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An investigation of response and stimulus modality transfer effects after dual-task training in younger and older

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It has been shown that dual-task training leads to significant improvement in dual-task performance in younger and older adults. However, the extent to which training benefits to untrained tasks requires further investigation. The present study assessed (a) whether dual-task training leads to cross-modality transfer in untrained tasks using new stimuli and/or motor responses modalities, (b) whether transfer effects are related to improved ability to prepare and maintain multiple task-set and/or enhanced response coordination, (c) whether there are age-related differences in transfer effects. Twenty-three younger and 23 older adults were randomly assigned to dual-task training or control conditions. All participants were assessed before and after training on three dual-task transfer conditions; (1) stimulus modality transfer (2) response modality transfer (3) stimulus and response modalities transfer task. Training group showed larger improvement than the control group in the three transfer dual-task conditions, which suggests that training leads to more than specific learning of stimuli/response associations. Attentional costs analyses showed that training led to improved dual-task cost, only in conditions that involved new stimuli or response modalities, but not both. Moreover, training did not lead to a reduced task-set cost in the transfer conditions, which suggests some limitations in transfer effects that can be expected. Overall, the present study supports the notion that cognitive plasticity for attentional control is preserved in late adulthood.

Keywords: cognitive plasticity, cognitive training, transfer, divided attention, executive function, aging

INTRODUCTION

Conversing on a cell phone while crossing the street, tuning radio channels while driving, and cooking while watching a TV program are a few activities of daily living that require dividing attention between two or more concurrent tasks at the same time. It has often been reported that aging is associated with a decline in divided attention abilities and dual-task performances (Verhaeghen and Cerella, 2002). Age-related deficits in executive control mechanisms that support dual-task abilities are a major research concern. Indeed, dual-task performances appear to be a good predictor of several negative outcomes in late life, such as falls (Verghese et al., 2002), bumping while walking (Broman et al., 2004), and car crashes (Chaparro et al., 2005; Clay et al., 2005; Kramer and Madden, 2008). Improving the ability to perform two tasks simultaneously could therefore have significant impacts in the prevention of adverse outcomes associated with aging.

It has been suggested that age-related deficits in dual-task performance can be attributed to non-executive processes such as general slowing, higher stimuli interference, and less risky strategies (Glass et al., 2000; Hein and Schubert, 2004), but a meta-analytic research that controlled for some of these confounding factors still found robust age-related deficits in dual-task performances (Verhaeghen et al., 2003). Indeed, older adults are slower and less accurate than younger adults when performing two tasks simultaneously and the age-related deficit cannot be accounted for by mere general slowing (McDowd and Shaw, 2000; Verhaeghen and Cerella, 2002; Verhaeghen et al., 2003). The age-related deficit in attention control processes that support dual-task performance have often been associated with the vulnerability of the prefrontal cortex during aging, which globally compromises executive control (Cabeza, 2001; Cabeza et al., 2004; Davis et al., 2008). Interestingly, a recent meta-analysis showed that age-related decline in executive control is not general, but seems to be specific to divided attention (Verhaeghen, 2011).

Recent studies have shown that cognitive training can help improve performances in attentional control tasks. This has been shown in switching tasks (Kray and Lindenberger, 2000; Cepeda et al., 2001; Kray and Eppinger, 2006; Kray et al., 2008; Karbach and Kray, 2009), inhibition tasks (Davidson et al., 2003; Thorell et al., 2008), and updating tasks (Dahlin et al., 2008b; Jaeggi et al., 2008). Several training studies have also demonstrated robust increase in dual-task performance after cognitive training. It has also been suggested that dual-task performance relies on at least two specific abilities: (1) the preparation and maintenance of multiple task sets, as indexed by the *task-set cost* and (2) the coordination of stimulus perception and simultaneous motor response executions, as indexed by *dual-task cost.* While training did not allow equivalent optimization in dual-task performances in older and younger adults in some studies, even after extensive training (Strobach et al., 2012), others showed equivalent improvement in task-set and dual-task costs in both older and younger adults (Kramer et al., 1995; Elke et al., 1999; Schumacher et al., 2001; Bherer et al., 2005, 2006, 2008).

Although these studies suggest that cognitive training leads to enhanced attentional control in older adults, few studies have reported convincing evidence of transfer effect after training (Dahlin et al., 2008b; Green and Bavelier, 2008; Owen et al., 2010). Transfer effects refer to the generalization of learning from the training task to an untrained task, often referred to as a transfer task. To date, little is known about the extent and limits of transfer effects after cognitive training. Among studies that used dual-task training with older adults, some studies have reported significant transfer effects (Kramer et al., 1995; Bherer et al., 2005, 2008) but others have not (Dahlin et al., 2008a; Green and Bavelier, 2008; Owen et al., 2010). Moreover, in studies that reported significant transfer effects, it remains unclear whether enhanced performance in untrained tasks were supported by an improved ability to maintain several response alternatives (reduