportions of males and females present in the ADHD symptoms groups (with a larger presence of boys) or to have more homogeneous groups by compensating the proportion of males and females, by including a larger number of girls. As the study design did not include comparisons between children with ADHD symptoms and TD children (but only between treated and untreated children), after a discussion with the teachers, we decided for the second alternative.

For all students involved in this investigation, we received appropriate approvals from their parents and schools. This study was carried out in accordance with the recommendations of "the ethic committee of the University of Padova."

Based on the outcomes of IPDDAI and on interviews with the teachers, children with low socioeconomic status, poor intellectual abilities (as measured by the IPDDAI specific control items), family or other relevant problems, and finally children that belonged to foreign communities were excluded from the sample. All the students were Caucasian; had no physical, sensory, or neurological impairments; spoke Italian fluently; and had grown up in an adequate socio-cultural environment.

Procedure

The procedure was defined on the basis of schools' constraints. In particular, after the administration of the teachers' rating scale and before the training, we were allowed to administer to all children a stop-signal test (Walk–No Walk Test [Ranette], Marzocchi et al., 2010). Furthermore, because we involved two different schools in the project, we were allowed to administer a second executive test, but this test was different in the two schools, according to their requests. In one school, a working memory test (the Dual Request Selective Task; Re and Cornoldi, 2007), and in the other one, an impulsivity control test was administered (Matching Figures MF-14; Marzocchi et al., 2010). The assessment was followed by 17 one-hour sessions distributed over a 9-week period, twice a week for the training group interested in executive functions and for the control group interested in the empowerment of cognitive functions, according to the usual school practices. One week after the end of the training, the teachers were invited to complete the IPDDAI again and the same measures collected before the trainings were recollected.

Walk–No Walk Test (Ranette; Frogs)

The Walk–No Walk Test ([Ranette], Marzocchi et al., 2010) is a paper-and-pencil test that evaluates control of attention and the inhibition of an ongoing response. It is derived from the "stop signal task" of Logan and Cowan (1984). The task requires children to follow a series of directions and stop an ongoing response when a particular event (a signal) occurs.

The test includes two A4 sheets of paper in which 20 stairs (one for each trial) are drawn with a little frog on the first step. The child is asked to cancel a step each time he or she hears the GO signal, while she/he has to stop every time she/he hears the STOP signal. The STOP signal is very similar to the GO signal but is different in its ending. Obviously, for every trial, there are many GO signals and only one STOP signal. The difficulty of this task is that the STOP signal is made in two parts, and the first part has the same sound as the GO signal. Therefore, the child must wait to hear the entire sound before providing the response in order to understand if it is a GO or STOP signal. The score is defined by the number of correct trials. Test–retest reliability of the test is $r = 0.70$.

Supplementary Assessment

The Working Memory Dual Request Selective Task (DRST)

The Dual Request Selective Task (DRST; Re and Cornoldi, 2007; see also Lanfranchi et al., 2004) is a visual spatial working memory task that assesses the ability to control information maintenance in working memory and to inhibit irrelevant information. The test is based on a 4 × 4 matrix (17 cm × 17 cm), divided into 16 cells. The matrix is blank with a red square always situated in the same position. DRST requires the children to perform a double task:

(1) Remember the first position indicated by the experimenter.
(2) Clapping hands when the experimenter indicates the red square.

To make the task more attractive, a small plastic frog is shown moving into the matrix.

There are 10 trials in order by difficulty level. Difficulty depends on the number of cells touched by the frog (length of the pathway) from a minimum of two to a maximum of six cells. There are two trials for each length level. The child must complete the entire task.

A trial is considered correct only when the child carries out both tasks correctly; in other words, clapping and remembering the first position. Also errors are considered in the task as they seem to represent a specific element of weakness in the case of children with ADHD symptoms (Cornoldi et al., 2001). Average time for this task is 10 min.

Cronbach alpha reliability for this test is high (0.84, according to Lanfranchi et al., 2015).

MF 14

The MF-14 test (Marzocchi et al., 2010) is derived from the impulsivity control MFFT test (Kagan, 1966). It assesses several executive components and, in particular, sustained attention and impulsivity control. The test consists of 14 items that include a target picture and six alternative pictures similar to the target. Among these pictures, only one is exactly like the target. The child has to identify the picture that is just like the target. The pictures represent everyday life objects. For the scoring of this test two parameters are considered:

- Number of errors.
- Response time (i.e., the time of the first response) that is assumed to represent a form of impulsivity.

Despite the fact that test–retest reliability collected in different studies and reported in the Manual (Marzocchi et al., 2010) is moderate both for errors (ranging between 0.49 and 0.60) and for response time (ranging between 0.41 and 0.50), the test has been validated and successfully used in a large number of studies (see Marzocchi et al., 2010).

Training

The training consisted of 17 sessions, each lasting 1 h, administered twice a week to the whole group of children (with ADHD symptoms and TD) separately for each school. The training (for some examples, see Re and Cornoldi, 2007) used activities presented in the published manual *Sviluppare la concentrazione e l'autoregolazione* (*Development of Concentration and Self-Control;* Re and Cornoldi, 2007; Caponi et al., 2008, 2009a,b) and was carried out by trained psychologists one per school. The activities proposed to the children can be divided in four main blocks:

(1) *Block 1:* The first two units introduced the behavioral strategies to maintain control and stay on task. The focus of these units was on the correct behaviors favoring the maintenance of attention (such as the right posture, inhibition of impulsive movements, focalization of the vision), self-control (monitoring of comprehension and attention), the control of the impulsive response ("don't give a hurried answer," "think and wait your turn before answering"), and maintenance and control of information in working memory. A nursery rhyme and a dummy were presented at the beginning of every unit to indicate the beginning of the specific activity.
(2) *Block 2:* The following six units trained selective attention, selective working memory based on a criterion, and the capacity of inhibiting impulsive responses. Games requiring paper and a pencil or a motor activity were proposed.
(3) *Block 3:* The next six units are related to sustained attention and the ability of considering the whole stimulus before giving an answer. The objective of these units was to increase the time of sustained attention and to increase the awareness of the time necessary to do an activity. Moreover there were

other activities on selective working memory in association with an interpolated task.

(4) *Block 4:* The final three units were dedicated to divided attention and shifted attention, or the ability to pay attention to two different stimuli simultaneously and to shift attention from a stimulus to another one, and on updating the information in working memory.

The training did not include activities directly related with the pre- and post-measures. Each session always had the same structure, as follows:

(1) *Metacognitive introduction:* The teacher captured the children's attention and commented on the goal of the day's activities.
(2) *Presentation of the cognitive requests:* The teacher explained the activities for the day.
(3) *Instructions and preliminary practice with the task of the day.*
(4) *Organization of task:* The teacher organized the activity and eventually divided the children in subgroups.
(5) *Practice with the complete task:* The teacher invited the children to do the complete task.
(6) *Promotion of strategic reflections:* The teacher asked the children to comment on the activities and report strategies that they had used or thought they could use. The teacher guided the children towards the indication of strategies.
(7) *Introspection and feedback.* The teacher asked to the children how well they thought they did the task, gave feedback to the children, and discussed reasons for eventual failures.

In the control condition, children were provided with an equivalent amount of time working on typical school activities, for example pre-reading and pre-writing exercises. These activities were carried out by the same psychologists who conducted the training.

Fidelity of Implementation

In order to have high fidelity in the implementation, the training was carried out by psychologists specifically knowledgeable about the use of the present program and all the activities were available in written form. The authors of the present paper had supervision meetings with the trainers every 2 weeks. During the training, the trainer maintained a daily journal of activities undertaken in each session. In each case, observed activities highly corresponded to the intended components of the lessons: in fact in 90% of the cases the activities were rated as perfectly corresponding to the training Manual. A written record was also maintained and observations and supervision sessions were carried out for the control condition by considering the topics of each session.

Results

The training was well received both by the children and the teachers who attended the sessions. Also parents expressed a positive impression of the project and some of them reported observations of the effective improvements for their children.

Concerning the data analysis, we compared trained vs. non-trained groups on the pre-test and, despite minor differences, did not find any significant differences between the trained and non-trained children with ADHD symptoms groups and between the trained and the non-trained TD groups, whereas the overall group of children with ADHD symptoms had a poorer performance than the overall group of TD children. As the experimental design was related to children with ADHD and the TD children were involved only in order to meet a school request and the selection of measures was calibrated on the characteristics of ADHD children, we decided to examine in the first instance the case of children with ADHD. Therefore we analyzed the data concerning children with ADHD symptoms using a group (training vs. non-training) by time (pre- vs. post-training) analysis of variance (ANOVA). As a further control, we examined whether the training had an effect on TD children. In addition, we analyzed the results with a clinical approach. Based upon the guidelines produced by the Italian National Consensus Conference (2007) on LD and associated recommendations (Tressoldi and Vio, 2008) and predefining a positive change of at least 1 SD to represent clinical improvement, we considered the percentage of participants who had such a positive change.

Considering the performance of children with ADHD symptoms on the Walk–No Walk Test (Ranette), we found a significant main effect of time $F(1,24) = 17.67$, $p < 0.001$, $\eta_p^2 = 0.42$. We did not find a significant main effect of groups ($F < 1$), but we found a significant interaction $F(1,24) = 8.92$, $p < 0.006$, $\eta_p^2 = 0.27$. *Post hoc* comparisons showed that the training group significantly improved ($p < 0.001$), whereas the slight increase in performance of the non-training group was far from significance ($p = 0.40$). A comparison between the two schools showed that the benefits of the training were similar in the two school systems [school A: ADHD symptoms training group pre $M = 4.41$ (SD = 3.64), post $M = 9.86$ (SD = 3.93); ADHD symptoms non-training group pre $M = 6.57$ (SD = 3.78), post $M = 8.71$ (SD = 5.09); school B: ADHD symptoms training group pre $M = 8.67$ (SD = 4.84), post $M = 13.5$ (SD = 2.81); ADHD symptoms non- training group pre $M = 9.5$ (SD = 6.92), post $M = 8.83$ (SD = 5.56)].

We found similar results with the supplementary tests. Indeed, for the errors at the *MF- 14 test* significant main effect of time $F(1,12) = 8.33$, $p = 0.014$, $\eta_p^2 = 0.41$ and interaction $F(1,12) = 7.11$, $p = 0.021$, $\eta_p^2 = 0.37$ were found, while we did not find a main effect of group ($F < 1$). Again, the interaction was due to the fact that children who followed the training improved their performance ($p = 0.002$), while the non-training group did not ($p = 0.88$). Concerning the *MF-14* response time, the difference between the pre- and post-measures, despite the fact that only approached the significance level, $F(1,12) = 4.69$, $p = 0.051$, was characterized by a substantial effect size, $\eta_p^2 = 0.281$. We did not find a main effect of group ($F < 1$) nor a significant interaction [$F(1,12) = 3.49$, $p = 0.086$, $\eta_p^2 = 0.225$], even if the mean scores showed that only the trained group became slower, i.e., more reflective in responding (pre-training $M = 9.58$, SD = 6.35; post-training $M = 18.07$, SD = 15.35), while the other group did not change (pre-training $M = 10.09$, SD = 3.32; post-training $M = 10.71$, SD = 5.60).

Considering the correct responses at the DRST task, we found a significant main effect of time $F(1,10) = 10.92$, $p = 0.008$, $\eta_p^2 = 0.52$, but we did not find a significant main effect of group or a significant interaction. For errors of DRST, we found the same pattern of results, i.e., a significant main effect of time $F(1,10) = 15.21$, $p = 0.003$, $\eta_p^2 = 0.60$, but no other significant effects. However, mean scores showed that the reduction of errors after the training was wider in the case of training group (pre-training $M = 9.17$, SD = 4.92; post-training $M = 4.83$, SD = 3.31) than in the other group (pre-training $M = 6.67$, SD = 3.61; post-training $M = 4$, SD = 2.83).

Finally, we analyzed the ratings given to the children on the IPDDAI rating scale by their teachers, and we found a main effect of time for the inattention subscale $F(1,24) = 28.86$, $p < 0.001$, $\eta_p^2 = 0.55$, while we did not find a significant group effect or interaction. We found the same pattern of results for the hyperactive subscale, i.e., only a main effect of time $F(1,24) = 33.61$, $p < 0.001$, $\eta_p^2 = 0.58$. In this case, as it can be seen in **Table 1**, according to the teachers, both groups (training and non-training) improved their behavior, and this happened to the same extent.

The fact that we were required to include typically developing children in the trained groups offered the possibility of examining whether the training affected them, despite the fact it had been designed for children with ADHD symptoms. In fact, for the test administered to all the children, i.e., the Walk–No Walk Test (Ranette), we found a significant effect of time $F(1,24) = 10.51$, $p = 0.003$, $\eta_p^2 = 0.305$, but we did not find neither the effect of group [$F(1,24) = 1.97$, $p > 0.05$, $\eta_p^2 = 0.076$] nor the interaction ($F < 1$). However, mean scores showed some improvement for the trained group and not for the control one (see **Table 2**). Concerning the other two supplementary tests, we only found, for the correct responses on the DRST, a main effect of time [$F(1,10) = 6.10$, $p = 0.033$, $\eta_p^2 = 0.379$]. On the contrary we did not find significant differences between groups, but the improvements were always more evident in the trained group. In the case of errors in the DRST task, only the group that followed the training reduced their number of errors (see **Table 2**). Concerning teachers' ratings of TD with the IPDDAI, there were no clear trends because the scores were already very low before the training.

Clinical Change

Table 3 displays the effect sizes of the changes and the number of participants meeting the clinical criteria (of an improvement of at least 1 SD). This type of analysis reveals specific improvements that may be negligible when group averages are analyzed, but it may be very important for the individual student.

Based on the clinical significance criteria, the training clearly improved students' performance compared with the non-trained children in all parameters, except for hyperactivity of the IPPDAI rating scale, with an effect size ranging from 0.41 (for IPDDAI inattention) to 2.37 (Walk–No Walk Test [Ranette]). Cohen's *d*

TABLE 1 | Mean scores obtained by the two groups (training and non-training) of children with Attention Deficit Hyperactivity Disorder (ADHD) symptoms before and after the training.

		Training		Non-training	
	N	***M***	**SD**	***M***	**SD**
Teacher rating scale					
IPDDAI Inattention pre	13	11.23	3.41	11.04	4.83
IPDDAI Inattention post	13	8.5	2.55	7.8	3.63
IPDDAI hyperactivity pre	13	10.57	5.35	11.8	4.61
IPDDAI hyperactivity post	13	6.92	4.32	8	4.10
Executive Function Tests					
Walk–Nowalk pre Correct trials	13	6.54	4.54	7.92	5.42
Walk–Nowalk Ranette post Correct trials	13	11.54	3.82	8.77	5.08
MF errors pre	7	25.71	10.09	20.57	6.29
MF errors post	7	14.86	7.56	20.14	9.51
MF time pre	7	9.58	6.35	10.09	3.32
MF time post	7	18.07	15.35	10.71	5.60
DRST correct responses pre	6	3.00	3.03	4.33	2.80
DRST correct responses post	6	5.67	2.66	6.50	2.07
DRST err pre	6	9.17	4.92	6.67	3.61
DRST err post	6	4.83	3.31	4.00	2.83

TABLE 2 | Mean scores obtained by the two groups (training and non-training) of children with Typical Development.

		Training		Non-training	
	N	***M***	**SD**	***M***	**SD**
Teacher rating scale					
IPDDAI Inattention pre	13	3.35	2.44	3.57	1.89
IPDDAI Inattention post	13	3.34	2.21	2.15	1.30
IPDDAI hyperactivity pre	13	2.84	2.04	3.69	2.28
IPDDAI hyperactivity post	13	2.19	1.92	2.96	2.62
Executive Function Tests					
Walk–Nowalk pre Correct trials	13	12.08	3.90	11	4.06
Walk–Nowalk Ranette post Correct trials	13	15.39	2.96	13.23	3.59
MF errors pre	7	17.57	10.89	18	7.96
MF errors post	7	12.57	10.55	15.86	5.15
MF time pre	7	12.89	8.55	20.47	26.99
MF time post	7	23.50	18.85	13.59	8.65
DRST correct responses pre	6	3.67	2.66	5.67	30.1
DRST correct responses post	6	6.33	0.82	5.83	1.72
DRST err pre	6	8	4.10	5.67	4.46
DRST err post	6	4	1.26	4.83	2.32

TABLE 3 | Clinical Comparison: number and frequencies of children of the ADHD group who changed of at least 1 SD from the pre to the post training, in the Training and Non-Training condition.

	ADHD		
Task	**Training**	**Non-Training**	***d***
IPDDAI Inattention	6/13 (46.15%)	4/13 (30.77%)	0.41
IPDDAI Hyperactivity	3/13 (23.08%)	4/13 (30.77%)	–0.23
Walk–Nowalk correct trials	6/13 (46.15%)	1/13 (7.69%)	1.33
MF errors	4/7 (57.14%)	0/7	2.37
MF time	1/7 (14.28%)	0/7	1.12
DRST correct responses	2/6 (33.33%)	1/6 (16.66%)	0.54
DRST errors	2/6 (33.33%)	1/6 (16.66%)	0.54

was calculated from the log odds as follows (Borenstein, 2009): *d = (ln(o)sqrt(3))/(pi).*

Conclusion

The main purpose of this work was to promote the executive functions of children with ADHD symptoms in the unique and delicate period represented by their preschool years. For this purpose, we conducted training on controlled attention, control of impulsive response, and working memory with 5-year-old children. The training had a metacognitive approach and aimed to improve the children's attention capacity, the control of their behavior, and information in working memory through playful activities that required them to maintain attention or to control their behavior. Children with ADHD symptoms were randomly assigned to the training condition and to the control condition involving school activities. As the schools required that the children were trained with other children who have a typical development in an integration perspective that did not isolate the children with ADHD symptoms, the typically developing children indicated by the two schools were trained together with the children exhibiting ADHD symptoms.

Results suggest that a training of executive functions may be effective although its effect was more evident in some measures (a significant interaction between training and phases was observed only for Walk–No Walk Test [Ranette] and the errors in MF-14), than in others. Moreover, the children with a TD who took part in the training improved their competences as well. The effects, however, were less evident for the associated inattentive and hyperactive problems as rated by the teachers, as the trained group actually improved, but a similar improvement was observed in the control group. Therefore, part of the improvement seemed to be due to the general activities proposed during this period to the children and to their associated maturation. In fact it should be noticed that, despite the fact that the period between the two compilations of the IPDDAI scale by teachers was relatively short (around four months) ratings significantly changed.

It must be noticed that the project required that the teachers rating the children shared the goals and the method and were therefore informed about the formation of the groups. This is a strength of the method but also a weakness for the interpretation of the teachers' ratings. However this bias did not seem to produce an optimistic view of the reduction of the symptoms in the training group. Actually, the bias could also have been in the opposite direction, bringing the teachers to pay more attention to the symptoms presented by the treated children.

Finally, based on the clinical significance criterion, that considered an improvement of at least one SD as a significant clinical change, we saw that the training group improved the performance of children with ADHD symptoms by comparison with the corresponding children of the non-training condition, further supporting the hypothesis that an intervention for controlled attention, control of impulsive behavior and working memory is possible at an early age. As executive functions are related with a series of school activities (e.g., comprehension, expressive writing, problem solving, etc.), we can hypothesize that the benefits can be extended to various aspects of schooling. However, in this study, we were not allowed to assess for far transfer effects, and the only general measure we had, based on the teachers' perceptions of attention and hyperactivity problems, did not reveal a training benefit. Only future research will be able to better understand this point.

Nevertheless, important clinical implications can be derived from this research. First, we have new evidence of the possibility of administering the training of executive functions to preschool children who exhibit ADHD symptoms. The present cognitive training had the advantages of being easily implemented within the preschoolers' usual activities; well received by children, teachers, and parents; and produced specific effects related to the structure and the pre-established goals of the program. However, it seems important to try to prevent subsequent severe consequences for primary school children, not only at the level of cognitive functioning but also at the level of the typically associated problems. Indeed, in kindergarten, children are more flexible, relations with peers, and with parents are still easily modifiable, and negative experiences can be avoided (Sonuga-Barke et al., 2006). Working with very young children can also help to prevent negative consequences on self-esteem and motivation and, as suggested by Kern et al. (2007), reduce the appearance of oppositional or deviant behaviors. Our study tried to offer a contribution in this direction, but it is in need of replication and generalization. In fact, our study presents a series of limitations including the small number of children trained, the small number and the modest reliability of measures we were allowed to use and the specificity of the observed effects, the impossibility to have individual clinical profiles of the children and to examine the factors that could explain why some children improved and others did not, and the modest involvement of their parents.

Even considering these limitations, our findings show that great attention should be devoted to early cognitive interventions for children with ADHD or exhibiting ADHD symptoms. Indeed, even if a diagnosis of ADHD is difficult in the preschool years, early identification and intervention could be very beneficial for the future of these children.

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Cognitive training for children with ADHD: a randomized controlled trial of cogmed working memory training and 'paying attention in class'

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The goal of this randomized controlled trial was to replicate and extend previous studies of Cogmed Working Memory Training (CWMT) in children with Attention-deficit/hyperactivity disorder (ADHD). While a large proportion of children with ADHD suffer from academic difficulties, only few previous efficacy studies have taken into account long term academic outcome measures. So far, results regarding academic outcome measures have been inconsistent. Hundred and two children with ADHD between the age of 8 and 12 years (both medicated and medication naïve) participated in current randomized controlled trial. Children were randomly assigned to CWMT or a new active combined working memory- and executive function compensatory training called 'Paying Attention in Class.' Primary outcome measures were neurocognitive functioning and academic performance. Secondary outcome measures contained ratings of behavior in class, behavior problems, and quality of life. Assessment took place before, directly after and 6 months after treatment. Results showed only one replicated treatment effect on visual spatial working memory in favor of CWMT. Effects of time were found for broad neurocognitive measures, supported by parent and teacher ratings. However, no treatment or time effects were found for the measures of academic performance, behavior in class or quality of life. We suggest that methodological and non-specific treatment factors should be taken into account when interpreting current findings. Future trials with well-blinded measures and a third 'no treatment' control group are needed before cognitive training can be supported as an evidence-based treatment of ADHD. Future research should put more effort into investigating why, how and for whom cognitive training is effective as this would also potentially lead to improved intervention- and study designs.

Keywords: ADHD, school-aged children, cognitive training, academic performance, randomized controlled trial

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a developmental psychiatric disorder that has its onset in early childhood and is characterized by inattention, impulsivity, and/or hyperactivity (American Psychiatric Association [APA], 2000). Multimodal treatment approaches, for instance psycho stimulant medication in combination with behavioral treatment, are recommended (Taylor et al., 2004). Despite the fact that this multimodal approach has been shown to be effective in reducing ADHD symptoms (MTA Cooperative Group, 1999; Van der Oord et al., 2008), it seems that these effects cannot be sustained beyond 24 months (Jensen et al., 2007). Furthermore in regard to stimulant medication, some children experience serious side effects (Graham and Coghill, 2008) and there is growing concern among parents about the unknown long term effects (Berger et al., 2008). Finally, it has been shown that current multimodal approach does not lead to improvements in academic performance (Raggi and Chronis, 2006; Van der Oord et al., 2008), a key area of functioning in every day life which is often disturbed in children with ADHD (Loe and Feldman, 2007). These limitations have led to a growing demand for alternative non-pharmacological interventions for children with ADHD.

Of great interests are interventions that target the underlying cognitive deficits which are assumed to mediate ADHD causal pathways. Targeting those underlying cognitive deficits would potentially lead to greater transfer and generalization to functioning in every day life (Sonuga-Barke et al., 2014). Within the domain of cognitive interventions, working memory (WM) training has received most attention as a potential effective intervention for children with ADHD for several reasons. First of all, WM (i.e., the function of actively holding in mind and manipulating information relevant to a goal) is a necessary mechanism for many other complex tasks such as learning, comprehension, and reasoning (Baddeley, 2007). Second, it is assumed that WM deficits are part of the causal pathway to ADHD symptoms (Barkley, 1997; Willcutt et al., 2005). It is estimated that 81% of children with ADHD have a deficit in the *working* component (central executive) of WM (Rapport et al., 2013), in contrast to the less impaired *memory* component (phonological and visuospatial storage/rehearsal).

One of the most widely implemented and investigated interventions that targets WM is Cogmed Working Memory Training (CWMT). The rationale behind this training is that by adaptively and intensively training both the storage and storage plus manipulation components of WM, improvements will transfer to other cognitive functions such as attention as a function of underlying overlapping neural networks (Klingberg, 2010). So far, nine studies (Klingberg et al., 2002, 2005; Holmes et al., 2010; Gray et al., 2012; Green et al., 2012; Egeland et al., 2013; Hovik et al., 2013; Chacko et al., 2014; van Dongen-Boomsma et al., 2014) that investigated the efficacy of CWMT in children with ADHD reported neurocognitive outcome measures. Six of these studies showed treatment effects on trained WM tasks (Klingberg et al., 2002, 2005; Gray et al., 2012; Green et al., 2012; Hovik et al., 2013; Chacko et al., 2014) and two studies have also shown treatment effects on untrained WM tasks (Holmes et al., 2010; Hovik et al., 2013). Within the literature this latter often refers to near transfer, i.e., improvement in untrained tasks that rely on identical cognitive processes that are targeted by the intervention. Furthermore, treatment effects have also been found on measures of attention (Klingberg et al., 2002, 2005), parent ratings of ADHD related behavior (Klingberg et al., 2005; Beck et al., 2010) and parent ratings of executive functioning (Beck et al., 2010). It has been suggested (e.g., Klingberg, 2010) that this should be interpreted as evidence for far transfer, i.e., improvements in tasks that tap cognitive processes other than the trained process. Despite these promising results, there are several meta-analyses (Melby-Lervåg and Hulme, 2013; Rapport et al., 2013; Cortese et al., 2015) that are skeptical about the putative effects of WM interventions such as CWMT, mainly regarding the far transfer measures such as academic performance.

Interestingly, within the scope of CWMT efficacy studies in children with ADHD, only few have also taken into account academic outcome measures (Gray et al., 2012; Green et al., 2012; Egeland et al., 2013; Chacko et al., 2014). This is remarkable both from a scientific and clinical perspective, as interventions that can alleviate the encountered academic problems for children with ADHD are needed. Up till now, studies that did investigate the effects on academic performance found treatment effects on off task behavior (Green et al., 2012) and reading (Egeland et al., 2013). Despite these promising results and on the other hand the critical notes from previous meta-analyses (Melby-Lervåg and Hulme, 2013; Rapport et al., 2013; Cortese et al., 2015), we do suggest that replication of previous CWMT studies in children with ADHD is necessary. There is still no consistent pattern of results, mainly in regard to far transfer measures such as academic performance. It has been noted that previous effect studies suffered from both theoretical and methodological flaws and several suggestions have been made to optimize future research.

The most frequently addressed methodological issue concerns the use of an inadequate control group (Shipstead et al., 2010, 2012a,b; Morrison and Chein, 2011; Chacko et al., 2013; Melby-Lervåg and Hulme, 2013). Within the scope of CWMT effect studies in children with ADHD, some studies have used non-active (e.g., waiting list, treatment as usual) control groups (Beck et al., 2010; Egeland et al., 2013; Hovik et al., 2013) which hinders blinding (Sonuga-Barke et al., 2014) and only overcomes simple test–retest effects (Morrison and Chein, 2011; Shipstead et al., 2012b). Others (Klingberg et al., 2002, 2005; Green et al., 2012; van Dongen-Boomsma et al., 2014) used low-demand, non-adaptive placebo versions which require considerably less time and effort then the active condition which also diminishes the amount and quality of interaction with the training aide (most often a parent) and CWMT coach (Chacko et al., 2013). Furthermore, in regard to academic outcome measures in previous CWMT studies in children with ADHD, only the study of Egeland et al. (2013) included long term assessment. Gathercole (2014) recently suggested that long term assessment of standardized academic ability tests are crucial as the child will need to exploit his or her improved WM capacity and this will only be visible after a lengthy period. Others (Sonuga-Barke et al., 2014; Cortese et al., 2015) also suggested that future trials should include a broader range of functional outcomes and long-term follow-up.

In current study we will replicate and, moreover, extend previous CWMT studies in children with ADHD between the age of 8 and 12 years by investigating the effects on neurocognitive functioning, academic performance, behavior in class, behavior problems and quality of life. As has been suggested (Shipstead et al., 2010, 2012a,b; Morrison and Chein, 2011; Chacko et al., 2013; Melby-Lervåg and Hulme, 2013), we will compare these effects with an active control group whose experience is closely matched to the training group in terms of effort (adaptive WM tasks in response to performance), time (equal interaction time with the coach) and performance related feedback. This active control group receives a cognitive training called 'Paying Attention in Class' (PAC) which was developed by the authors. This training consists of a WM – and a compensatory executive function training. Next to adaptive WM tasks, this intervention also targets a broader set of executive functions that are impaired in children with ADHD with a main focus on how to use those executive functions in the classroom. The following research questions were addressed in this study: (1) What are the effects of CWMT on measures of neurocognitive functioning, academic performance, behavior in class, behavior problems and quality of life? and (2) Is an active control intervention equally effective as CWMT?

Materials and Methods

Participants

Children were recruited in two different ways for this study. First, clinical care providers from two clinical care departments of the De Bascule (Academic Centre for Child and Adolescent Psychiatry, Amsterdam) referred eligible children to the researcher. Second, healthcare staff members (usually remedial teacher or school psychologist) of schools in the region of Amsterdam contacted the researcher when they had eligible children. In both cases, the researcher visited the school for an information meeting to extensively inform the staff members. Parents of children who met criteria for participation were approached and informed by the school staff member. Eligible participants were (a) children between the age of 8 and 12 years, (b) diagnosed with ADHD by a professional according to the guidelines of the Diagnostic and Statistic Manual of Mental Disorders DSM-IV (American Psychiatric Association [APA], 2000). Children with comorbid learning disabilities (LDs) and/or oppositional defiant disorder (ODD) were also included. Children on medication were only included when they were well-adjusted to their medication, which meant that they were not participating in a medication trial, and type and dosage of medication was unchanged at least 4 weeks prior to the start and during the training. Exclusion criteria were (a) presence of psychiatric diagnoses other than ADHD/LD/ODD, (b) Total Intelligence quotient < 80, (c) significant problems in the use of the Dutch language and (d) severe sensory disabilities (hearing/vision problems). Parents filled out an application package containing a written informed consent form, questionnaires of demographic- and background information and the Dutch translation of the Social Communication Questionnaire (SCQ; Warreyn et al., 2004) to screen for autism spectrum disorder. The 'Lifetime' version of the SCQ consists of 40 questions that have to be answered with 'yes' or 'no.' A total raw score of 15 or higher indicates a likelihood of the presence of autism spectrum disorder and is recommended as a cutoff-score. Children with a total score of 15 or higher were excluded from this study. The attention/hyperactivity, ODD and Conduct Disorder modules of the Diagnostic Interview Schedule for Children IV (DISC-IV; Steenhuis et al., 2009) were administered by the research assistant(s) by telephone to confirm ADHD diagnose and to rule out for potential Conduct Disorder. Parents were also asked to send a copy of the diagnostic psychiatric report of their child to establish the subtype of ADHD and rule out other potential psychiatric problems that met exclusion criteria. The expert view, based on the diagnostic psychiatric report, was leading for establishing the subtype of ADHD. If the subtype was not described in the report, we used the Attention/Hyperactivity module of the DISC-IV (Steenhuis et al., 2009) to establish the subtype. A short version of the WISC-III-nl (Wechsler, 2005) with the subtests Similarities, Block Design, Vocabulary and Information was administered to estimate the Total Intelligence quotient if there were no prior recordings available. At baseline, there were no significant differences between the two groups for the demographical and clinical characteristics (**Table 1**) except for type of education. The PAC group contained significantly more children from special primary schools (e.g., children with mild learning- or behavior difficulties) but no children from special education schools (e.g., children with severe behavior or psychiatric problems).

Interventions

Cogmed Working Memory Training

Cogmed Working Memory Training is a computerized training program aimed to train WM. It consists of a variety of game-format tasks that are adaptive, which means that difficulty level is being adjusted automatically to match the WM span of the child on each task. The program includes 12 different visuospatial and/or verbal WM tasks, eight of these tasks (90 trials in total) are being completed every day (Klingberg et al., 2005). Children followed the standard CWMT protocol which means following the computer training program for 5 weeks, five times a week, ∼45 min a day. The program was provided via the internet on a laptop in a separate room. Children were trained individually at school, guided by a trained developmental psychologist (training aid) who was supervised by a certified Cogmed Coach. Teachers were invited to attend an information meeting in which the content of CWMT was

TABLE 1 | Demographic and clinical characteristics.

	CWMT ($n = 50$)	PAC ($n = 50$)	*p (t, X^2, or Fisher's exact test)*
Age, mean (*SD*) in years	9.8 (1.3)	10.0 (1.3)	ns
Gender			
Male, no (%)	35 (70)	37 (74)	ns
Full-Scale IQ, mean (*SD*)	103.1 (15.1)	99.2 (12.9)	ns
Medication for ADHD, no (%)	26 (55.3)	29 (61.7)	ns
ADHD diagnose, no (%)			
Combined	29 (58)	35 (70)	ns
Inattentive	15 (30)	10 (20)	
Not otherwise specified	6 (12)	5 (10)	
Comorbid disorders, No (%)			
Dyslexia	8 (21.1)	15 (35.7)	ns
Dyscalculia	0	2 (4.8)	
Oppositional defiant disorder	2 (5.3)	0	
Enrollment, no (%)			
Clinical care	7 (14)	14 (28)	ns
School	43 (86)	36 (72)	
Type of education, no (%)			
Regular primary	44 (88)	43 (86)	$X^2(2) = 6.789$, $p = 0.034$
Special primary	2 (4)	7 (14)	
Special education	4 (8)	0	
SES, no (%)			
Low < 25.000	10 (24.4)	6 (13.6)	ns
Average 25.00–35.000	6 (14.6)	12 (27.3)	
High > 35.000	25 (61)	26 (59.1)	
Ethnicity, no (%)			
Mother Dutch	41 (87.2)	36 (73.5)	ns
Father Dutch	35 (76.1)	31 (63.3)	ns

CWMT, Cogmed Working Memory Training; PAC, Paying Attention in Class; SES, social economic status.

explained by first author, it was communicated that teachers did not have an active role during treatment if children received CWMT.

Paying Attention in Class

'Paying Attention in Class' is an experimental combined WM- and compensatory training that has been developed by members of our research team. Children are trained individually outside the classroom for 5 weeks, five times a week, ∼45 min a day; the same duration as in the CWMT protocol. This PAC intervention contains three key elements; first of all, this intervention offers psycho education about executive functions that are related to classroom behavior. By making children more aware of these executive functions needed for adequate classroom behaviors, they obtain more insight in their own learning behavior. The psycho education addresses five executive functions, based on information processing and are important in a learning situation namely: paying attention, planning skills, WM, goal-directed behavior, and metacognition. For each executive function, five sessions in the protocol are devoted to that topic. For instance in regard to paying attention, it is explained to children that sitting straight in your chair or taking a deep breath might help to focus on the task. The psycho education is offered through an audio-book, with a 'brain castle' metaphor. It is explained that only by following the right journey (first pay attention, make a plan, remember the task etc) in your head, i.e., 'brain castle,' you will manage to finish a task in the classroom. During this journey, the audio-book introduces them to the so called 'brain guards' (i.e., strategies such as repeat instruction or visualize) or 'brain bandits' (i.e., pitfalls such as distraction or acting to fast). The brain castle and it's guards and bandits are also visualized with drawings, plastic cards and stickers. Every day the audio-book ends with a different cue (depending on which executive function is discussed), for example 'I repeat what is said.' This cue will be repeated throughout the session by the coach if necessary and the cue has to be practiced within a neuropsychological – and school task related exercise.

Second, this intervention contains three paper and pencil adaptive WM tasks: a visual spatial span task, a listening recall span task, and an instruction paradigm task (30 trials in total) which are practiced on a daily basis to improve WM capacity. The sequence of each trial is extended after two correct trials. In the listening recall tasks, the coach reads aloud a certain amount of sentences and the child has to evaluate and tell whether the particular sentence is true or false. After this, the child has to reproduce the last word of each sentence in the correct order. The visual spatial span task is a paradigm of the Corsi block-tapping task (Corsi, 1972) which consists of a template with ten small blocks. The child has to tap the same cubes as the coach but then in the reversed sequence. The instruction task was based on a previously described analog task (Gathercole et al., 2008) and consists of a paper template and cards that contains pictures of school related items. The coach reads aloud an instruction that the child has to execute for example "*Point to the big circle and pickup the small blue pen.*" For each next level one action or one extra item was added so the next sentence could be "*Pickup the large yellow book and a scissor and put them on the small square.*" Each WM task was ended after ten executed trials. At the end of each session, the child fills out a high score list for each task to keep track of their performance.

The third key element of this intervention is the central role of optimizing generalization to the classroom-situation. First of all, the strategies and pitfalls introduced through the audio-book described above will be illustrated and practiced by performing school related tasks, such as arithmetic, in a workbook during the session. The coach stimulates the child to use the cue from the audio-book and the coach also monitors whether the child uses any of the 'brain guards' or whether the child encounters 'brain bandits.' Performance on these school related tasks is not important, in stead reflection on the process is stimulated by the coach. The second way to improve generalization to the classroom is realized by a registration card which the child brings back to class. This card contains the cue of the day (for example, 'I repeat what is said') and is meant to remember the child to practice the cue in the classroom. It will also inform the teacher about the cue so that he/she can monitor or stimulate the child to practice. Finally, we closely involved the teacher in the process by informing him/her with the protocol and by giving him/her an active part in the process. Teachers received a written manual, which contained information about how to recognize WM problems in the classroom and information about the intervention itself. Furthermore, they were asked to daily record whether the child applied the cue in class through structured observation forms. The structured observation forms contained four specific statements, for instance 'The child is able to repeat the instruction,' that had to be rated on a four point Likert scale. Subsequently, the coach reviewed this observation form the next day which gave the coach information whether the child visibly applied the cue in the classroom.

Standardization Interventions

Developmental psychologists were trained as 'training aides' according to the CWMT protocol (Gerrits et al., 2012) and also trained as therapists for the PAC intervention. During an interactive 3 h course, provided by a member of the research team, the developmental psychologists were introduced in the theoretical background and practical implications of both interventions. The PAC intervention consists of a written manual for the trainer with clear instructions for each task/component and daily score sheets for the WM tasks. Since the psychologists trained both children in the CMWT group as children in the 'PAC' group, they were asked not teach the specific 'PAC' skills to the children (i.e., not apply the psycho education) in the CWMT group. A total of 31 psychologists and five CWMT coaches were deployed in this study.

Treatment Adherence

For both interventions the developmental psychologists received weekly supervision by a certified Cogmed Coach and clinical staff member of the Bascule in which they discussed the progress and clinical difficulties. Also the trainers filled out a daily diary per child for observations and special circumstances. Finally the Cogmed Training Web and the PAC workbook were used to monitor the results of the training. These three documents were used to create a checklist for evaluating treatment compliance.

Measures

Neurocognitive assessment and academic performance were the primary outcomes of this study. Behavior in class, behavior problems and quality of life were the secondary outcome measures. Assessment took place at school in a separate room at three consecutive moments: at baseline, directly after treatment, and 6 months after treatment.

Compliance

For both groups, we used the number of completed training sessions and improvements on the trained tasks as a measure for compliance. Treatment compliance was defined as completing twenty or more sessions, as has been reported in previous studies (Klingberg et al., 2005). For the individuals in the CWMT group, we used the *Improvement Index* as a measure of improvements on trained tasks. This index is generated by the program and reflects the difference between the *Start Index* (mean of three best trials on days 2 and 3 of the training based on two tasks) and the *Max Index* (mean of the best three trials on the best 2 days of training based on two tasks). For the individuals in the 'PAC' group we reported three different improvement indexes namely a *visual spatial index*, a *listening recall index* and an *instruction index*, referring to the improvements on the three trained tasks.

Primary Outcomes

Neurocognitive assessment included tasks that measure attention (Creature Counting and Score!: Manley et al., 2004), verbal WM (Digit Span:Wechsler, 2005; Comprehension of Instruction and Word List Interference: Zijlstra et al., 2010), visual spatial WM (Span Board: Wechsler and Naglier, 2008), planning skills (Six Part test BADS-C: Tjeenk-Kalff and Krabbendam, 2006), and inhibition (Inhibition: Zijlstra et al., 2010). Finally, parents and teachers filled out the Dutch version of 'The Behavior Rating of Executive Functions' (BRIEF) questionnaire (Smidts and Huizinga, 2009). This questionnaire consists of 75 items which can chart the following executive functions: inhibition, shifting, emotional control, initiation, WM, planning and organization, organization of materials and monitoring. These clinical scales form two broader indexes: the Behavioral Regulation Index (i.e., the scales Inhibit, Shift and Emotional Control) and the Metacognition Index (i.e., the scales Initiate, WM, Plan/Organize, Organization of Materials, and Monitor). An overall score, the Global Executive Composite, can also be calculated. T-scores of 65 and above are considered as a clinical score.

Academic performance was measured with tests for word reading fluency, automated math and spelling. Word reading fluency was measured with the '*Een Minuut Test*' (Brus and Voeten, 1973), this test consists two parallel cards which each hold 116 words. The child receives the instruction to read out loud (fast and accurate) as many as possible words in 1 min. The '*TempoTest Automatiseren*' (De Vos, 2010) was used to measure the degree of automated math. The test consists of four subtests: addition, subtraction, multiplication and division calculations. For each subtest, the child has to make as many as possible sums in 2 min with a maximum of 50. The '*PI dictee*' (Geelhoed and Reitsma, 1999) was used to measure spelling skills and consists of two parallel versions (A and B). Each version consists of 135 words that are divided in nine blocks of 15 words each. For each word, a sentence is read aloud and the child is asked to write down the repeated word. From a time-saving point of view, not all blocks were administered. The starting point was the educational age of the child and if there were three or more mistakes in that block, the previous block was also administered. The test was ended if the child made eight or more mistakes in one block. All raw scores were converted into a Learning Efficiency Quotient (educational age equivalent divided by the educational age) which allows for comparison across grade and age. We also performed secondary analysis in terms of accuracy (% correct) for the word reading fluency and automated math task as these tasks had a time restriction. We calculated an accuracy score for each point in time by dividing the raw scores of correct answers through the raw scores of total amount of produced words or sums and multiplying this answer by 100. As we had no Learning Efficiency Quotient scores for these raw scores, we added a variable 'age at assessment' as a covariate in the modal for analysis.

Secondary Outcomes

Behavior in class was reported by the teacher using the Learning Condition Test: this is a 70 item questionnaire that measures Direct Learning Conditions (concentration, motivation, work rate, task orientation, working according to a plan, persistency) and Indirect (social orientation, social position in class and relationship with peers and teacher) Learning Conditions (Scholte and van der Ploeg, 2009). Items can be rated on a five point Likert scale, a high score indicates a negative prognoses.

Behavior problems were assessed by both teacher and parents using 'The Child Behavior Checklist for Ages 6–18' (Verhulst et al., 1996) and 'Teacher's Report Form for Ages 6–18' (Verhulst et al., 1997). We reported the scale 'Attention Problems' since improved attention is one of the putative transfer effects of WM training; a T-score of 65 and above is considered as problematic. We also reported the scale 'Externalizing Problems' which consist of the two problem-scales rule breaking behavior and aggressive behavior; a T-score of 60 is considered as problematic.

Quality of Life was measured with the Dutch translation of the Kidscreen-27 questionnaire (Ravens-Sieberer et al., 2007) and was completed by parents and the child. It covers five dimensions of quality of life: physical well-being, psychological well-being, autonomy and parents relations, social support and peers and school environment. The raw scores are converted into T-scores: a higher score reflects a higher quality of life.

Procedure

The ethics approval for this study was obtained from the Medical Ethical Committee (2011_269) at the Academic Medical Centre in Amsterdam, the Netherlands. After enrollment children were randomly allocated to either the Cogmed Working Memory Training or the experimental PAC intervention by a researcher independent of the research team. The Clinical Research Unit of the Academic Medical Centre composed a randomization list, stratified by age (8–10 and 11–12 years) with a block size of six. The independent researcher assigned the children in predetermined random order and 1:1 allocation. Subsequently, the independent researcher informed the training aides and Cogmed coach about the allocated condition for each child. Parents and teachers were not explicitly informed about the allocation, however, the interventions were so dissimilar in appearance and application that parents and teachers cannot be marked as blind raters. Prior to treatment they were invited to participate in an information meeting at school where they were informed about the contents of the interventions. Two to three weeks prior to treatment, parents and teachers received the questionnaires mentioned above via e-mail or hard copy on request. One week prior to treatment, a member of the research team (who was blind for the allocation) administered the neuropsychological tasks from each child at a silent (if available) room at school. Post-treatment assessment took place within 1 week after the last training session and follow-up assessment took place after 6 months. The treatment sessions were completed during morning school hours, aligned with teachers, for both intervention groups. Training periods were planned in between school holidays so that training sessions would not be interrupted for a longer period of time. Children in both intervention groups received daily small reward such as stickers or extra playtime from the coach. In addition, they received a small presents (e.g., pencil or toy) after each week of training, regardless their improvements in trained tasks.

Statistical Methods

The intention-to-treat (ITT) approach was used to compare treatment effects. The Statistical Package for Social Sciences, version 19 (IBM SPSS 19), was used for the statistical analysis. Demographic and clinical characteristics were analyzed with independent t-tests for continuous variables and Chi-square and Fisher exact tests for dichotomous variables. Outliers were removed if they had a z-score of < -3.29 or > 3.29 and were replaced with the second highest value. A linear mixed model was used for each outcome variable as a function of Time, Condition and Time-by-Condition interaction. Secondary analyses were performed with age and gender as covariates. Missing data was considered missing at random and was not imputed because using linear mixed model analyses has the benefit of using every observation for each participant if a baseline score is present. The covariance type for each outcome measure was based on the smallest Akaike's Information Criterion. The significance level was set at $p = 0.05$ (two-tailed). A Bonferroni correction was performed to evaluate the effect of multiple testing which resulted in a significance level of $p = 0.003$ for the neurocognitive outcome measures ($n = 15$) and a significance level of $p = 0.005$ for the academic performance measures ($n = 11$). In addition to these analyses, Cohen's d was calculated as an effect size by subtracting the difference between groups for the change scores (post – baseline and follow up – baseline for both groups), dividing that by the pooled standard deviations of both groups at baseline. A paired samples t-test was conducted on the mean scores of the Start- and Max Index to test whether the children in the CWMT improved significantly on the improvement index. Paired samples t-tests were also conducted for the *visual spatial index*, *listening recall index,* and *instruction index* for the children in the PAC group. Independent t-tests at baseline showed that groups did not differ on any of the outcome measures prior to treatment, however, there was a trend for Spelling $p = 0.057$ possibly due to the fact that were almost twice as much children with Dyslexia in the 'PAC' condition. The difference in Dyslexia between the two groups was non-significant however.

Results

Between January 2012 and May 2013, a total of 115 children were assessed for eligibility; 10 children were excluded because

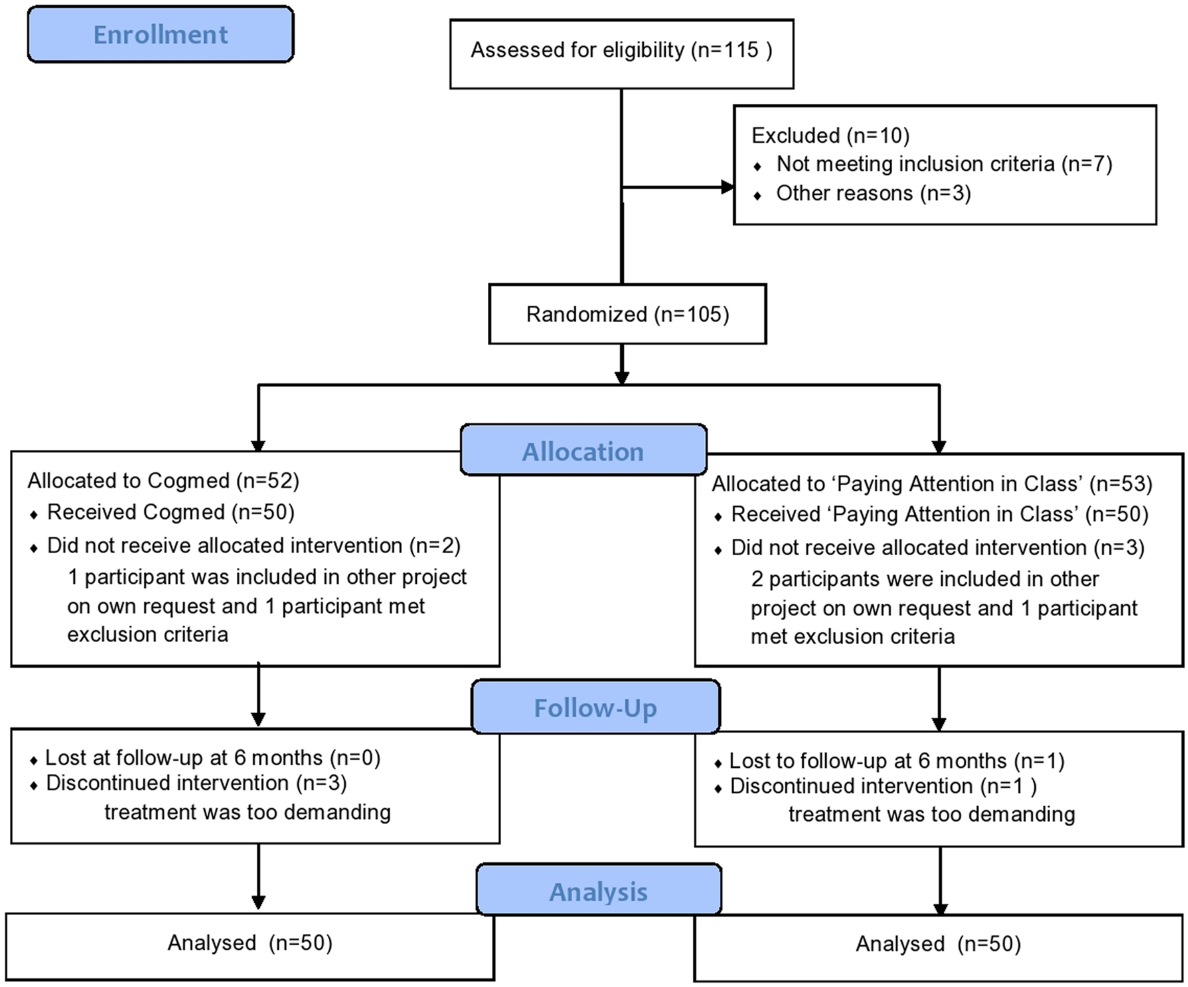

FIGURE 1 | CONSERT flow diagram.

they did not meet inclusion criteria or for other reasons (**Figure 1**). One hundred and five children were included and randomized, 52 children were allocated to the CWMT and 53 were allocated to the PAC intervention. Three children from the PAC intervention group and two children from the CWMT group did not start treatment after allocation because either they met exclusion criteria after all or they were included in a different research project due to time scheduling problems. This resulted in 50 children starting with CWMT and 50 children starting with PAC.

Compliance Measures

Of the 50 children who followed CWMT, 47 children (94%) met the compliance criteria of 20 or more complete sessions. Paired samples t-test showed that children in the CWMT group improved significantly on the *Improvement Index* with a mean *Max Index* of 94.25 (SD = 12.71) and a mean *Start Index* of 72.62 (SD = 9.26), $t(49) = -17.796$, $p < 0.001$. Of the 50 children who followed the PAC training, 46 workbooks were available for analysis of compliance. Forty-two children (91.3%) met the compliance criteria of twenty or more complete sessions (i.e., psycho education, tasks in workbook, and WM tasks). Paired samples t-test showed that children improved significantly on the *visual spatial index* with a mean of 3.5 (SD = 0.74) at the start of training and a mean of 5.42 (SD = 1.35) at the end of training, $t(47) = 11.409$, $p < 0.001$. Children also improved significantly on the *listening recall index* with a mean of 2.45 (SD = 0.72) at the start of training and a mean of 4.40 (SD = 1.21) at the end of training, $t(46) = 11.758$, $p < 0.001$. Finally, children improved significantly on the *instruction index* with a mean of 3.54 (SD = 1.01) at the start of training and a mean of 8.29 (SD = 1.96) at the end of training, $t(47) = 18.24$, $p < 0.001$.

Primary Outcomes

Neurocognitive Assessment

As can be seen in **Table 2**, a significant effect of time at post-treatment was found for attention (Creature Counting, correct answers; $p = 0.000$), verbal WM (Word List Interference Remember; $p = 0.000$, Comprehension of Instruction;

TABLE 2 | Results on neurocognitive assessment.

	Baseline		Post-treatment		Follow-up		*p* Effect time pre–post	*p* Effect time pre-fu	*p* Effect group	*p* Interaction effect	d^1 (CWMT-PAC)	d^2 (CWMT-PAC)
	CWMT	PAC	CWMT	PAC	CWMT	PAC						
Score!	8.7	8.2	7.8	6.8	9.6	8.6	0.000[a]	0.137	0.06	0.537	0.19	0.19
Creature counting												
Correct	9.3	9.6	11.3	10.9	10.8	10.1	0.000[a]	0.013[b]	0.372	0.346	0.26	0.38
Time	9.5	9.8	10.3	9.3	10.9	10.4	1	0.015[b]	0.448	0.151	0.38	0.23
Digit Span	9.5	8.8	11.2	8.8	10.7	9.2	0.021[b]	0.004[b]	0.009[b]	0.018[b]	0.57	0.27
Span board	47.7	45.3	58.8	48.2	56.3	49.1	0.000[a]	0.000[a]	0.000[a]	0.000[a]	0.85	0.49
WLI												
Repeat	9.9	9.9	10.3	10.6	10.6	10.5	0.039[b]	0.005[b]	0.919	0.666	−0.13	0.04
Remember	11.7	11.1	13	13.2	12.4	12.7	0.000[a]	0.000[a]	0.947	0.12	−0.33	−0.13
Six part test	8.8	8.9	9.7	9.9	10.5	10.2	0.012[b]	0.000[a]	0.926	0.729	−0.04	0.14
COI	9.3	9.2	11	11.1	11.1	10.8	0.000[a]	0.000[a]	0.824	0.728	−0.08	0.08
Inhibition switching												
Mistakes	7.5	7.5	5.4	4.9	4.7	5.6	0.000[a]	0.000[a]	0.811	0.137	−0.09	0.16
Time	113.2	111	101.9	98.6	94.6	94.3	0.000[a]	0.000[a]	0.595	0.522	−0.02	0.1
BRIEF parents												
BRI	56.1	54.6	53.8	52.8	55	54	0.003[a]	0.606	0.46	0.93	−0.05	−0.05
MCI	59.7	61	56.6	57.8	57.9	58.8	0.000[a]	0.033[b]	0.494	0.973	0.01	0.05
BRIEF teacher												
BRI	63.5	60.3	63.3	57.8	58.6	58	0.85	0.102	0.217	0.379	0.14	−0.16
MCI	67.1	67.2	63.4	64.9	60.1	61.8	0.019[b]	0.003[a]	0.682	0.811	−0.07	−0.09

CWMT, Cogmed Working Memory Training; PAC, Paying Attention in Class; WLI, word list interference; COI, comprehension of instruction; BRIEF, Behavior Rating of Executive Functions; BRI, Behavioral Regulation Index; MCI, Metacognition Index. Raw scores where used for amount of correct answers and time for the Inhibition task; Span board and BRIEF scores are expressed in t-scores; all other scores are expressed in standard scores. d^1 = difference between groups for the change scores post to baseline for both groups, divided by the pooled standard deviations of both groups at baseline. d^2 = difference between groups for the change scores follow up to baseline for both groups, divided by the pooled standard deviations of both groups at baseline.
[a]$p = <0.003$ (significant after Bonferroni correction); [b]$p < 0.05$.

p = 0.000), visual spatial WM (Span Board; p = 0.000), inhibition (Inhibition correct answers; p = 0.000 and time; p = 0.000), parent rated Behavioral Regulation Index (p = 0.003) and Metacognition Index (p = 0.000). A significant effect of time at post-treatment for Score! (sustained attention) was also found, however, this was a decrease.

At follow-up, significant effects of time were found for verbal WM (Word List Interference Remember; p = 0.000, Comprehension of Instruction; p = 0.000), visual spatial WM (Span Board, p = 0.000), planning (Six Part test; p = 0.000), inhibition (Inhibition correct answers; p = 0.000 and time; p = 0.000) and teacher rated Metacognition Index (p = 0.003).

A significant group effect was found for the Span Board task (p = 0.000, d^1 = 0.87; d^2 = 0.49) in favor of CWMT. An interaction effect was also found for Span Board task (p = 0.000). When the forward and backward condition for Span Board task were analyzed separately, results showed that there was only a significant group (p = 0.000) and interaction (p = 0.000) effect for the Forward condition.

Academic Performance

There were no significant time, group or interaction effects on the Learning Efficiency Quotient scores of word reading fluency (**Table 3**). Results showed one effect of time at follow up for the subtest ‘division’ of the automated math task (p = 0.005), however, this was a decrease of performance. It should be noted here that sample size of the multiplication and division subtests at baseline was a lot smaller than the sample size of the multiplication and division subtests at follow up. The subtests multiplication and division were not administered for children in lower grades as they do not yet acquire these multiplication and division skills yet. After Bonferroni correction results revealed a trend group effect (p = 0.036) and trend effect of time at follow up (p = 0.045) for spelling. As children in the CWMT group already performed better at baseline, we suspected that Dyslexia moderated the results. When Dyslexia was entered in the model as a covariate, the trend effect of group was no longer present (p = 0.150).

For the accuracy scores (see **Table 4**) results showed a significant group effect in favor of CWMT (p = 0.003) on word reading fluency, but without a significant interaction effect (p = 0.312). Further inspection of the data revealed that children from the CWMT group already significantly performed better at baseline (p = 0.004) than the children in the ‘PAC’ group possibly due to the fact that were almost twice as much children with Dyslexia in the ‘PAC’ condition. We therefore again entered Dyslexia as a covariate in the model and found that the group effect was no longer significant (p = 0.046) after Bonferroni correction. Finally, we found no significant time, group or interactions effects for the accuracy scores of the automated math task.

TABLE 3 | Learning efficiency quotients of academic performance measures.

	Baseline		Post-treatment		Follow-up		*p* Effect time pre–post	*p* Effect time pre-fu	*p* Effect group	*p* Interaction effect	d^1 (CWMT-PAC)	d^2 (CWMT-PAC)
	CWMT	PAC	CWMT	PAC	CWMT	PAC						
WRF	0.783	0.731	0.761	0.695	0.854	0.755	0.614	0.105	0.276	0.451	0.04	0.15
Automated math												
Addition	0.729	0.672	0.736	0.701	0.717	0.675	1	1	0.413	0.855	−0.07	−0.05
Subtraction	0.658	0.636	0.688	0.628	0.662	0.609	1	1	0.375	0.573	0.14	0.11
Multiplication	0.761	0.765	0.798	0.802	0.716	0.743	0.614	1	0.872	0.952	0	−0.01
Division	0.693	0.714	0.719	0.715	0.639	0.646	1	0.005[a]	0.863	0.766	0.1	0.06
Spelling	0.692	0.584	0.723	0.608	0.756	0.625	0.238	0.045[b]	0.036[b]	0.856	0.03	0.11

CWMT, Cogmed Working Memory Training; PAC, Paying Attention in Class; WRF, Word reading fluency. All scores are expresses in a learning efficiency quotient. d^1 = difference between groups for the change scores post to baseline for both groups, divided by the pooled standard deviations of both groups at baseline. d^2 = difference between groups for the change scores follow up to baseline for both groups, divided by the pooled standard deviations of both groups at baseline.
[a]$p = < 0.005$ (significant after Bonferroni correction); [b]$p < 0.05$.

TABLE 4 | Accuracy scores of Word reading fluency and Automated math.

	Baseline		Post-treatment		Follow-up		*p* Effect time pre–post	*p* Effect time pre-fu	*p* Effect group	*p* Interaction effect	d^1 (CWMT-PAC)	d^2 (CWMT-PAC)
	CWMT	PAC	CWMT	PAC	CWMT	PAC						
WRF	96.4	93.2	96.4	94.3	97.2	95	0.952	0.584	0.003[a]	0.306	−0.21	0.13
Automated math												
Addition	96.4	96.7	97.4	97	96.3	97.2	0.652	1	0.709	0.499	0.13	−0.11
Subtraction	91.7	93.5	95.1	92	93.9	93.5	1	1	0.614	0.055	0.15	0.17
Multiplication	91.7	90.2	91.3	89.6	92.9	93.2	1	0.869	0.555	0.574	0.02	−0.08
Division	88.8	86.5	86.5	84	90.5	91.6	1	0.936	0.691	0.537	0.01	−0.17

CWMT, Cogmed Working Memory Training; PAC, Paying Attention in Class; WRF, word reading fluency. All scores are reflect the percentage of correct answers. d^1 = difference between groups for the change scores post to baseline for both groups, divided by the pooled standard deviations of both groups at baseline. d^2 = difference between groups for the change scores follow up to baseline for both groups, divided by the pooled standard deviation of both groups at baseline.
[a]$p = < 0.005$ (significant after Bonferroni correction).

Secondary Outcomes

Behavior in Class

Analyses for the Direct Learning Condition scale showed no significant effects of time (post-treatment; $p = 0.395$, follow-up; $p = 1.000$), group ($p = 0.060$), or interaction ($p = 0.068$). Non-parametrical tests were performed for the Indirect Learning Conditions scale since data was not equally distributed. We only found a significant decrease for the CWMT group from pre treatment ($M = 60.23$) to follow-up ($M = 57.27$), $p = 0.022$. However, this decrease was not significantly different from the PAC group ($p = 0.975$).

Behavior Problems

Parent ratings of 'Attention Problems' showed a significant effect of time at post-treatment ($p = 0.000$) and follow-up ($p = 0.000$). There was no significant group ($p = 0.593$) or interaction effect ($p = 0.138$). The parent rated scale of 'Externalizing Problems' also showed a significant effect of time at post-treatment ($p = 0.000$) and follow-up ($p = 0.000$) but no significant group ($p = 0.627$) or interaction effect ($p = 0.243$). Teacher rated 'Attention Problems' also showed a significant effect of time at post-treatment ($p = 0.007$) and follow-up ($p = 0.001$) but no significant group ($p = 0.149$) or interaction effect ($p = 0.558$). No significant time, group, or interaction effect was found for the scale 'Externalizing Problems' as rated by teachers.

Quality of Life

We found no significant time, group or interaction effects for any of the five dimensions of quality of life that were rated by parents or the child.

Discussion

The aim of this study was to replicate and extend previous studies of CWMT in school-aged children with ADHD. This was the first randomized controlled trial that contained an active control group in which children received adaptive WM tasks in response to performance, equal interaction time with the coach and performance related feedback. Therefore, in contrast to previous effect studies of CWMT in children with ADHD, the experiences of the trained and control group were more similar in terms of effort and expectations in current study. Another strong aspect of current study was the fact that, next to broad neurocognitive measures, it included long term (6 months) assessments of areas that reflect functioning in everyday life, i.e., academic performance, behavior in class, behavior problems, and quality of life in a noteworthy large sample.

Although results showed an effect of time on verbal WM, attention, inhibition, planning, parent, and teacher ratings of executive functioning and ADHD related behavior, no superior effect of CWMT was found on these measurements in comparison to the effects of the PAC intervention. No significant time or treatment effects were found for academic performance, behavior in class, and quality of life. We were only able to replicate one treatment effect on visual spatial WM as was also found by previous efficacy studies of CWMT in children with ADHD (Klingberg et al., 2002, 2005; Gray et al., 2012; Hovik et al., 2013). Our results showed that the treatment and interaction effect was only apparent for the Forward condition of the Spatial Span task which suggests that CWMT only had a superior effect on short term memory in comparison to the PAC intervention, as was previously pointed out by Rapport et al. (2013). Most trained tasks within CWMT contain visual spatial (working) memory elements which strongly resembles the Spatial Span task that was used for the assessment of visual spatial WM. In contrast, the PAC intervention contains only one trained task that resembles the Spatial Span task. Therefore we suggest that this treatment effect should be viewed as a practice effect and not a measure of (near) transfer. We were not able to replicate treatment effects that were previously found on verbal WM (Holmes et al., 2010; Hovik et al., 2013), measures of attention (Klingberg et al., 2002, 2005; Egeland et al., 2013), parent ratings of ADHD (Klingberg et al., 2005; Beck et al., 2010) and executive functioning (Beck et al., 2010) and measures of academic performance (Green et al., 2012; Egeland et al., 2013). We suggest that there are several explanations for the fact that current study could not replicate treatment effects of CWMT that were found in previous studies.

First of all, regarding the neurocognitive measures, we suggest that the difference in control groups added to these inconsistencies. For instance, previous studies have used no-contact control groups such as treatment as usual (Egeland et al., 2013; Hovik et al., 2013) which corrects for test–retest effects. However, it does leave the possibility open that the trained and control group approached the post-assessment differently in terms of motivation (Shipstead et al., 2012a). This same argument also accounts for the studies that used low-demand, non-adaptive control groups (Klingberg et al., 2002, 2005). Improvements on post-training measures might reflect the belief that training should have a positive influence on cognition (Morrison and Chein, 2011). It is questionable whether the use of a low-demand, non-adaptive control group sufficiently convinces participants that they are engaged in cognitive training (Shipstead et al., 2012a). As results did indicate effects of time, we suggest that non-specific treatment factors partially might explain current findings. We suggest that positive reinforcement during training should be considered as a plausible mechanism. Next to models that view executive dysfunction as a causal model for ADHD, there are also models that emphasize the sub-optimal reward systems (delay aversion/motivational style) as a second and co-occurring causality for ADHD (Sonuga-Barke, 2003). Dovis et al. (2012) showed that incentives significantly improved WM performance of children with ADHD and the intensity of the incentive determined the persistence of performance over time. In our study, children in both groups received performance related feedback during training and were encouraged during performance. In addition, they received daily small reward at the end of each session (e.g., stickers or playtime) and a small present on a weekly basis. It is plausible that the encouragements and incentives obtained during training altered their motivation in regard to performance. Despite the strong design of current study, it should be noted that this study did not contain a 'no treatment' control group (e.g., waiting list) as a third arm for allocation. Therefore we cannot rule out other possible cofounders such as test–retest effects, passage of time or therapeutic benefit. Choosing and developing control groups remains challenging for future trials as ethical constraints make it difficult to implement 'no treatment' groups and there still is no consensus about how a control group should be designed (von Bastian and Oberauer, 2014).

Regarding the results on academic outcome measures, we suggest that the heterogeneity of the used samples make it difficult to interpret results across CWMT studies. For instance, while current study included both inattentive and combined subtype children, others (Egeland et al., 2013) only included children with the combined subtype. Another factor that could contribute to the inconsistencies in results concerns the inclusion of children with comorbid learning difficulties. For instance, just as current study, Gray et al. (2012) used a sample of children with comorbid LDs, others (Egeland et al., 2013; Chacko et al., 2014) did not report whether they included children with comorbid learning difficulties. Recently it has been suggested (Sonuga-Barke et al., 2014) that the response to different forms of training should be compared between clinical subtypes and neuropsychological subgroups. Furthermore, we suggest that future research should pay closer attention to individual differences such as age, biological factors, personality, and initial cognitive ability as these factors have been mentioned as potential moderators of treatment effect (Jaeggi et al., 2011; Jolles and Crone, 2012; von Bastian and Oberauer, 2014). For instance, it was suggested that WM training might be more effective for subgroups of ADHD, for instance ADHD plus WM problems (Chacko et al., 2013). This would reflect the 'room for improvement' hypothesis in which children with a lower ability at the start of training (for instance WM) show larger improvement on training gains as there would be more room for improvement than children with more normal ability levels who will reach their ceiling capacity much faster. A study of Holmes et al. (2009) might support this view as they showed that mathematical ability improved in children with low WM skills after following WM training.

Next to paying more attention to individual differences, we also suggest, in line with current comments of Gathercole (2014), that future research should take a closer look into how to assess academic performance. Many previous studies contained standardized ability tests for complex skill domains such as reading and mathematics. According to Gathercole (2014) the problem with these standardized ability tests is that they tap cumulative achievements which makes them strongly dependent on prior learning and relatively insensitive to recent changes in learning capacities. Determining the true and distinctive effect of training in terms of academic outcome measures remains challenging as there is one complicating factor that is often overlooked. While test–retest effects and maturation (passage of time) are often taken into account, it is much harder to control for the potential new skills that children have been exposed to in between assessment periods. In addition, children in lower grades are most likely more frequently exposed to new skills during a certain time period in comparison to children in higher grades. One possible way to overcome this problem is by following the example of a study from Holmes and Gathercole (2014). They used National Curriculum assessments in English and math to calculate the sublevel improvements for the relevant academic year. Conclusively, despite the fact that our results are in line with most recent meta-analyses (Rapport et al., 2013; Cortese et al., 2015), we suggest that more information can be gained from future trials if individual differences and solid academic outcomes measures are taken into account.

Finally, regarding the effects on parent and teachers ratings of ADHD related behavior and executive functioning, we again suggest that the difference in control groups added to the inability to replicate treatment effects of previous CWMT studies. It has been previously suggested that non-adaptive placebo control interventions (e.g., Klingberg et al., 2005) require considerably less time and effort from the coach (usually parent) than active conditions. This has direct implications for interpreting parent-rated improvements as it diminishes the quantity and quality of parent-child interaction (Chacko et al., 2013). Also, studies that used non-active (e.g., waiting list, treatment as usual) control groups (Beck et al., 2010) might have created bias as these type of control groups hinder blinding (Sonuga-Barke et al., 2014). It is possible that post-test change may reflect expectations that were created by the act of receiving treatment rather than actual changes that were brought about by treatment (Morrison and Chein, 2011; Shipstead et al., 2012b). In current study, parents were not involved in the delivery of the interventions and the interaction time with the coach was equal for children in both groups. Therefore, we suggest that treatment effects on parent ratings of ADHD (Klingberg et al., 2005; Beck et al., 2010) and executive functioning (Beck et al., 2010) in previous studies should be interpreted with caution. However, although parents were not actively informed about treatment allocation in current study, they cannot be considered objective raters as it was communicated that both interventions were active. A meta-analysis of Sonuga-Barke et al. (2013) showed that effects of ADHD ratings after cognitive interventions dropped to non-significant if outcomes of probably blinded raters were considered. This same argument might also explain current effects of time on teacher ratings. Both interventions were delivered at school during school hours so teachers were daily reminded that children were receiving treatment. Furthermore, teachers were invited to attend an information meeting that contained information about WM problems in the classroom and information about the interventions. From a clinical perspective, we can only encourage the involvement of teachers in such intensive interventions. However, from a scientific point of view it remains challenging how to incorporate teachers perspective. We suggest that future studies should incorporate classroom observation rated by blinded and objective persons. As was suggested by Green et al. (2012), teachers are probably less objective as they already formed a general impression of the behavior patterns of a child and they may not be sensitive in detecting positive changes.

Conclusion

In summary, when compared to an active intervention, a superior effect of CWMT could only be found on a trained visual spatial WM task. Although children in both groups improved on broad measures of neurocognitive functioning supported by both parent and teacher ratings, these results should be interpreted with caution as they might be related to methodological and non-specific treatment factors. We suggest that future trials with well-blinded measures, a third 'no treatment' control group and adequate (far) transfer measures are needed before cognitive training can be supported as an evidence-based treatment of ADHD. Furthermore, we suggest that future studies should be aimed at gaining more insight in *why* and *how* cognitive training is effective with possible support from neuro-imaging studies. This might shed some light on the question why some of the transfer measures are improved and others are not and may subsequently lead to improved intervention designs. Another important area to explore regards the area of *who* could benefit most from cognitive training. This concern would be of high clinical value in terms of treatment adherence, financial resources and effort resources from children, parents, teachers, and health care professionals.

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Improving executive function in childhood: evaluation of a training intervention for 5-year-old children

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Executive function (EF) refers to a set of higher order cognitive processes that control and modulate cognition under continuously changing and multiple task demands. EF plays a central role in early childhood, is associated and predictive of important cognitive achievements and has been recognized as a significant aspect of school readiness. This study examines the efficacy of a group based intervention for 5-year-old children that focuses on basic components of EF (working memory, inhibitory control, cognitive flexibility). The intervention included 12 sessions, lasted 1 month and used low-cost materials. Seventy-five children took part in the study. The results indicate that the children who attended the intervention outperformed controls in simple and more complex EF tasks. Specifically, these children exhibited increased abilities to delay gratification, to control on-going responses, to process and update information, and to manage high cognitive conflict. These results suggest the possibility that this intervention, which may be easily implemented in educational services, can promote EF during preschool period before the entrance in primary school.

Keywords: executive function, training, preschool, inhibition (psychology), working memory, cognitive flexibility

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Introduction

Executive function (EF) refers to a set of cognitive abilities that allow individuals to control thoughts and actions in the face of new or complex situations in which an automatic or impulsive response is not useful (see Miyake and Friedman, 2012). These functions help individuals select the most advantageous choice when confronted with the complex and heterogeneous demands of life and include skills such as the ability to suppress inappropriate responses (inhibition), the ability to flexibly shift between ideas and activities (cognitive flexibility), and the capacity to hold, to update and actively manipulate information in mind (working memory) (Miyake et al., 2000). In addition to this traditional cognitive model, an emotional component of EF has also been conceptualized. Zelazo and Müller (2002) have made a distinction between the development of relatively "hot" emotional aspects of EF and the development of more purely "cool" cognitive aspects. Whereas, cool EF is likely to be elicited by relatively abstract and context-free problems, hot EF is required in situations that involve the regulation of affect and motivation. Cool EF is evoked in situations or activities that are cognitively demanding and emotionally neutral (e.g., retrieving information after being manipulated mentally, such as during a working memory task); hot EF is elicited in situations where there is motivational involvement, such as when a reward is expected. It has been suggested that hot and cool EF typically work together as part of a more general adaptive system (Zelazo and Carlson, 2012).

The Role of EF During Development

Although EF develops over a long period of time that spans from the first year of life until late adolescence, the most impressive change in EF skills occurs during the preschool period (Garon et al., 2008). The rapid growth in EF that takes place between the ages of 3 and 5 enables children to organize their thinking and behavior with increasing flexibility, decrease their reactive responding to contextual cues, and engage in self-regulated and rule-governed behavior (for a review see Garon et al., 2008).

Individual variations in the development of EF within this age range have been found to be associated with and predictive of important cognitive achievements, such as self regulation (Sokol and Müller, 2007), social competence, specifically the Theory of Mind (Hughes and Ensor, 2007), and learning abilities (Blair and Razza, 2007). EF deficits have been found in several psychopathological conditions such as Attention-Deficit Hyperactivity Disorder (ADHD, Castellanos et al., 2006), pervasive developmental disorders (Pellicano, 2012), intellectual disabilities (Lanfranchi et al., 2009), and learning difficulties (Andersson and Lyxell, 2007).

In particular, EF development is significantly related to a child's learning ability (Bull et al., 2008; Brock et al., 2009). The relationship between early EF and later school achievements is fairly robust. Longitudinal research has suggested that EF skills contribute significantly to both mathematical and literacy achievement (Bull and Scerif, 2001; Blair and Razza, 2007; Clark et al., 2010) in children of various ages with and without specific learning disabilities (Müller et al., 2008; Best et al., 2009). As reported by Wass (2015) early individual differences in cognitive control capacity may mediate the later-emerging differences in learning skills and academic outcomes in typical development (Snyder and Munakata, 2011) and in atypical conditions, such as children from low-SES backgrounds that are more likely than their peers to have reduced EF (Welsh et al., 2010), children at risk of ADHD (Lawson and Ruff, 2004) or children with genetic disorders (Cornish et al., 2012).

Efficacy of EF Intervention in Children

In recent years, several types of training aimed at enhancing EF have been proposed (Diamond and Lee, 2011). Although there are still several open questions regarding the efficacy of EF interventions (Morrison and Chein, 2011; Shipstead et al., 2012; Melby-Lervag and Hulme, 2013), they still may represent an opportunity for children at risk for specific disorders and for clinical populations. For example, although parent training and medical treatment are the most common clinical approaches to ADHD (Klingberg et al., 2005; Charach et al., 2013) tested a working memory computer training program for ADHD children (RoboMemo, Cogmed Cognitive Medical Systems AB, Stockholm, Sweden) that showed positive results for working memory and transfer effects on inhibition performance that were maintained at follow up.

Though the promising results of EF interventions (Klingberg et al., 2005; Holmes et al., 2009; Diamond and Lee, 2011), most studies were focused on school age children (8–12 years, Diamond and Lee, 2011), sometimes with contradictory results (no EF gains in children with autistic spectrum disorder, Fisher and Happe, 2005; a positive effect in children with intellectual disabilities, Söderqvist et al., 2012).

Thus far, to our knowledge, only a limited number of studies have investigated the effect of EF intervention on preschool children (e.g., 4–6 years), despite the potential preventive effect of early intervention (Sonuga-Barke and Halperin, 2011). Actually, as suggested by Melby-Lervag and Hulme (2013) younger children may show significantly larger benefits from training than older children and the promotion of EF development during the preschool period could increase the school readiness of children (Blair, 2002).

Regarding preschool interventions, different types of program have been developed for typical children. Comparing the effects of these interventions using a cost-benefit approach is difficult because they differ in duration (long- vs. short-term interventions), setting (individual vs. group interventions), and materials.

The long-term programs are generally group-based interventions that correspond to a school curriculum and are provided in educational services over the entire length of the preschool or during the year before the primary school entrance (e.g., Bierman et al., 2008a,b; Raver et al., 2011). An example of such an intervention is Tools of the Mind curriculum developed by Bodrova and Leong (1996) based on a Vygotskian approach. The program emphasizes the development of underlying skills such as paying attention, remembering on purpose, logic, and symbolic representation; opportunities to learn cognitive and socio-emotional self-regulation abilities are interwoven into almost all classroom activities throughout the day. In a randomized trial, Diamond et al. (2007) found that preschoolers from low-income families who attended the Tools of the Mind Program showed markedly better EF performance than control group.

Nevertheless, the implementation of this type of intervention have some strict requirements, such as time resource, the commitment of school principals, intensive teacher training and good student–teacher ratios (see also Lillard and Else-Quest, 2006; Domitrovich et al., 2007). The need for such resources can make these programs expensive and can reduce their feasibility.

Short-term interventions are generally individualized training to be carried out over periods ranging from 1 week to 1 month (see Appendix A for a review). They include several computer-based trainings with rather intensive time schedules lasting from 2 to 5 weeks with 2 to 5 sessions per week (Rueda et al., 2005, 2012; Thorell et al., 2009; Bergman Nutley et al., 2011) or paper-and-pencil activities with three to eight short sessions concentrated in a week (Dowsett and Livesey, 2000; Kloo and Perner, 2003). Finally, a mixed individual and group training that use different types of activities and games has been proposed by Röthlisberger et al. (2011). Their intervention focused on the basic components of EF—i.e., working memory, interference control and cognitive flexibility—and represents a good trade-off between individualized computer-based interventions and large-group curriculum interventions. Prekindergarten (5-year-old) and kindergarten children (6-year-old) were involved in daily sessions of approximately 30 min in which three different tasks were performed in three different ways: in a group, in pairs of children and individually. The tasks were adapted versions of some well-known EF tasks (e.g., Simon says, Luria's hand game, dimensional card sorting, listening recall). Activities were carried out twice a week by a trained experimenter and by the teachers, who were trained and supervised by the experimenter, on the remaining 3 days.

Although short-term interventions differ in terms of training procedures and the EF components targeted, they have generally proven to be effective in promoting working memory (Bergman Nutley et al., 2011; Röthlisberger et al., 2011, for only prekindergarten children; Thorell et al., 2009) and cognitive flexibility (Kloo and Perner, 2003; Röthlisberger et al., 2011 only for prekindergarten children). Regarding interference control, the results are rather mixed. One study found significant training effects in preschool children with poor inhibitory skills (Dowsett and Livesey, 2000), another study found this effect only in kindergarten children (Röthlisberger et al., 2011), and three studies of typically developing children failed to find any increase (Rueda et al., 2005, 2012; Thorell et al., 2009). Finally, to our knowledge, only the study by Rueda et al. (2012) found a partially positive effect of the training on hot EF, which was still present at follow-up.

The results of studies on early EF interventions are promising and suggest that different strategies may be useful for enhancing EF during preschool period. However, most studies documented the effectiveness of interventions only on a limited set of EFs: some studies focused on specific EFs components (such as working memory); and showed some limitation for a use in preschool educational settings.

Early EF intervention that could be implemented in educational services for preschoolers could represent a prevention strategy for children with a potential delay or impairment in the development of EF, such as children from low socioeconomic backgrounds (Noble et al., 2005; Farah et al., 2006; Kishiyama et al., 2009) or children at risk for ADHD symptoms (Diamond and Lee, 2011). This type of program could be very useful in responding to the needs of diverse populations of children that are not always adequately identified and managed during the preschool years.

Nevertheless, previous EF training programs for preschool children, though partially effective, can be challenging and expensive when applied in standard educational contexts. Most programs are highly resource-consuming because, in some cases, they require the specific training of teachers and in the other cases the interventions are based on short-term individualized activities that should be conducted under the supervision of a trained adult.

The Present Study

The aim of the present study was to evaluate the efficacy of a training program designed to promote EF during preschool period, in particular in 5-year-old children that are present in educational services before to start the primary school at age of six, by following a cost-effective approach suitable for educational services. The key point is whether a play-based group training that can be easily implemented in school settings, including low-resource contexts, may be as effective as other, more expensive types of interventions, to increase EF. To develop a training, suitable for educational services that requires low cost material and low time and personnel resources, may be a strategy to reduce the gap in EF level through children at risk, such as children from disadvantage social condition, before school entrance.

No computers or other technical equipment was used, and all required materials were simple, inexpensive, and readily available. The training activities were completely separate from the assessment tasks to avoid the observation of any apparent increases in EF in the training group that may have resulted from intensive practice on the assessment tasks rather than real improvements in EF.

To demonstrate the efficacy of the training in promoting EF, an extensive battery was used to assess the three core EF components (i.e., inhibition, shifting, and working memory). The tasks were selected to evaluate growing levels of cognitive control and both the hot and cool aspects of EF. We expected the intervention to be effective in improving different EF abilities, such as inhibition, working memory and flexibility, immediately after the end of the training.

Methods

Participants

Five-year-old children who attended four public educational services (kindergarten) in commonly recognized disadvantage areas in the main province of a northwestern region of Italy were enrolled for this study. In Italy, children from 3 to 5 years old attend kindergarten that offer a pre-primary curriculum, that emphasizes activities that enhance creativity, social attitudes, autonomy, and learning, and it supports school readiness. Kindergartens are mostly public and free of charge for families, except for lunch fees, which depend on family income. Attendance at kindergartens is non-compulsory, but it is almost universal: more than 95% of the target children attend kindergarten before to start the primary school at age of six. Depending on the school, classes are age-homogeneous or age-heterogeneous; in the latter case, 3 to 5 year old children share most of the educational activities, except for lab activities, in which only one age group is included at a time. Additionally, in the case of age-homogeneous classes, small-group activities are equally common. Classes are composed maximum of 29 children. For this study, the priority was given to schools serving areas commonly recognized as low-income ones in which most of the children attended full time.

As shown in **Figure 1**, the project was presented to 132 families; 38 parents refused to give consent to participation, and 4 children were excluded due to ascertained developmental disorders Children with special needs or disabilities are fully integrated into the regular classroom, nevertheless we preferred to initially verify the efficacy of our training in children with typical development. The parents of the remaining 90 children filled up the parental informed consent and provided information about their socio-demographic conditions and their children's

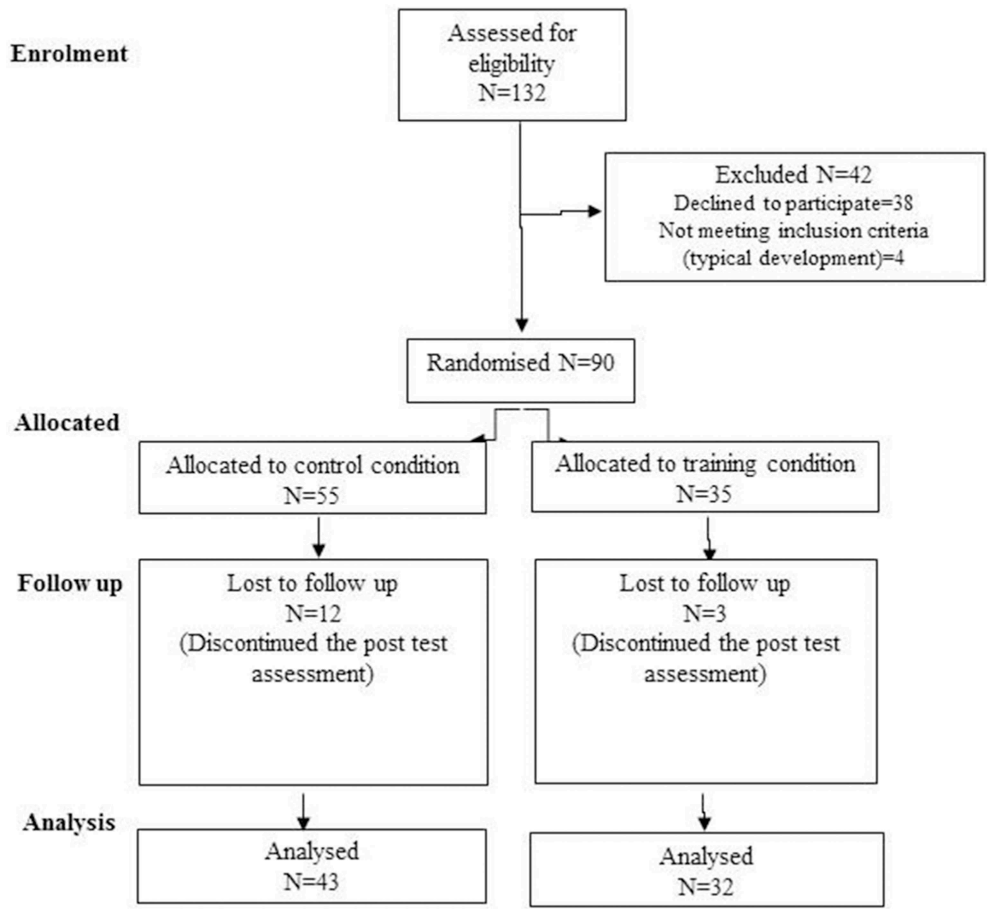

FIGURE 1 | Participants flow chart.

behavior by completing two brief questionnaires. The 90 children were assigned randomly to the training and control groups. Five children were selected at random from each class to be included in the training group, whereas the remaining children formed the control group. This procedure was adopted to guarantee that the control and experimental children shared the same school setting and that school context could not differently affect EF development. At the end of the random assignment, the training group and the control group consisted of 35 and 55 children, respectively.

In contrast to other studies (Rueda et al., 2005; Thorell et al., 2009), we did not include both active and passive control groups for the following two reasons: no differences emerged from the comparisons of the performances of passive and active groups in previous studies (Rueda et al., 2005; Thorell et al., 2009), and we wanted to compare this training with standard kindergarten activities, which usually include small-group activities for children of the same age.

At the post-intervention assessment, 15 children (12 controls and 3 experimental children) did not complete the evaluation due to prolonged absence from school and were consequently excluded from the analyses. The 15 children who were excluded from the study did not differ from the others with regard to their socio-demographic characteristics. All of the children included in the intervention attended at least 8 out of 12 sessions.

The final sample consequently consisted of 75 children ranging in age from 62 to 76 months ($M_{\text{age}} = 68.6$; SD = 3.5; 53% female): 43 children comprised the control group ($M = 68.6$; SD = 3.6; age range: 62–75 month; 58% female), and 32 children comprised the training group ($M = 68.7$; SD = 3.5; range: 63–76 months; 47% female).

Procedure

Pre-test assessments were conducted for both the control and training groups. Following the pre-test, which lasted approximately 2 weeks, a month of training within the regular kindergarten day commenced for the intervention group only. After training, all of the children were immediately reassessed no later than 2 weeks following the end of the training.

All tasks described in the following section were administered twice (i.e., pre- and post-training), with the exception of the Colored Progressive Matrices (CPM, Raven, 1947). The CPM were used as a screening measure to verify that there were no difference for intelligence at baseline for the two groups. In both the pre- and post-training conditions, the children were tested individually by trained psychologists, blind to children condition, over three sessions that lasted approximately 20–25 min each. The assessments took place at school in a silent room during the kindergarten day. The tasks were administered in a fixed order for two main reasons. First, a fixed order is preferred for the investigation of individual differences (see Carlson and Moses, 2001; Wiebe et al., 2008), and fixed orders allow for the control of session duration and the variation of tasks according to the materials, response modalities and abilities required. The order in which tasks were administered, as well as a summary of the variable labels, is reported in **Table 1**.

Measures

EF Assessment

Tasks were selected based on the following criteria: 1. All tasks required the children to actively control their reactions. Impulsive or automatic responses led to mistakes. 2. Most of the tasks were well-known EF measures in child research. 3. The tasks were chosen to minimize the effects of non-executive abilities, such as the children's vocabulary and knowledge, and the instructions were simple, involved familiar materials and required different types of input and output modalities (i.e., verbal/visuospatial stimuli, hot/cool situations, motor/verbal responses, and pencil paper/computer tasks). 4. All tasks differed from the training activities. 5. The tasks required different levels of control the ranged from simple motor control to conditions of high cognitive conflict. Most of the tasks had multiple codings, such as time and accuracy.

Hot EF Tasks

To assess hot aspects of EF, two delay tasks were used.

Delay task

This task (adapted from Kochanska et al., 1996) is a version of the standard delay paradigm that is frequently used to assess the ability of children to delay gratification (see Kochanska et al., 2000). The child is asked to wait as long as she can before opening a gift box and the latency is recorded (Delay Task Time, expected range 0-no limit).

Gift wrap task

This task (Kochanska et al., 1996) is used to evaluate the ability to delay gratification and inhibit undesirable behaviors in children (Carlson and Moses, 2001; Carlson, 2005). Children were told that the examiner would wrap a present behind their back and that they should not peek until the examiner said they were allowed to do so. The examiner then noisily wraps the gift over a period of 60 s. The latency to the first peek (Gift Wrap Task Time, expected range 0–60 s) and the total number of peeks during the 1-min interval were coded (Gift Wrap Violations, expected range 0-no limit).

Inhibition Tasks

A set of different tasks was used to assess inhibition.

Circle drawing task

This task (Bachorowski and Newman, 1985) is a well-known measure of the motor inhibition of an on-going response that has been used for both adult (Wallace et al., 1991) and childhood assessments (Geurts et al., 2005; Marzocchi et al., 2008; Usai et al., 2014). The child must trace with his finger over a 17 cm diameter circle from a starting point to an ending point. The task is administered twice. On the first administration, neutral instructions ("trace the circle") were given, and on the second administration inhibition instructions were given ("trace the circle again but this time as slowly as you can"). Larger time differences indicate better inhibition (slowing down) on the part of the participant in her continuous tracing response. Time in seconds was recorded for each trial. Scores were calculated as the slowdown relative to the total time using the following formula: $T2-T1/T2+T1$, where T1 and T2 were the times recorded for the first and second trials, respectively (Circle drawing task, expected range negative to positive values-no limit).

TABLE 1 | Summary of the assessment battery: the order of tasks for each session and the variables labels used in each task to assess EF and cognitive abilities are reported.

	Tasks' order for each sessions	Variables		To assess
	Variables	**Control group**	**Training group**	**Difference between groups at baseline level**
1° Sess.	Preschool matching figure task	Matching errors; matching time		Inhibition
	Arrow flanker task	Arrow flanker accuracy, arrow flanker time		Inhibition
	Backward word span	Backward span		Working memory
	Colored progressive matrices	Raven matrices		Intelligence
2° Sess.	Go/No-Go task	Go/No-Go Accuracy, Go/No-Go Time		Shifting
	Circle drawing task	Circle, proportion of slow down		Inhibition
	Keep track	Keep track, sum of correct items		Working memory
3° Sess.	Dots task	Dots Accuracy, dots time		Shifting
	Mr. Cucumber	Mr. Cucumber, sum of correct items		Working memory
	Gift wrap task	Gift wrap time, gift wrap violations		Delay of gratification
	Delay task	Delay time		Delay of gratification

Preschool matching familiar figure task

This task (adapted by Kagan, 1966) measures the child's ability to restrain impulsive responses and to compare the target with all of the pictures by shifting attention from the target to each alternative. The child is asked to select from among different alternatives the figure that is identical to the target picture at the top of the page. In the form that has been adapted for kindergartners, this task involves five alternatives and is comprised of 14 items. The number of errors (Matching Errors, expected range 0–56) and the mean latency between the presentation of the item and the child's response were recorded (Matching Time, expected range 0-no limit).

Arrow flanker task

The Flanker task (adapted from Ridderinkhof and van der Molen, 1995) is a well-known paradigm that is used to evaluate the ability to inhibit irrelevant interfering stimuli (Eriksen and Eriksen, 1974; Kramer et al., 1994). The child is required to respond to a left or right pointing arrow presented at the center of the computer screen by pressing a left or right response button. The arrow is flanked by two arrows pointing in the same direction (congruent condition, 16 items) or in the opposite direction (incongruent condition, 16 items) or by two simple lines in the neutral condition (16 items). After a brief training consisting of six items (two of each condition), 48 items are randomly presented (16 items per condition, half left and half right). A warning cross (500 ms in duration) preceded the stimulus (1500 ms in duration). After the stimulus, the screen turned blank for 500 ms. Response times for each item (Arrow Flanker Time, expected range 0–3 s) and accuracies in the incongruent condition were recorded (Arrow Flanker Accuracy, expected range 0–16).

Shifting Tasks

Two different tasks were used to assess shifting.

Go/No-Go task

The go/no go task (adapted from Berlin and Bohlin, 2002) is a well-known paradigm that tests the abilities of both adults and children to inhibit prepotent responses (Durston et al., 2002; Verbruggen and Logan, 2008). In the third condition, the children are asked not only to restrain an automatic response but also to pay attention to, and shift between, different dimensions of the same object. While in front of a computer screen, the child is instructed to press the space bar according to the instructions given by the examiner for the following three conditions: 1. "Press the space bar when you see a blue figure; do not press when you see a red figure." (30 items: 12 blue stars, 12 blue balls, 3 red stars, 3 red balls); 2. "Press the space bar when you see the star; do not press when you see the ball" (30 items: 12 red stars, 12 blue stars, 3 red balls, 3 blue balls); and 3. "Press the space bar when you see a blue star, do not press for the remaining figures" (40 items, 32 blue stars, 4 blue balls, 2 red stars, 2 red balls). The percentage of go responses was 80% in each of the three conditions. The stimulus duration was 3000 ms, and the blank page that appears after each stimulus lasted 1000 ms. The sum of the correct responses in the no go conditions (Go/No-Go Accuracy, expected range 0–8) and the mean response time for all of the three conditions were calculated (Go/No-Go Time, expected range 0–3 s).

Dots task

This task (Diamond et al., 2007) is a high cognitive conflict task in which the child has to shift between rules according to the stimulus presented (see Diamond et al., 2007; Diamond and Lee, 2011). A heart or a flower appears on the right or left of a computer screen. The child is told that he must press on the same side as the heart but on the side opposite the flower, which requires inhibiting the tendency to respond on the side where the stimulus appeared. After a brief training session with heart and flower items, the test began, and hearts and flowers were intermixed in the test. The sum of the correct responses (Dots Accuracy, expected range 0–3 s) and the mean latency for correct responses were recorded for each child (Dots Time, expected range 0–20).

Working Memory and Updating Tasks

Three tasks were used to assess children working memory and updating ability.

Backward word span

This task (Ciccarelli, 1998) is a traditional working memory task (Carlson, 2005; Alloway et al., 2006). This task requires the child to recall a sequence of spoken words in reverse order. Words were presented approximately once per second. After an illustration trial, the test begins with three trials of two words. The number of words increments by one every three trials until three lists are recalled incorrectly. The maximum list length at which two sequences were correctly recalled was scored (Backward Span, expected range 1–9).

Mr. Cucumber

This task (Case, 1985) is a measure of working memory in children (Morra, 1994). The examiner presents a large outline drawing of an extra-terrestrial character with a number of colored stickers attached to it at specific body parts (e.g., on the nose, on the left antler, etc.) for 5 s. The child is then shown a colorless drawing and asked to indicate the positions of the stickers in the previously presented figure. There are three items per level (from 1 to 8 stickers, in ascending order). An item is scored as correct if the child points at all of the correct body parts and no other body parts. One point is given for each consecutive level on which a child correctly indicates at least two items, and one third of a point is given for each correct item beyond that level (Mr. Cucumber, expected range 0–8).

Keep track

The Keep Track task (adapted by Van der Ven et al., 2011) is a working memory task that is suitable for assessing updating ability in both adults (Miyake et al., 2000) and children (Van der Sluis et al., 2007; Van der Ven et al., 2011). A computerized version of the Keep Track task was created. The child was shown pictures, each of which belonged to one of the following five categories: animals (dog, cat, fish, bird), sky (sun, moon, stars, cloud), fruit (strawberry, grapes, pear, apple), vehicles (train, bicycle, motorbike, car), and clothes (socks, skirt, t-shirt, shoes). Before each trial, the child was asked to pay special attention to one (first three trials) or two designated categories (last three trials). The pictures were shown in series of six. During the presentation of each series, the child had to name each picture. At the end, the child had to recall the last item in each designated category, which required managing the interference cause by the other named pictures. The number of designated categories increased from one (in the first three series) to two (in the last three series). During picture presentation, small pictures symbolizing the to-be-remembered categories were shown at the bottom of the screen to serve as a reminder. One point was given for each correct response, and 0.5 points were given if the child was not able to recall the item and asked to see all the pictures in the requested category again (Keep Track, expected range 0–9).

Fluid Intelligence

The Colored Progressive Matrices Test (Raven, 1947) was administered to measure fluid intelligence and was used as a screener. It is a multiple choice test of abstract reasoning in which the child is required to complete a geometrical figure by choosing the missing piece among 6 possible drawings; the patterns progressively increase in difficulty during the 36 items presented (CPM, expected range 0–36).

Parent Report Questionnaire

Parents evaluated children using the Attention and hyperactivity symptoms scale, Parents version (Cornoldi et al., 1996) a rating scale in which parents report the prevalence of their child's inattentive behaviors (9 items) and hyperactive-impulsivity symptoms (9 items) on four-point Likert scales (from never = 0 to very frequently = 3). The scale has been validated and standardized for the Italian population and exhibits good reliability and validity (Marzocchi and Cornoldi, 2000). This scale was used in the pre-test assessment to verify that the control and training groups did not differ in their levels of dis-attention or hyperactive behavior.

Training

The intervention program we developed aimed to foster EF skills through a series of small group game activities that require progressively higher levels of inhibitory control, working memory, and cognitive flexibility. Specifically, the intervention was proposed to small groups of five children, while the others children performed the normal kindergarten activities that include small group laboratories. The intervention was performed three times a week and it included 12 sessions of approximately 30 min each over approximately 1 month; the training took place at school in a silent room during the kindergarten day.

For the intervention, we adopted a play-based approach to intervention using the same story and characters through which the children enact roles during and across sessions to involve the children and maintain their motivation to collaborate. Specifically, in the first session, children are invited to listen to the fantasy story of Chicco and Nanà, two little goblin friends attending kindergarten. Unfortunately, the two friends have difficulty thinking carefully before acting such that, while preparing a magic potion, they erroneously transform themselves into a mouse and a cat, a condition in which it is difficult to be friends. To be converted into goblins again so that they may attend primary school, their teacher wants them to overcome 10 different challenges that will help them become more regulated. The children are asked to help Chicco and Nanà, by overcoming different challenges (intervention activities) that require EF skills.

All of the training activities were different from the assessment tasks that were administered to the children before and after the intervention, which required increasing levels of cognitive control and active participation on the part of each child. All of the activities were specifically designed for 5-year-old children so that they were challenged and engaged but also experienced a manageable level of difficulty. Each activity required that the entire group reach the fixed goals; thus, the children had to collaborate and positively reinforce each other to reach the goal (for a brief description of the training activities, see the Training Description in the Appendix B).

In order to help children manage the activities, all of the training sessions were structured in the same way so that the children could focus on the new activity without being distracted by the setting. Each activity started with a brief warm-up activity to introduce the session; then, the children were given an explanation for the new activity and were assigned their roles and tasks; finally, the session ended with a metacognitive activity.

The adult introduced the activities and the rules that all children had to respect, facilitated the interaction among the children, provided suggestions and support only when strictly necessary, and helped children to be autonomous in managing and controlling the game. Each child was given a different role with a specific responsibility—for example, the director was in charge of managing the players' behavior. During the session, the roles were exchanged. The children were invited to resolve conflicts by complying with the rules of the activity and respecting the roles they were assigned. Moreover, we provided concrete aids to help the children develop and practice self-regulation strategies through concrete experiences with physical materials. Every training session ended with a metacognitive activity that consisted of asking children to color smiling faces reported on a schedule according to their self -perception of their EF and to share strategies that they considered useful in performing the challenges. Special attention was paid to support the children's self-esteem and well-being during the activities, and the children were praised for their efforts during and at the end of each session.

The training involved low-cost, easily available materials (e.g., colored markers, pens and pencils, cardboard, paper, printed materials). The activities were designed to be included in the standard kindergarten curriculum, which emphasizes learning through play. Finally, the small-group approach, which is typically part of the standard organization in Italian kindergartens, can be easily implemented in the daily school schedule.

The training was carried out by a trained psychologist. The fidelity of training implementation was ensured by requiring to the training psychologist to know the aims of the training, how to perform the activities and to manage the situation by consulting the training book that we developed. At this level of evaluation, we decided to do not involve teachers before determining whether our training was effective. At the end of the project, teachers received a brief course in which the research findings were presented, the training books were shared and the teachers were supported in learning training aims and activities. An online version of the training book was developed to permit free download.

Results

Descriptive analyses were conducted on pre-test and post-test data to verify the variables' distributions and the rate of missing data and outliers. Then, chi-square and *t*-test were performed to verify the existence of differences between the training and control groups at baseline on socio-demographic variables, children's symptoms of inattention and hyperactivity, and pre-test task performance (i.e., on the EF tasks and Colored Progressive Matrices). Subsequently, pre-to-post differences between the groups, using pre-test scores as covariates, were performed to investigate training efficacy. To verify the relative magnitudes of the experimental treatment, effect sizes (range: 0–1) were calculated using Cohen's (1988) effect size formula.

Descriptive Statistics for the EF Tasks, Considering Pre- and Post-Tests, and Reliability

Descriptive statistics (i.e., means, standard deviations, possible score ranges, skewness, and kurtosis) for the EF tasks were conducted with respect to data from the pre- and post-EF task assessments. Large interindividual variabilities were recorded for most tasks. No floor or ceiling effects were found with the exception of the first two conditions of the Go/No-Go Task. The percentage of missing values ranged from 0 to 3%, with a single exception of 9% in the third condition of the Go/No-Go Task, which was mostly attributable to the duration of the task.

Scores that deviated from the mean by 3 standard deviations (SDs) or more were considered outliers and were excluded from the analyses. Outliers comprised 0–1% of the data across all of the tasks with exception of the Delay Task, in which 6% of the data were considered outliers. All the tasks were normally distributed, with the exceptions of the Delay Task and the Preschool Matching Familiar Task (time), for which logarithmic transformations were used to obtain improved skewness and kurtosis parameters.

Pearson correlations between the control group's performance on EF tasks at the pre and post test showed that, across all tasks, the retest reliability was moderate, with a mean $r = 0.58$ (range = 0.41–0.99).

Verifying Differences between Training and Control Groups at the Baseline Level before the Training

No significant differences between the control and training groups were found at baseline in terms of mothers' and fathers' levels of education, parents' perceptions of social and economic support, family income, levels of inattention and hyperactive behavior as reported in the parent report questionnaires, percentage of bilingual children, presence of brothers or sisters, children's mean age, gender distribution, or general cognitive abilities (no children scored below the 25th percentile), as reported in **Table 2**.

As shown in **Table 3**, no differences between the control and training groups were found with respect to EF tasks performance at the pre-test assessment, with the sole exception of the Arrow Flanker Task; in this task, the control group outperformed the training group in terms of accuracy.

Results of the Efficacy Study

To test the efficacy of our training, we conducted a between-group comparison (training vs. control group) using analyses of covariance with the pre-test scores from each individual task covariates. This statistical technique, which combines regression analysis and analysis of variance, is preferable to the use of repeated measures analyses for experimental designs with pre- and post-tests (Dimitrov and Rumrill, 2003).

The analysis of the training efficacy revealed a significant effect of group on post-test performance after controlling for pre-test levels in the following tasks (**Table 4**): the Delay Task [$F_{(1, 64)} = 8.61$, $p < 0.01$]; Gift Wrap Time [$F_{(1, 73)} = 8.41$, $p < 0.01$]; the Circle Drawing Task [$F_{(1, 72)} = 7.38$, $p < 0.01$]; Preschool Matching Familiar Figure Task accuracy [$F_{(1, 73)} = 5.10$, $p < 0.05$]; Arrow Flanker Task time [$F_{(1, 70)} = 4.14$, $p < 0.05$]; Dots Task accuracy [$F_{(1, 71)} = 6.04$, $p < 0.05$]; Backswords Word Span [$F_{(1, 71)} = 4.13$, $p < 0.05$]; and Keep Track [$F_{(1, 73)} = 8.03$, $p < 0.01$].

For all of these tasks, the results indicate that the children who took part in the training performed better than the children who only attended the standard preschool activities. The only exception was the Gift Wrap hot task, in which the control children increased their waiting time at the second assessment, whereas the training children did not. The training group outperformed the control group in most inhibitory control tasks and also in two of the three working memory tasks (Backswords Word Span and Keep Track) and the Dots Task, which required cognitive flexibility.

To verify the relative magnitudes of the experimental treatment, effect sizes were calculated using Cohen's (1988) effect size formula (*d*). Based on this formula, an effect size of 0.20 is considered small, an effect of 0.50 is considered medium, and an effect of 0.80 is considered large. As shown in **Table 4**, the effect sizes of the training ranged from medium to large for the majority of the tasks.

Discussion

Several studies have confirmed the importance of EF in development (Bull et al., 2008).

However, early EF interventions have shown only partial results, and most were not developed for widespread use in preschool settings because they required trained personnel, time resources or technical equipment. Nevertheless, the development of an early EF intervention that can be easily implemented in educational services could be useful for enhancing

TABLE 2 | Training vs. control group comparison: socio-demographic characteristics and parental reports of the children's behavior at baseline, before beginning the training.

	Training group	Control group		
Mother years of education	12.53	12.31	$t_{(1,56)} = 0.236$, $p = 0.814$	No difference
Primary school, 5 years of ed.	0	4%		
Secondary sc., 1°grade, 8 years of ed.	31%	23%		
High School Diploma, 13 years of ed.	47%	58%		
University, 18 years of ed.	22%	15%		
Master, 22 years of ed.	0	0		
Father years of education	12.61	10.68	$t_{(1,54)} = 1.947$, $p = 0.057$	No difference
Primary school, 5 years of ed.	0	4%		
Secondary sc., 1°grade, 8 years of ed.	29%	48%		
High school diploma, 13 years of ed.	55%	40%		
University, 18 years of ed.	10%	8%		
Master, 22 years of ed.	7%	0%		
Family Earn by year			$X^2_{(5,43)} = 8.545$, $p = 0.129$	
≤10,000	14%	14%		No difference
10,000–15,000	17%	0		
15,000–20,000	10%	43%		
20,000–25,000	21%	7%		
25,000–30,000	17%	21%		
≥30,000	21%	14%		
Perceived economical support			$X^2_{(3,51)} = 1.299$, $p = 0.729$	
Insufficient	0	4%		No difference
Quite sufficient	19%	17%		
Acceptable	42%	46%		
Quite good	30%	33%		
Optimal	0	0		
Perceived social support			$X^2_{(4,53)} = 1.158$, $p = 0.885$	
Insufficient	17%	8%		No difference
Quite sufficient	7%	8%		
Acceptable	24%	21%		
Quite good	17%	21%		
Optimal	35%	42%		
Family with more than one child	65%	66%	$X^2_{(1,75)} = 0.002$, $p = 0.963$	No difference
Parents report on child				
dis-attentive behaviors	7.09	7.19	$t_{(1,73)} = -0.068$, $p = 0.946$	No difference
hyperactive-impulsivity symptoms	6.86	6.72	$t_{(1,73)} = 0.109$, $p = 0.913$	
Birth in Italy	100%	100%	–	No difference
Italian as the first language spoken	100%	100%	–	No difference
Bilingual children	16%	9%	$X^2_{(1,75)} = 0.757$, $p = 0.384$	No difference
Children mean age	68.60	68.69	$t_{(1,73)} = -0.100$, $p = 0.921$	No difference
Sex distribution, percentage of female	58	47	$X^2_{(1,75)} = 0.935$, $p = 0.333$	No difference
General cognitive ability (Raven Matrices)	16.60	17.19	$t_{(1,73)} = -0.922$, $p = 0.360$	No difference

school readiness and reducing the gap in EF development between typical and at risk children (such as children from disadvantaged contexts and those with poor working memory or suspected ADHD), especially when they are not yet properly identified.

The present study was conducted to examine the efficacy of an EF training program that was developed to be suitable for educational services using low cost materials and limited time and personnel resources. The training targets 5-year-old children attending the last year of preschool.

TABLE 3 | Training vs. control group comparison: EF tasks performance at baseline level, before the training.

	Training group	Control group	Difference at baseline level, pre test assesment	
DELAY OF GRATIFICATION				
Delay time	1.08	1.27	$t_{(1, 66)} = -1.768$, $p = 0.082$	No difference
Gift wrap time	28.83	27.15	$t_{(1, 73)} = 0.389$, $p = 0.698$	No difference
Gift wrap vilations	2.76	2.34	$t_{(1, 69)} = 0.856$, $p = 0.395$	No difference
INHIBITION				
Circle	0.41	0.33	$t_{(1, 73)} = 1.470$, $p = 0.146$	No difference
Matching time	0.74	0.82	$t_{(1, 71)} = -1.422$, $p = 0.160$	No difference
Matching errors	12.98	13.06	$t_{(1, 73)} = -0.065$, $p = 0.948$	No difference
Arrow flanker accuracy	07.49	9.56	$t_{(1, 73)} = -2.092$, $p = 0.040$	Control > Training
Arrow flanker time	874.90	846.08	$t_{(1, 72)} = -0.803$, $p = 0.425$	No difference
SHIFTING				
Go/No-Go accuracy	5.61	5.2	$t_{(1, 66)} = 0.776$, $p = 0.441$	No difference
Go/No-Go time	745.36	715.26	$t_{(1, 66)} = 0.585$, $p = 0.561$	No difference
Dots accuracy	12.77	13.03	$t_{(1, 73)} = -0.065$, $p = 0.948$	No difference
Dots time	1177.75	1237.91	$t_{(1, 73)} = -0.672$, $p = 0.819$	No difference
WORKING MEMORY				
Backward span	1.98	2.03	$t_{(1, 72)} = -0.378$, $p = 0.706$	No difference
Mr: Cucumber	1.64	1.71	$t_{(1, 72)} = -0.489$, $p = 0.626$	No difference
Keep track	3.15	4	$t_{(1, 73)} = -1.741$, $p = 0.086$	No difference

Training Effects on EF

The training produced positive results in all of the three principal EF components—i.e., inhibition, working memory and cognitive flexibility—whereas previous studies had found significant effects only in specific EF dimensions, such as working memory (Thorell et al., 2009). Only Röthlisberger et al. (2011) had found substantial training effects for both working memory and cognitive flexibility in a sample of 5-year-old children, while interference control improved only in a sample of 6-year-old children.

The dissimilarity between the training activities and the tasks adopted in the assessment lead us to believe we measured real improvements in EF capacity and were not observing a mere task-training effect. The training group performed better in both the simple and the more complex tasks. The training group exhibited increased inhibition abilities, particularly in the control of ongoing motor responses as measured by the Circle Drawing Task and in the control of impulsive reactions as measured by the Preschool Matching Familiar Figure Task. The training group required less time to find the correct response in the presence of interfering stimuli in the Flanker Task, exhibited enhanced working memory abilities in both the Backward Word Span and Keep Track Task, and exhibited better performance in the Dots Task, which measured both inhibition and working memory in a switching context. Regarding the latter task, Diamond (2002) indicated that this task requires the conjunction of two simultaneous demands: holding information in mind and inhibiting inappropriate responses, a combination that is truly difficult—particularly, if one's mental settings have to be continually switched according to task changes. These types of tasks thus require continuous cognitive control and are indicative of cognitive flexibility. An increase in these functions is therefore particularly significant in terms of the cognitive prerequisites for school readiness and academic performance because cognitive flexibility is significantly associated with both school achievement (see, for example, Bull et al., 1999) and superior approaches to learning that begin in the preschool period (Vitiello et al., 2011).

Regarding hot EF, the effects of the training were rather mixed, and the results suggest that the training did not consistently influence these EF components. In the Gift Wrap Task, the controls outperformed the training children, who exhibited reduced waiting time at the second assessment, whereas, in the Delay Task, the opposite pattern was found: the control children performed worse at the second assessment. Both of the tasks that we used to evaluate hot EF are associated with the ability to cope with frustration. Although the children were asked to manage their negative feelings somewhat—for example, while waiting their turn to provide an answer—during the training activities, this aspect was not specifically addressed by the training.

The training children outperformed the control group in the majority of the EF tasks. This study demonstrates that it is possible to enhance EF skills using an ecological training in which 5-year-old children are engaged in a series of group play based activities. The ecological setting may be particularly useful in reducing regulation difficulties due to EF deficit such as in ADHD children. This type of training indeed stimulates children to regulate themselves during and through playing with peers. The use of a real life situation such as playing in a preschool setting could be useful to help children generalize the cognitive improvements at least to other similar situations or tasks. For now, in fact, there is no convincing evidence of the generalization of WM and EF training to other skills for both typically and atypically developing children (Melby-Lervag and Hulme, 2013; Rapport et al., 2013).

TABLE 4 | Comparison of the performances of the training and control groups in the EF tasks post-assessment: means, standard deviations, the results of between-group (control vs. training groups) analyses of covariance using pre-test scores as covariates and effect sizes are reported (*$p < 0.05$; **$p < 0.01$).

		Post-Training assessment		Group effect		
	Group	**Mean**	***SD***	**F**	**Direction**	**Effect size**
DELAY OF GRATIFICATION						
Delay time	Control	0.83	0.62	8.61**	**Training > Control**	0.70
	Training	1.25	0.57			
Gift wrap time	Control	33.72	18.90	8.41**	***Control > Training***	0.65
	Training	22.08	16.62			
Gift wrap violations	Control	2.14	2.02	0.07	*No difference*	0.44
	Training	2.11	1.87			
INHIBITION						
Circle	Control	0.37	0.25	7.38**	**Training > Control**	0.35
	Training	0.46	0.26			
Matching time	Control	0.73	0.28	3.08	*No difference*	0.44
	Training	0.84	0.19			
Matching errors	Control	13.02	6.93	5.10*	**Training > Control**	.45
	Training	10.28	4.61			
Arrow flanker time	Control	888.57	7.96	4.14*	**Training > Control**	0.61
	Training	820.95	6.40			
Arrow flanker acc.	Control	11	3.93	0.42	*No difference*	0.28
	Training	12.09	3.77			
SHIFTING						
Go/No-Go time	Control	711.41	194.41	0	*No difference*	0.02
	Training	714.71	177.43			
Go/No-Go accuracy	Control	5.61	2.22	0	*No difference*	0.16
	Training	5.94	2.02			
Dots time	Control	1125.28	322.36	3.3	*No difference*	0.14
	Training	1168.77	292.99			
Dots accuracy	Control	12.44	3.82	6.04*	**Training > Control**	0.53
	Training	14.59	3.14			
WORKING MEMORY						
Backward span	Control	1.98	0.64	4.13*	**Training > Control**	0.43
	Training	2.22	0.42			
Mr. Cucumber	Control	1.83	0.62	1.54	*No difference*	0.27
	Training	2.01	0.66			
Keep track	Control	3.78	2.14	8.03**	**Training > Control**	0.65
	Training	5.34	2.69			

Limitations and Future Directions

Three major limitations of this study should be noted. First, the training was administered by a trained psychologist. To verify the effectiveness and generalizability of this training, evaluation of the training as administered by teachers is required. Second, we did not evaluate whether the gains in EF shown by the training group endured over time or whether they were associated with greater school readiness or enhanced achievement at the end of kindergarten and Grade 1. Third, we did not include an active control group; although we controlled for test-retest effects, it may be important to investigate the intervention effect considering an active control group that is matched with respect to time and effort with the training group (Brehmer et al., 2012).

Nevertheless, the results of this study are promising; these results indicate that it is possible to foster the development of different aspects of EF with relatively simple interventions. Future studies might seek to investigate the transferability of this training program and the exploration of long-term effects on EF and school achievement. Given the importance of cognitive and emotion regulation for children's school adjustment, further research should also explore what could be improved in the training program to observe more consistent effects on hot EF. Finally, it may be particularly helpful to verify the effect of this type of intervention with at risk children (e.g., children from disadvantage context) or atypical children, such as children with low EF due to social disadvantage, ADHD children, learning difficulties children.

Conclusion

In conclusion, this study confirms the efficacy of a school-based intervention that addressed all of the EF components in 5-year-old children. Differently from most intervention studies that engage school age children, this intervention focuses on preschool children. Moreover, in contrast to previous preschool interventions, this training was developed using a low-cost approach to make it feasible for educational services. Specifically, a group-based approach was preferred because it is easier to implement within the daily schedules of preschool settings than individualized interventions. Second, we preferred the use of easily available materials to ensure that the intervention may also be suitable for educational services located in disadvantaged and low-resource contexts, in which children are at higher risk of poor EF.

Given the predictive association between EF and later achievement, interventions that begin in preschool period may lead to better outcomes, especially among children who are at risk, because they may experience increase school readiness and thereby reduce the achievement gap associated with socioeconomic disadvantage (Lawson et al., 2013; Nesbitt et al., 2013). In conclusion, the development of low-cost EF training that could be feasible for educational settings should be considered a priority for prevention research.

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Supplementary Material

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2015.00525/abstract

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Executive Functions and the Improvement of Thinking Abilities: The Intervention in Reading Comprehension

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In this paper, we propose a preliminary theory of executive functions that address in a specific way their relationship with working memory (WM) and higher-level cognition. It includes: (a) four core on-line WM executive functions that are involved in every novel and complex cognitive task; (b) two higher order off-line executive functions, planning and revision, that are required to resolving the most complex intellectual abilities; and (c) emotional control that is involved in any complex, novel and difficult task. The main assumption is that efficiency on thinking abilities may be improved by specific instruction or training on the executive functions necessary to solving novel and complex tasks involved in these abilities. Evidence for the impact of our training proposal on WM's executive functions involved in higher-level cognitive abilities comes from three studies applying an adaptive program designed to improve reading comprehension in primary school students by boosting the core WM's executive functions involved in it: focusing on relevant information, switching (or shifting) between representations or tasks, connecting incoming information from text with long-term representations, updating of the semantic representation of the text in WM, and inhibition of irrelevant information. The results are consistent with the assumption that cognitive enhancements from the training intervention may have affected not only a specific but also a more domain-general mechanism involved in various executive functions. We discuss some methodological issues in the studies of effects of WM training on reading comprehension. The perspectives and limitations of our approach are finally discussed.

Keywords: executive functions, working memory, reading comprehension, Intervention programs, education

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INTRODUCTION

Human thought involves the building of mental representations by integrating external and previously stored information, and their manipulation in a cognitive space: working memory (WM). Thinking can involve a goal or it may just involve a wandering mind, but it always requires WM's activation and use. For this reason it is affected by its processing and storage limits. Higher-level thinking abilities such as complex text comprehension, deductive reasoning, writing, and meaningful school learning operate sequentially. They consist of diverse component subtasks and demand that people keep their attention focused throughout the entire process. Besides the initial construction of representations, higher cognitive tasks require individuals to keep the goal of the task in mind, to shift from one sub-task to the next, and to update representations by activating Long Term Memory (LTM) information. The fulfillment of these complex cognitive tasks demands people to activate all their WM resources in a controlled and supervised way. The more complex and novel the intellectual task an individual is faced with the more involved WM's executive processes are in its resolution.

There is an obvious corollary to the tight relationship between WM's executive processes and thinking abilities: One way to improve these abilities is by training people in the use and activation of executive processes during the execution of novel and complex tasks involved in these abilities. This approach has three main theoretical components: (a) a proposal about the executive processes involved in higher cognitive abilities; (b) an analysis of how these executive processes operate while carrying out the complex and novel tasks selected; and (c) a proposal regarding how the executive processes can be trained. The two first components are peculiar to our proposal; the third component is common with the current theoretical and experimental approach of WM training.

In this paper we shall present our theoretical approach and how it can be applied to the acquisition of reading comprehension in childhood. In the next section we will address the relationship between WM and executive functions, and explain our theoretical proposal regarding executive functions and its development. After that, we will tackle a central issue for training: the modifiability of WM and executive functions. Later we will describe our training program on WM's executive functions involved in reading comprehension. The improvement of reading comprehension in primary school using our approach has been confirmed already and we will include some of the results we have found in diverse experiments. Finally, we will address the perspectives and limitations of our theoretical conception on the improvement of thinking abilities.

WORKING MEMORY AND EXECUTIVE FUNCTIONS

Working memory and executive functions (EFs) are tightly related but have diverse theoretical and experimental origins. EFs have its origin in neuropsychology, particularly in the work of Alexander Luria. Although the term "executive function" comes from Lezak (1982), Luria was the first author who conceptualized it. Luria (1966) was a prominent soviet neuropsychologist whose work led him to postulate connections among the frontal lobes (or the prefrontal cortices, PFC), executive functioning and problem solving. He documented the behaviors of individuals who suffered frontal lobe damage while they attempted to solve a problem and concluded that problem-solving behavior was dependent on a number of essential skills, or executive functions, which were dependent on the frontal lobes. Luria described the main components of executive functioning as: anticipation (setting realistic expectations, understanding consequences), planning (organization), execution (flexibility, maintaining set), and self-monitoring (emotional control, error recognition).

During the last quarter of the past century extensive work in this area has been done. Different functional circuits within the prefrontal cortex have been described from a neuroanatomical point of view. This work has confirmed the role of the frontal lobes in executive functioning (Fuster, 1989; Cummings, 1993). The idea that every executive process is mediated by the PFC (i.e., the frontal executive hypothesis), has long been widely accepted. It provides a conceptual framework for the belief that all executive processes are alike in critical ways. However, diverse studies have shown that EFs do not depend solely on the PFC. Other cortical and non-cortical regions of the brain are also involved in the cognitive and emotional processes that we call EFs (see Alvarez and Emory, 2004).

The development of diverse brain regions directly related with EFs, particularly the PFC but also the anterior cingulate, parietal cortex, and the hippocampus, is particularly relevant in infancy and early childhood. This development entails the early overproduction of synaptic connections, followed by their selective pruning or reduction, and the establishment of new circuits and interconnections between diverse brain regions (see Johnson, 1998; Diamond, 2002). Whereas maturation and structural development seem to predominate in childhood, an important development of efficiency in the use of available cognitive resources occurs from 10 to 12 years that results in large performance differences between children and young people (e.g., Jolles et al., 2011).

As a matter of fact, the study of brain development has shown that adolescence is a critical stage. A number of studies have shown that in this age period structural changes are still occurring in the prefrontal cortex: the proliferation of synapses occurs up to adolescence, and the pruning of neuronal connections continues till the third decade of life in adulthood (Blakemore and Frith, 2005). However, the most relevant modification in the adolescent brain is likely the global increase in the myelinization process. The enlargement of the sheath that covers and isolates neuronal axons is responsible for an increase in the speed of neural connection. It thus yields a parallel rise of the efficiency of brain computations underpinning the development of intellectual abilities and particularly EFs (Nelson et al., 2006).

In spite of extensive work carried out during the past 30 years and the increase in neuroscientific evidence regarding their cortical underpinning, EFs are still considered an elusive concept (Jurado and Rosselli, 2007) that possibly involves some confusion (Klenberg et al., 2001). Most of the confusion comes from their tight relationship with WM and with higher-level cognitive abilities. In order to reduce this conceptual confusion, it is necessary to clarify the relationship between EFs and WM, as well as to distinguish EFs from higher thinking abilities such as comprehension, reasoning, or problem solving. In this paper, we propose a preliminary theory of EFs that address in a specific way their relationship with WM and higher-level cognition. This conception is mainly based on two influential perspectives: Diamond's cognitive developmental neuroscience work on EFs, and experimental work on executive control processes in the fields of attention and WM.

Diamond (2009, 2013) has developed one of the most comprehensive proposals on the EFs. According to Diamond, the EFs enable the mental manipulation of ideas, thinking before acting, managing novel information and unanticipated challenges, inhibiting and resisting temptations, and staying focused during the execution of difficult tasks. Diamond notes there is general agreement that there are three core EFs: (1) working memory that holds information in mind and works with it; (2) inhibition or inhibitory control, including self-control (behavioral inhibition), and interference control (selective attention and cognitive inhibition); and (3) cognitive flexibility, that is adapting cognitive behavior to changing demands or priorities. Cognitive flexibility is related to task switching and is the opposite of rigidity. According to Diamond, there are other higher order EFs, such as thinking, problem solving, and reasoning, which are built from the core EFs (Collins and Koechlin, 2012; Lunt et al., 2012). As we will see, our proposal shares with Diamond the existence of core and higher order EFs. However, our view regarding the relation between WM and EFs, as well as between EFs and thinking abilities, differs from Diamond's view.

A second crucial perspective on the EFs comes from experimental research on cognition, particularly attention, and WM. Attention can be defined as the prioritization of information matching the individual's task goals (Nobre and Stokes, 2011). Attention has been treated as representing a cognitive filter (Broadbent, 1958), a basic model to stimuli orientation (Posner, 1980), but also as a control process of WM (Shiffrin and Schneider, 1977). Attention and WM are tightly related. In fact, they are increasingly viewed as overlapping constructs (see Awh et al., 2006; Gazzaley and Nobre, 2011). Thus, recent theoretical models of WM describe a function for attention, although in these models there is not much agreement on its specific role.

Within this perspective, the work by Miyake et al. (2000) has been particularly influential (see Garon et al., 2008). These authors carried out a differential study with university students that found support for the existence of three main EFs: (1) response inhibition (the ability to inhibit dominant, automatic, or pre-potent responses), (2) updating WM representations (the ability to monitor incoming information for relevance to the task at hand and then appropriately update it by replacing older, no longer relevant information with newer, more relevant information), and (3) set shifting (the ability to flexibly switch back and forth between tasks or mental sets). These authors showed that these three EFs are diverse, but tightly interrelated and overlapping. Recent neuroimaging studies also indicate unity and diversity of EFs in terms of brain localization (Collette et al., 2005). Likewise, a number of authors have addressed the question of whether the unity/diversity framework appropriately describes the structure of EFs in children, adolescents and adults (see, e.g., Miyake and Friedman, 2012). Findings indicate that the latent factor structure of executive control changes qualitatively over development, from a unitary structure in preschoolers to multiple components in school-age children and adolescents.

The study of the relationship between EFs and higher-level cognition has been frequently carried out according to Baddeley's multiple-component model of WM (Baddeley and Hitch, 1974; Baddeley, 1986, 2000). According to this theory, the WM system includes two domain-specific storage structures or slave systems (the phonological loop and the visuo-spatial sketchpad), an episodic buffer that links these two components with LTM, and a central executive (CE). The CE is the main component of the WM system and it is in essence based on the "supervisory attention system" described by Norman and Shallice (1986). CE not only has to coordinate the other components but is also in charge of the attentional control of information. Two related and influential models of WM are: Cowan's (1999) embedded-processes model, and Engle's (2001; Unsworth and Engle, 2007) general capacity model. In spite of their differences, Baddeley's, Cowan's, and Engle's models all share the idea of a domain-general CE in charge of controlling cognitive resources while solving new or difficult tasks.

Following the recent proposals of these authors (see Miyake et al., 2000; Engle, 2002; Cowan, 2005; Baddeley, 2007), in this paper we claim that there are four main core WM EFs involved in the on-line execution and monitoring of complex intellectual tasks: to focus and sustain attention, to switch attention, to activate and update representations, and to inhibit automatic processes and discard irrelevant information. All four of these CE processes demand cognitive effort and resources.

Focusing and sustaining attention is an EF that is required in order to solve any non-automated task. It involves the capacity to resist possible distractors and keep attention focused on a task. During infancy, focusing may be a difficult task since at this age attention is mainly determined by environmental factors such as novelty. In complex tasks, focusing allows individuals to orient their attention on a number of elements or blocks of information, keeping them in their mental space in a voluntary and conscious way.

A second CE function, related with focusing, is the capacity to switch attention. It allows changing one's attention from one stimuli, representation, or process to another, according to internal goals and task demands. In order to solve complex tasks, we must not only be able to fix our attention on those elements (stimuli or representations), or processes relevant to the execution of a task, but also must be able to shift our attention to other necessary aspects or components of the task. Thus, switching attention involves moving in a flexible way the focus of attention from one entity to another. This is supported by meta-analytical neuroimaging studies that provide neural evidence for switching (Wager and Smith, 2003). These studies conclude that switching seems to involve neural mechanisms located in the parietal cortex, which again argues against the exclusive frontal-executive hypothesis.

Processes related to "updating" information not only involve the simple active maintenance of relevant ongoing processing elements, but they also involve a "review" of the "fitness" of the representations generated and managed from new elements (i.e., a kind of "supervision" and "monitoring" of the information when approaching the objectives of the task). This is what happens for example during text comprehension. The process of text understanding requires readers to activate prior knowledge in order to continuously achieve appropriate semantic synthesis, and thus to update mental representations regarding the meaning of the text. Recent research confirming the capacity of updating to predict fluid intelligence explicitly stresses the importance of this process in higher-level cognition (see Friedman et al., 2006; Chen and Li, 2007; Belachi et al., 2010).

The capacity to inhibit information or representations that are not relevant to the task involves prioritizing the processing of some types of information over other types. However, inhibition involves not only the process of selecting information, but also the capacity to resist new information while maintaining essential information relevant to carry out the online task (see Borella et al., 2008). Thus, the inhibitory control of attention enables us to selectively attend, focusing on what we choose to attend to and suppressing any other stimuli, processes, or responses. These processes are critical in those complex tasks in which information processing are beyond the capabilities of the WM. A way to avoid overloading WM is to inhibit irrelevant representations and discard unnecessary information. Another ability related to inhibition is cognitive reflection (see Frederick, 2005). This ability involves controlling the behavior in a thoughtful way and inhibiting the first answer that comes "to mind" when solving difficult intellectual problems.

As we can see, our view includes the three classic executive functions proposed and tested in a classical study by Miyake et al. (2000): shifting, updating and inhibition, with the addition of a fourth component: focusing. The relevance of focusing is widely recognized in education: as every teacher knows, focusing and sustaining attention is a main executive process in school learning. In fact, according to Baddeley (2007), the capacity to focus and direct attention is probably WM's most crucial EF. One influential perspective on the role of WM capacity in mental work and cognitive development makes a different claim (see Pascual-Leone, 1987, 2000). It argues for the relevance of a component of mental attention that allows one to allocate capacity-limited attention to representations held in WM. According to Pascual-Leone, mental-attentional capacity is a limited capacity to hold in mind at any one time different information elements or schemes that are relevant for intellectual task resolution. Mental capacity is counteracted by a mechanism of mental attention interruption that corresponds to the ability to actively interrupt or inhibit the schemes that are not relevant to the task. From this perspective, Im-Bolter et al. (2006) proposed a fourth components model. Besides the two basic attentional components, mental activation capacity and mental inhibition capacity, they also include two executive components: shifting and updating. This model has shown its predictive capacity in children with specific language impairment. It has been extended to the study of how these four components contribute to children's ability to solve multiplication word problems (Agostino et al., 2010). The main difference between this model and the proposal of this paper is that we consider the four components as central EFs of WM.

When resolving a complex and novel task, such as reading a difficult text, the actions of these four WM executive functions are tightly related. Resolving a task as such always requires breaking it down into subtasks, and thus focusing and switching attention between these. It also demands that individuals retrieve knowledge stored in LTM in order to update representations during the execution process. This updating, however, also implies inhibiting older elements and information in its representation. Likewise, in order to be able to inhibit representations and discard information, individuals have to be focused on the relevant components of the task and resist and sustain their attentional focus in spite of the temptations invoked by the context or the stimuli itself.

TABLE 1 | Main types of executive functions.

General Characteristics	Executive Functions
WM's on-line core EFs Every complex and novel cognitive task demand their use	*Focusing and sustaining attention* *Switching attention* *Activating and updating representations* *Inhibition of responses and information*
Off-line higher order EFs Most complex intellectual abilities such as reasoning and problem solving demand their use.	*Planning future behavior*
They are carried out within WM and require to apply core WM's EFs	*Revision of task execution*
Emotional processes They are involved in solving any kind of complex, novel and difficult task.	*Emotional control of behavior*

Although, our main objective in this paper is centered on the four core EFs that concern the present on-line control and resolution of a cognitive task, our conception, following Diamond's proposal, entails also other higher order EFs (see **Table 1**). There are EFs that focus not only on on-line tasks, but instead on the future (i.e., planning), or on past behavior (i.e., revision). These higher order EFs are required in most complex cognitive abilities such as problem solving, reasoning, and writing. Planning involves the selection, formulation and evaluation of a sequence of thoughts and actions to achieve a desired goal (see Morris and Ward, 2005). It allows a person to analyze and adjust the available information, as well as the strategies and processes needed to solve tasks. In fact, problem solving and planning tasks, such as the Tower of Hanoi or the Tower of London, have frequently been used to measure executive functioning especially sensitive to frontal lobes dysfunction (see Goel and Grafman, 1995).

Likewise, the ability to successfully resolve complex thinking tasks is associated with the need to evaluate the processes and results that make up the diverse tasks executed during its resolution. Thus, a final revision mechanism is needed to ensure that actions are performed in line with prior demands. Writing is probably the clearest example of complex intellectual ability that requires revision (Allal et al., 2004). Other examples of this need for revision are: solving mathematical problems or drawing deductive reasoning inferences, but also processes relating to complete understanding and learning about complex matters. Revision should be focused on the analysis and control of procedures applied and implemented to ensure a correct resolution.

Apart from the core and higher order cognitive EFs, there is another executive function clearly involved in an individual's action: the emotional control of behavior. In other words, the ability to modulate emotional responses by bringing rational thought to bear on (or resist) our own feelings. Emotional control underlies all human behavior, including higher-level cognition and the executive processes previously analyzed and described. In fact, emotional activation can interfere with cognitive control processes in healthy individuals, and thus depression is associated with impaired disengagement from negative information (Aker and Landro, 2014).

Therefore, our theoretical proposal claims the existence of three main kinds of EFs: (a) on-line core WM executive functions: focusing attention, switching attention, activating and updating representations, and the inhibition of automatic processes and responses; (b) off-line higher order EFs centered either on planning future cognitive behavior or on revising prior behavior already executed; and (c) emotional control that includes not only the control of desires and affections, but also the control of anxiety and emotions that underlie the execution of new and complex intellectual activities.

Higher order EFs, planning, and revising, involve the four core EFs since they are also carried out within WM, even if they are not necessary in some tasks and abilities, such as ordinary reading comprehension. As we can see, all cognitive EFs are tightly related with WM: the four core EFs are part of the CE functions; and the two higher EFs are the result of applying core EFs to the task of foreseeing and organizing future actions, and to reviewing and evaluating prior behavior and actions. Another difference between core and higher order EFs is that the latter overload WM and frequently require external support or memory. The difference between core and higher order EFs is also clearly shown in their development.

As diverse authors have shown, the first years of life are crucial in the development of core EFs (Diamond, 2006; Garon et al., 2008). For example, a rudimentary ability to select a stimulus and to focus attention is present early in infancy. The development of attention during infancy allows preschoolers to focus on internal representation and resist the attraction of environmental stimuli (Rothbart and Posner, 2001). Focusing and shifting are obviously related but they seem to show separate developmental paths in early infancy (see Posner et al., 2006). The ability to shift attention between two objects appears during the 1st year, and in the 2nd year children should already be able to shift between an internal representation and a perceived stimulus. Likewise, from 3 to 5 years old, children show a significant improvement in attention switching between tasks when the active maintenance of information and inhibition is required (Diamond, 2002). There are diverse response inhibition tasks that can be labeled as simple and complex (see Garon et al., 2008). Simple inhibition tasks, such as the ability to suppress a dominant response, involve a minimal WM demand, and they develop in the 1st year of life. Complex inhibition tasks involve a higher WM demand, such as in Stroop tasks that require people to hold a verbal rule in mind, respond according to it, and inhibit an automatic response. The development and acquisition of this kind of complex inhibition comes later, from 3 to 5 years old (see Garon et al., 2008). The study of updating by requiring participants to recall the last items of a list of letters was first used by Morris and Jones (1990), however there is very little evidence of its development. Belachi et al. (2010) used a more complex relevance-based updating task (see Palladino et al., 2001), in which participants were asked to remember the smallest items of a list of objects. They found a linear pattern that increased with age in children between 5 and 11 years old, similar to that obtained with other measures of WM and fluid intelligence. As we see below, we used a semantic updating task in two studies.

The core EFs, as different studies have shown (e.g., Huizinga et al., 2006; Best et al., 2009), continue to develop until adolescence or even young adulthood. The study of the development of higher order EFs, planning and revision, is practically inexistent and there is little known about it (see however, Nurmi, 1991). Although planning and revising also begins to develop in infancy, higher order EFs are of belated acquisition. The age period when they mainly develop and reach their maximum level is late adolescence and young adulthood. In a parallel way and underlying the development of most complex thinking abilities, the development of higher order EFs is likely result of the multiple and repeated realization of diverse complex intellectual tasks in educational contexts (see Best et al., 2009).

THE MODIFIABILITY AND TRAINING OF WM AND EFS

A number of studies focused on training-induced cognitive and neural plasticity have provided evidence that cognitive abilities and brain activity are potentially modifiable (see e.g., Karbach and Schubert, 2013). Consistent with this view, many studies have investigated the effectiveness of cognitive training interventions to improve WM, as well as to help overcome cognitive deficits or learning difficulties (for reviews, see Morrison and Chein, 2011; Shipstead et al., 2012; Titz and Karbach, 2014; von Bastian and Oberauer, 2014). Growing empirical evidence indicates that WM training interventions can lead to real and lasting gains not only in typically developing pre-schoolers (see Diamond, 2012), in school-aged children and adolescents (for a review, see Karbach and Unger, 2014) up to adulthood (e.g., Karbach and Kray, 2009), but also in children with cognitive deficits or learning difficulties (Klingberg, 2010). This is true particularly for studies investigating the benefits of WM training programs that involve adaptive tasks (i.e., tasks in which participants are given many trials to perform that are at or slightly above their current ability). The meta-analytic review undertaken by Melby-Lervâg and Hulme (2013)—including studies with clinical and typically developing samples of children and adults—indicates that WM training programs produce significant and immediate improvements in measures of verbal WM, with larger gains occurring in studies with younger children (below age 10 years) relative to older children, as well as moderately sized immediate gains on measures of visuospatial WM. These authors conclude that, even though memory training programs appear to produce short-term specific training effects, there is no clear evidence that such benefits are durable and generalizable to other skills.

It may be noted that one aim in many WM training interventions is not only to improve performance on WM tasks, but also to obtain transfer or generalizing effects to new tasks or domains that have not been trained (for a discussion, see von Bastian and Oberauer, 2014). Theoretically, if it is assumed that WM reflects a general attentional resource limitation, and considering the strong relation between WM and performance in a multitude of tasks (Cowan, 2005), we would predict that training WM, if successful, should show transfer effects to untrained tasks (Shipstead et al., 2012). The underlying idea is that training should lead to an increase in a domain-general attentional capacity that is critical for performing many diverse tasks. Particularly, the improvements in WM functions might be beneficial for individuals with poor WM skills and for those who are at risk of learning difficulties (e.g., Gathercole and Alloway, 2008). It, therefore, appears necessary to assess the extent to which WM training programs are effective in increasing measures on tasks similar to those trained (near-transfer effects), as well as on scores on tasks that have not been trained directly (far-transfer effects), either within the same cognitive domain or even to more general cognitive abilities relying on WM. In that respect, a number of recent studies provide some evidence that WM training can optimize an individual's performance in a number of other cognitive measures. For instance, Klingberg et al. (2002) reported that young adults trained using a protocol that combines multiple WM tasks improved significantly on cognitive control and general fluid intelligence measures. Using the same paradigm, these authors also found similar improvements in cognitive control and general fluid intelligence in children with ADHD (see also Klingberg et al., 2005).

As for executive processes, there are very few studies that have specifically investigated transfer from WM training to EFs. For instance, Salminen et al. (2012) investigated transfer effects from WM training to different aspects of executive functioning. Participants were trained on an adaptive complex task that requires simultaneous performance of a visual and an auditory *n*-back task. Transfer tasks measured four executive processes separately: WM updating, coordinating the performance of simultaneous tasks (dual task) and sequential tasks (task switching), and the temporality of attentional processing. The results indicate that, following training, participants improved in the trained task, in the WM updating transfer task, in a task switching situation, and in attentional processing. However, there was no transfer to the dual task. Further evidence comes from other studies showing that training on task-switching improves cognitive flexibility and generalizes to new untrained tasks assessing other dimensions of executive functioning (e.g., Karbach and Kray, 2009).

However, the conclusions about transfer effects from WM training are not consistent across studies, a fact that has stimulated a debate regarding the potential efficacy of training for improving not only WM but also related cognitive abilities (e.g., Titz and Karbach, 2014). The empirical evidence on the generalizability of training gains is quite mixed (for a discussion, see von Bastian and Oberauer, 2014). Some researchers indeed report only significant improvement on the trained tasks (e.g., Jaeggi et al., 2011). Others reveal occasional near transfer to tasks that were not explicitly trained but share similar task features with the training tasks (e.g., Dunning and Holmes, 2014), and sometimes even more far-removed transfer to tasks measuring a different construct (reading comprehension, e.g., (Dahlin, 2011); mathematics, e.g., (Holmes and Gathercole, 2014); fluid intelligence, e.g., Borella et al., 2010). Furthermore, the results of some studies show the maintenance of these effects (e.g., Dahlin, 2011), alongside others reporting that the effects were not maintained at follow-up measurements (St. Clair-Thompson et al., 2010). To date, it does not seem feasible to reject one of the positions in favor of the other. The inconsistency of results regarding the efficacy of WM training are explained by large differences in terms of the methodologies that have been adopted across studies (see Shipstead et al., 2012; Melby-Lervâg and Hulme, 2013). Besides methodological issues, to draw consistent conclusions about the effectiveness of WM training it is also important to consider that the magnitude of training-induced gains are potentially influenced by the underlying mechanisms mediating transfer, not to mention additional factors that could influence the success of training interventions (for a review, see von Bastian and Oberauer, 2014). Therefore, it seems more appropriate to analyze under which circumstances WM training can improve cognitive performance. Moreover, it remains open which type of training most efficiently supports the occurrence of transfer effects.

IMPROVING READING COMPREHENSION BY TRAINING THE INVOLVED WM'S EXECUTIVE FUNCTIONS

We aim to contribute to the debate on the feasibility of WM executive functioning training. A relevant question we are concerned with is whether and to what extent interventions that contribute to enhancing WM's executive processes involved in higher-level cognitive abilities, such as reading comprehension, would improve these abilities. This is of particular relevance in childhood and adolescence, given that executive functioning is not only related to higher-level cognitive abilities contributing to academic success, but also to performance in the classroom (for reviews, see Swanson and Alloway, 2012; Titz and Karbach, 2014). In this section, we begin with an examination of studies demonstrating alternative approaches to WM training that provided evidence favoring the conclusion that WM training can benefit reading comprehension. We follow with a description of our training proposal on WM's executive functions involved in reading comprehension.

Reading comprehension is considered a complex and highly demanding cognitive task that involves the simultaneous process of extracting and constructing meaning (e.g., Kintsch, 1998). The functional role of WM in reading comprehension and its component skills has been well-established, both in typical developing children (Cain et al., 2004) and in individuals with poor reading comprehension abilities (e.g., Carretti et al., 2009). As numerous authors have maintained, WM plays a crucial role in storing the intermediate and final products of a readers' s computations, as well as coordinating the processes of constructing and integrating a semantic representation from the text (e.g., Just and Carpenter, 1992; Ericsson and Kintsch, 1995). Besides the role of the phonological component of WM for reading comprehension, growing evidence supports the involvement of the diverse yet interrelated CE processes and underscores the importance of attentional control (see e.g., De Jong, 2006). For instance, Swanson et al. (2006) pointed out that the EF of coordinating cognitive operations is required to integrate information from text and LTM. Likewise, Palladino et al. (2001; see also Carretti et al., 2005) linked WM's updating to reading comprehension skills. Also, whereas Yeniad et al. (2013) reported the relation between shifting and reading, De Beni and Palladino (2000) have underscored the function of inhibiting possible representations and discarding information in reading comprehension.

Despite the strong relation between WM's executive functions and reading comprehension, there are very few studies that have assessed the effects of WM and EFs training on reading comprehension. In that respect, a review by Titz and Karbach (2014) showed limited but converging evidence for positive effects of process-based complex WM training (i.e., training of specific cognitive processes, without explicit strategy training) on academic abilities, particularly in the domain of reading. The benefits were found in typically developed students as well as in children with cognitive deficits and learning difficulties. In contrast, other studies found significant improvements in tasks assessing the CE components of WM after training, but no improvements were found on reading comprehension (e.g., St. Clair-Thompson et al., 2010). A possible explanation of these contradictory results about the effectiveness of WM and EFs training may stem from differences regarding the kinds of interventions employed in existing studies and the characteristics of the study sample. More specifically, variations across studies were identified in several factors that could influence the success of training interventions, such as the type of training procedure, the intensity, and duration of training, stepwise adjustment of task difficulty to individual performance during training, or the design of the control conditions. The following discusses some methodological issues in the studies of effects of WM training on reading comprehension.

A subset of previous training studies are focused on a training procedure that elicits practice on only a single task (or several variants of one type of task), and which allows the individual to analyze specific aspects or functions of WM. For instance, Chein and Morrison (2010) developed an adaptive training protocol that involved verbal and spatial adaptive versions of a complex WM span task that taxes several different processes, such as encoding, attention, and WM updating. After 4 weeks of intensive training, participants (mean age of 20 years) improved significantly more than non-active controls on measures of complex WM span as well as on complex reading comprehension tasks, as measured by a standard reading test (Cohen's $d = 0.58$). Since training improved different abilities, the authors inferred that the training task must have affected a domain-general mechanism responsible for attentional control processes.

Positive transfer to reading comprehension has also been reported in studies using WM training protocols based on a range of computer-based memory tasks. The most well-known program is Cogmed WM Training battery (CWMT), a battery of video-game-like tasks, each aimed at improving WM and executive control (Klenberg et al., 2001; for a controversy on CWMT, see Shipstead et al., 2012). The difficulty level of each task is adjusted for each trial to ensure that the individual is working at her or his personal limits. For instance, in Dahlin's intervention study (2011), primary school students (9–12 years) with special needs were trained daily by using tasks from the CWMT for 30–40 min over a period of 5 weeks in school settings. The computerized training program included both visuo-spatial and verbal working memory tasks, with a fixed number of trials (100) to be completed each day. The results showed that, compared to the passive control group of Klingberg et al. (2005), children improved on reading comprehension (Cohen's $d = 0.88$), but not on word decoding or orthographic verification experimental tests, and the benefit was maintained for 6 months.

Along this line, two studies involving typically developing children have yielded consistent results by applying a computerized WM training intervention based on complex WM tasks from the Braintwinster battery (Buschkuehl et al., 2008). First, Loosli et al. (2012) applied a brief (10 sessions over 2 weeks), adaptive computerized WM training program based on a complex WM span task from the battery to train children (9–11 years) to improve reading performance. These authors found that, compared to a passive control condition, the training intervention significantly enhanced experimental group performance on the trained WM task, but also on a standardized reading test (Cohen $d = 0.20$). Particularly, WM training had a smaller impact on single-word reading performance than on text comprehension tasks. Second, Karbach et al. (2015) found that 14 sessions of an adaptive WM training applying tasks from the Brain twister battery improved performance in elementary-school children (mean age = 8.3 years) on untrained WM tasks and on a standardized test of reading abilities. Moreover, transfer to untrained WM tasks was maintained over 3 months. The analysis of individual differences revealed compensatory effects with larger gains in children with lower WM and reading scores at pretest.

As we can see, the aforementioned studies report findings that support the view that WM has the potential to improve reading comprehension. Prior evidence mainly comes from studies that have applied a process-based WM training program based on intensive practice on memory tasks. The applied tasks do not only require storage, but also additional processing demands. Thus, these training programs might rightly be considered CE training. Given this approach, training often yields large improvements on the trained tasks, but it also results in transfer effects to reading comprehension. Additionally, the interventions often implemented an adaptive training procedure. In that respect, Karbach et al. (2015) demonstrated that adaptive WM trained resulted in larger training gains than non-adaptive low-level training on the same tasks (active control group), but the question is still open whether adaptivity really plays an important role for the effectiveness of WM training interventions (see, von Bastian and Oberauer, 2014).

Nevertheless, there are certain issues in these studies that should be acknowledged. First, one common practice has been to compare the performance of the training group to that of a non-active control group, but one that did not attend any intervention. In this way, it raises the question of what degree performance changes within the training group can be attributed to the training tasks instead of to the existence of an intervention *per se* (Shipstead et al., 2012). Another issue that arises when trying to draw conclusions about the effectiveness of these training approaches is that the evidence is only based on one reading comprehension measure. The interpretation of these findings may be problematic because generalization could be the result of idiosyncratic relationships between the trained and assessment tasks, and not because of any enhancement in the underlying ability thought to be measured by the assessment task itself. As Shipstead et al. (2012) pointed out, transfer effects of training should be demonstrated using a wider variety of tasks.

On the other hand, most of the previous training programs have involved individual training sessions that were not part of classroom activities. Also, prior training procedures were implemented by researchers under controlled and intensive conditions that cannot feasibly be achieved in non-research situations. As a consequence, it is not clear how the training of WM is applicable in educational settings or to whole classes (see Gathercole et al., 2006). Interestingly, it was found that adaptive WM training based on tasks from CWMT battery transferred to new untrained WM tasks, but not to basic word reading abilities in children (8–11 years old) with low WM ability (Holmes et al., 2009; Dunning and Holmes, 2014). In contrast, a similar training program administered by teachers to their own pupils (aged 9–11 years) with low academic abilities improved, compared to a passive control group, children's performance in English, as measured by means of a national standard assessment test (Holmes and Gathercole, 2014). These results suggest that WM training has the potential to transfer to academic abilities, even when conducted by teachers in real-life conditions in schools, with effect sizes (Cohen's d effect sizes range from 0.56 to 0.67) comparable to those reported in research studies.

From an applied point of view, the importance of having the teaching of WM and its processes embedded into the classroom curriculum is obvious. Adopting this perspective, some WM and EFs training interventions are based on teaching strategies that address EFs in classroom activities (e.g., Meltzer et al., 2007; Gaskins et al., 2007) Among the few studies that have attempted to enhance WM by means of a range of activities suitable for including in the school timetable and conducting in classroom, the one conducted by Carretti et al. (2014) deserves mention. They implemented a training procedure that combined a range of activities focusing on WM and on metacognitive reflection in reading comprehension. After training by teachers, the authors found medium to large positive effects on reading comprehension skills in primary school children (8–10 years), and the effects were maintained after 11 months. These findings highlight the relevance of integrating WM training into the classroom curriculum.

As for our theoretical view, we propose a novel approach regarding how EFs can be improved through training in educational settings (for details, see García-Madruga et al., 2013). This new training program was designed to improve reading comprehension in primary school students by boosting the executive processes of WM involved in it: focusing on relevant information, switching (or shifting) between representations or tasks, connecting incoming information from text with long-term representations, updating of the semantic representation of the text in WM, and inhibition of irrelevant information. A few training principles were assumed that, as Diamond pointed out (2013, p. 154), seem to hold for effective training: (1) executive functioning training appears to transfer; (2) EFs demand needs to be continually and incrementally increased; and (3) practice is key.

A main feature of this training program is that it was directly implemented into reading comprehension activities. However, the main focus of the training procedure was not to train reading comprehension itself, but to train the conscious control of the cognitive processes involved in it. For this purpose, a variety of reading comprehension tasks were used for training, of which four core WM EFs are particularly involved (see **Table 2**). The focusing function on specific and relevant information to resolve the task is present in all of them. The switching function is particularly required on the tasks in which readers have to shift back and forth between diverse pieces of information or when the task includes diverse subtasks. Connecting with long-term knowledge is particularly necessary when performing tasks that require combining information from the task with information from long-term memory. The updating function is present in those tasks that require monitoring and coding incoming information relevant to the tasks at hand and then appropriately revising the items held in WM and replacing older, no longer relevant information with newer, more relevant information. Finally, the inhibition of irrelevant information occurs in tasks in which students need to inhibit or override the tendency to produce a more dominant or automatic response. In order to make the trained EFs easy to understand and remember, distinctive icons were used to represent them throughout the training program (see **Table 2**). Adopting an adaptive training perspective, researchers gradually increased the items within each task, as well as the difficulty of the task by increasing, throughout the training sessions, the number of units of information (e.g., words, actions, frames…) to be followed (remembered or integrated), or the distance between critical sentences in the text to answer a comprehension question. Training tasks, examples, variables manipulated for increasing the difficulty, and sessions in which each task was performed are shown in **Table 3**.

The first and last intervention sessions were particularly relevant. In the first session one of the researchers explained in a detailed and direct way the component processes as well as the outcome of reading comprehension. Participants understood and consciously agreed that text comprehension is a real complex task that requires the activation and control of their cognitive resources by using the core EFs. In the last training session students were led to reflect on the utility of the four basic executive processes for diverse daily intellectual activities; likewise, we insisted on the idea that the repeated practice of the four basic processes would be developed such that students could become "mental athletes." In this final session a personal diploma was presented to each of the students.

TABLE 2 | The executive processes trained, their icons, and the tasks used in García-Madruga et al. (2013; exp. 2) and Carretti et al. (under revision).

Executive Function	Icons	Tasks tapping into each executive function
Focusing		Vignettes in Order, Decoding Instructions, Sentences in Order, Anaphora, Inconsistencies, Inferences, Main Idea, Changing Stories and Integrating Knowledge
Switching		Anaphora, Inconsistencies, Inferences and Integrating Knowledge
Activating and Updating Representations in WM		Vignettes in Order, Decoding Instructions, Sentences in Order, Anaphora, Inferences, Main Idea and Changing Stories
		Sentences in Order, Anaphora, Inconsistencies, Inferences, Changing Stories and Integrating Knowledge
Inhibition		Vignettes in Order, Decoding Instructions, Sentences in Order, Anaphora, Inconsistencies, Main Idea, Changing Stories and Integrating Knowledge

Another feature of this training intervention is that it promotes controlled processes through a metacognitive approach, so that the participants receive guidance to recognize and form awareness of the involvement of control processes involved in training program activities, as well as to think about their importance. The instructional techniques used were: (a) explicit instruction by the trainer in the EFs related to the task; (b) modeling examples of the task by the trainer; (c) guided practice; and (d) student independent practice. As a final outcome, the proposal of using repetitive practice was intended to achieve some kind of automated behavior, but always under the control and monitoring of executive processes. That is, it shares features of both implicit and explicit training (Klingberg, 2010).

Our proposed training approach differs in various ways from that of previous training research conducted with children. A key difference is that, instead of intensive training on WM tasks, children performed different text-processing tasks each day selected from the battery of eight tasks included in the training program, as showed in **Table 3**. Also, unlike many other WM-training studies in which only one training task was used (e.g., Loosli et al., 2012), our training procedure was implemented through a variety of reading comprehension tasks. The tasks we used require increasingly higher attentional control resources and can hence improve students' use of executive processes during reading. Finally, instead of intensive and long training time used in other approaches (e.g., Klingberg et al., 2005), a relatively minimal amount of training time was required in the training program we developed (10–12 sessions of 50 min over 4 weeks).

Evidence for the impact of our training proposal on WM's EFs involved in reading comprehension comes from three studies applying this program to train typical developing children. We expected that even small increases in WM's executive functioning through training would significantly improve children's performance on reading comprehension. These studies attempted to avoid some of the methodological concerns of previous WM training studies (see Shipstead et al., 2012) by using more appropriate WM span tasks, different tasks in the pre- and post-testing than those used in training, more than one measure for WM's EFs and reading comprehension, and active contact groups when possible.

The first study (García-Madruga et al., 2013, exp. 1) was conducted with third-grade students (8–9 years) who were trained for approximately 50 min a day for 12 days over a 4-week period in the classroom. Reading comprehension was assessed at pretest and posttest intervention by means of a Spanish version of the Diagnostic Assessment of Reading Comprehension Test (EDICOLE: August et al., 2006; García-Madruga et al., 2010), a test based on a theoretical analysis of the main components of this ability (Hannon and Daneman, 2001): text information memory, inferences based on information provided in the text, and integration of accessed prior knowledge with new text information. In the experimental group, there was a significant gain after training in the posttest for reading comprehension (Cohen's $d = 0.67$). Moreover, compared with that of a control group that received normal class instruction in Spanish language and reading comprehension, there was a significant higher pretest to posttest gain in the experimental group for reading comprehension, and this effect was large (Cohen's $d = 0.72$). In addition, a Spanish version of the Reading Span Task (RST; Daneman and Carpenter, 1980) for primary school students (Orjales et al., 2010) was used to measure WM capacity at pre- and post-test evaluation. The gain found in favor of the experimental group for RST was not significant. The lack of improvement in this WM measure might be due to the fact that RST is a task that loads mainly on storage and verbal components, even though it is a CE measure.

The second study (García-Madruga et al., 2013, exp 2) was conducted with a larger experimental group and a shorter time period for the entire pretest-intervention-posttest period. Following the procedure described above, the participants (ages 8–9 years) were trained for 10 days in their classroom over a 4-week period. Before and after training, all participants were assessed on reading comprehension by means of the EDICOLE Test, as in Exp. 1, and three complex WM and CE measures of WM capacity. First, a verbal analogy span test for primary-school children (Orjales and García-Madruga, 2010) was used. It has an underlying structure similar to the RST, but instead of only reading aloud and selecting the last word of each sentence, participants have to solve a verbal analogy inference, and store and remember the correct word solution. Second, participants performed a semantic updating span task (Gómez-Veiga et al., 2010; based on Palladino et al., 2001), in which the recall of a variable number of items following a specific semantic criterion

TABLE 3 | Training tasks, examples, variables manipulated for increasing difficulty, sessions in which each task was performed, and the number of items, in García-Madruga et al. (2013, Experiment 2) and Carretti et al. (under revision).

Task	Description *Participants were required to…*	Example of task item	Difficulty	Sessions	Items
Vignettes in Order	To put in order an increasing number of vignettes	Arrange the following pictures frames	Number of frames	1, 2	50
Decoding written instructions	To read verbal instructions, interpret and perform complex written instructions involving the integration of a sequence of actions	*Write your name and two surnames. Then, draw a circle around the last letter of your name and the first letter of your last surname. Do it without lifting your pencil.*	Number of actions to be performed	2, 3, 4, 5, 6, 7, 8, 9,10	48
Sentences in Order	To organize series of sentences into the correct order to create a coherent story	Arrange the following sentences: *Maria looks for her place* *Maria buys the ticket* *The movie has started* *Maria waits in the line*	Number of sentences	3, 4	26
Anaphora WM	To solve semantic anaphora, and then store and remember the word solution in a growing series of inferential problems	*Robert painted it white before the summer arrived.* *– roof* *– façade*	Number of words to be remember	4, 5	14
Detecting textual inconsisten-cies	To act as a detective looking for mistakes in a text, either an inconstancy between two ideas expressed or an inconsistency between text and reader's prior knowledge	Internal: *Laura used eyeglasses to read (…) Laura's eyesight was excellent*. External: *Elena was flying in the depths of the lake when he decided to go back.*	*Internal*: distance between sentences *External*: salience of the inconsistency	5, 6, 7	30
Making inferences	To make a text-based inference —integration among individual sentences in the text—, or elaborative inferences —integration of general knowledge with information in the text	(Student reads the text)…Ask the next questions: *Why did they put the sparrow near to the fireplace?*	*Text-based*: Distance between sentences, *Elaborative:* Memory load	6, 7	30
Following changing stories	To read a text including a stream of information in which the relevant facts are constantly changing; to actively keep track of the information as they read it and, at several points of the story, to determine the state of different aspects of the story at that time	*In what order were the horses at the end of the race?*	Number of units of information to be followed	8, 9	18
Integrating information from different formats	To focus and switch attention to different units of information presented on a screen in different formats (i. e., text, video, pictures), in order to be able to answer several questions that required the integration of multiple sources of information	After watching the video and reading the test, ask the following question: *What type of solar eclipse is presented in that picture?*	Number of units of information to be integrated across sources	8, 9	15

in a list of words is measured. Third, a Spanish adaptation of the visuospatial selective span task developed by Cornoldi et al. (2001) was used to assess students' visuospatial WM capacity and the executive processes related to the control of a dual task.

The results of experiment 2 confirmed significant gains after training in the experimental group on the three main components of reading comprehension, and the effects were around medium size: memory and recalling new information presented in the text (Cohen's $d = 0.33$), inferences (Cohen's $d = 0.62$), and integration (Cohen's $d = 0.65$). The effect size for the overall EDICOLE was large (Cohen's $d = 0.79$), as in experiment 1. There was also a significant increase after training on semantic updating and visuospatial WM measures, and the effect was medium to large (Cohen's $d = 0.62$ and 0.77, respectively). However, no significant gain was found after training on the analogy test of WM capacity. As can be noted, the training program yielded greater benefits on the two components of comprehension—inferences and integration—that require an extra mental operation. In these components of reading comprehension, executive control is more involved than it is in text memory. Moreover, the diverse effects of training on participants according to their prior abilities on reading comprehension, as measured by EDICOLE in pretesting, indicate that low reading comprehension students reached a very clear and significant greater gain after training than the high reading comprehension group (Cohen's $d = 0.34$). Since the training program was particularly adapted to the low reading comprehension group, the results support the arguments in favor of adaptive training (e.g., Salminen et al., 2012). Another interesting point is that the use of three tasks in Exp. 2 to evaluate WM training effects, different from those used in training, has allowed us to provide evidence of significant gains in WM's executive functioning and, therefore, a transfer effect of training on the executive process measures. However, the lack of a control group in this experiment requires us to be prudent.

The third study Carretti et al. (under revision) replicated the effects of the training procedure on reading comprehension and extended the results obtained by García-Madruga et al. (2013). The trained group's performance was compared with that of an active and a passive control group before and after the training (10 sessions) and in follow-up sessions 2 months later. The groups were comparable in terms of age (8–9 years old), decoding ability and vocabulary. The active control group took part in standard classroom activities for developing reading comprehension (e.g., read a text and answer different kinds of questions on details of the text). Reading comprehension performance was assessed by using an Italian version of EDICOLE and an Italian standardized reading comprehension test for primary school (Cornoldi and Colpo, 2011). WM capacity was assessed by using an adaptation of the semantic updating span task (Palladino et al., 2001). The results indicated that the trained group—following the procedure described in García-Madruga et al. (2013, exp. 2)—performed better on the standardized measure of comprehension than did both control groups at posttest. At follow up, the trained group performed better than the active or the passive control groups on EDICOLE measures, but the effects were not robust and showed signs of fading. Whereas the trained group's gains from pre- to post-test were medium in terms of effect size for both reading comprehension measures, there was a large effect for WM measure, and the benefits of training were maintained 2 months after intervention.

Overall, the findings regarding the effects of this training approach support the view that it is possible to promote reading comprehension in children by boosting the CE functions during the process of reading, even when training is conducted as part of classroom instruction. Particularly, it provides evidence for the higher contribution of WM's EFs training to those components that require more executive control in reading comprehension tasks: inferences and integration. The results of these studies are consistent with the assumption that cognitive enhancements from our training proposal may have affected not only a specific but also a more domain-general mechanism involved in various executive processes. We note that, since the training tasks took the form of a reading comprehension task and participants were not trained by using WM tasks (except for the anaphora task that share the underlying structure with WSP and the analogy span test), it is difficult to separate the specific differential weight of WM's executive processes training with that of reading comprehension practice to explain the improvement of reading comprehension. Nevertheless, the finding that confirms the efficacy of the intervention in reading comprehension is a relevant result of this training approach. Some transfer effects may also be found by using another complex reading comprehension task to assess the training efficiency. As significant transfer effects were found in different studies (García-Madruga et al., 2013; Carretti et al., under revision), using the same procedure and two different reading comprehension tests that were performed by different experimental groups, we rather think that the beneficial effects found are driven by the training intervention.

As a matter of fact, the training program was relatively brief (10 sessions in Exp. 2), which is shorter than the training time used in other approaches (e.g., Dahlin, 2011), and involved practice distributed over 4 weeks. Even so, this training approach seems to produce effects on measures of WM executive processes and reading comprehension comparable to other training regimes aforementioned, and maintenance effects were also found in reading comprehension as well as in WM measures. The benefits of standardized measures of reading comprehension, as well as those similarly obtained from other training programs, suggests that training improvements may transfer to ecologically valid measures of reading in students of primary school. However, as mentioned, the benefits at follow-up were not robust. Jaeggi et al. (2008) reported dose-dependent effects of training, with more sessions leading to larger transfer effects. Given the reduced number of sessions included in our training program, some further sessions would likely be needed in order to maintain gains at follow up. This hypothesis is requiring, obviously, an empirical test confirmation. In addition, more systematic research is needed to define the optimal intensity and duration of the training intervention.

Finally, we think that training would yield similar results in other complex reading comprehension tasks that demand the precise, deep, and controlled understanding of texts. This hypothesis would require further research and confirmation. In contrast, according our view WM's executive processes training might have smaller impact on those reading tasks that place less demand on WM such as basic word reading skills (see Holmes et al., 2009; Dahlin, 2011; Loosli et al., 2012).

CONCLUSIONS

In the current paper we have presented an overall view of EFs that includes three main kinds of processes: core on-line EFs, higher order EFs, and emotional control. This theoretical proposal is based in recent theoretical and experimental breakthroughs and attempts to clarify the relations between WM, EFs, and higher-level cognition. A corollary of this theory is that we can improve thinking abilities by improving the use of executive functions during the process of solving complex cognitive tasks involved in each kind of thinking ability. We have also presented an instructional program to improve reading comprehension based on training the core executive processes involved in the solution to a set of selected tasks, as well as the main results found in a set of training experiments recently carried out.

As briefly discussed, an important feature of executive processes is that they are potentially modifiable. There is a considerable amount of evidence on WM and executive function interventions and training, although their overall generalizing effect is still a matter of debate. Our proposal does not require a high generalizing effect since we are intervening on the executive processes involved in a set of tasks that represent the complexities and difficulties of reading comprehension. Our experimental findings on reading comprehension confirm an improvement in reading comprehension and WM executive processing measures in posttest and follow-up measures. From our theoretical perspective we certainly expect some kind of generalization. Given that the same EFs are involved in two different higher-level cognitive abilities, generalizing the results between the two abilities is possible. Therefore, we share the idea of a domain-general mechanism (WM and EFs) that might underlie the generalization effect found recently in diverse studies (Klingberg et al., 2005; Buschkuehl et al., 2008; Jaeggi et al., 2008; Persson and Reuter-Lorenz, 2008; Chein and Morrison, 2010). However, our view maintains that if we want to achieve robust and significant effects, the repeated and adaptive training of complex WM task is not enough. Instead, we have to go a step further and train the WM's executive functions involved in solving a set of representative tasks of the particular higher-level cognitive ability we want to improve. In other words, our view maintains that in order to improve thinking abilities the domain-general mechanism is insufficient. There are also domain-specific competences requiring the active use of EFs which have also to be trained.

Moreover, higher-level cognitive abilities cannot be reduced to the EFs involved in them. In other words, we do not agree with Diamond when she explicitly says that higher-level thinking, reasoning and creativity are in fact EFs. In our opinion, these higher-level intellectual abilities, that is, thinking and fluid intelligence, share the crucial role of EFs, but they are themselves not EFs. They are the result of applying executive processes to solve particular kinds of intellectual problems. They entail the manipulation of diverse kinds of representations, use diverse beginning and ending points, follow different thinking sequences, and have diverse aims.

Our view on the relationship between higher-level abilities and EFs suggests that a similar improvement to that obtained in reading comprehension can be achieved in other higher-level abilities as reasoning and problem solving. The design and development of the instructional programs for improving other intellectual abilities entails two main components: (a) a general theoretical view on EFs and how they can be instructed; and (b) a specific theoretical analysis of each of the higher-level abilities and the role of the EFs that operate on it, that will allow an adequate selection of the tasks to be instructed. A new training program on WM's executive functions to improve deductive reasoning in Secondary school students has been designed by our research group (García-Madruga et al., 2015) but not yet experimentally tested. Like reading comprehension, deductive reasoning requires the construction of representations, but its peculiar feature is to manipulate these representations in order to arrive at, if possible, a necessary conclusion. This goal-oriented sequential task of manipulating representations is performed in WM and can be defined as a kind of updating process driven by reasoners' meta-deductive knowledge and goals. The program is based on training participants in the four core EFs and a higher order one: revision. According to our view, these EFs underlie the application to solving diverse deductive tasks of two meta-deductive concepts (consistency and necessity) and two meta-deductive strategies (searching for counterexamples and exhaustivity).

Finally, we would like to address various limitations and perspectives of our theoretical conception regarding the improvement of thinking abilities. We have outlined the preliminary character of our theoretical view on EFs. Our proposal still requires empirical verification, particularly the two cognitive higher-order EFs, planning and revision, and their relationship with WM and core EFs, as well as their developmental pattern. Our experimental work has tested the efficacy of a program to improve reading comprehension, but not our theoretical view on EFs. In this regard, a second main limitation affects our experimental work. Given the overlapping nature of the core EFs involved in reading comprehension, our training experiments do not allow us to differentiate the role of each of the four core EFs. It is possible however to evaluate the relevance of each of the tasks used in training, as in fact is done in our second experiment (García-Madruga et al., 2013).

We are now working on an obvious testable prediction of our view: the empirical comparison of training efficacy between our instructional program on WM's executive functions involved in reading comprehension and an equivalent program based only on training the verbal and spatial complex WM task used by Chein and Morrison (2010), the n-back WM task frequently used in training studies, and our Analogy and Anaphora WM tasks. For that purpose, we will use diverse pre- and post-training measures of reading comprehension, WM's executive processes and fluid intelligence. Likewise, a more detailed analysis and evaluation might be done in the future with respect to the impact of higher order cognitive EFs such as planning and revision. For instance, the specific role of planning and revision in problem solving and reasoning, respectively, might be evaluated by introducing (or not) the training of these EFs, other than the core EFs, in instructional programs to improve these intellectual abilities.

The final aim of our programs to improve reading comprehension or reasoning through the intervention on the relevant EFs also includes moving beyond these abilities in our attempt to improve education. EFs are involved in every learning task that requires a cognitively active and controlled performance from the learner (see e.g., Meltzer, 2007). The role of EFs is therefore crucial in the acquisition of basic instrumental skills such as reading, writing, and arithmetic. Likewise, EFs are required in the acquisition of diverse kinds of academic content. For instance, complex declarative learning is another higher-level intellectual ability in which EFs are obviously involved and one that directly depends on reading comprehension and reasoning. In a directly related way, WM and EFs deficits underlie learning and intellectual disability. The intervention on the EFs particularly involved in diverse learning and intellectual disabilities is thus a promising way to improve an individual's performance. According to our view, these interventions demand a previous and detailed analysis of each particular disability and the role of EFs involved in it, in order to design an instructional program and select the appropriate training tasks. Although WM and EFs play a role as a domain-general mechanism that underlies intellectual and learning disabilities, there is not a domain-general procedure of improving them. Domain-specific procedures and programs to improve WM and EFs are required if we want to improve individuals' learning and intellectual disabilities.

AUTHOR CONTRIBUTIONS

All authors listed, have made substantial, direct and intellectual contribution to the work, and approved it for publication.

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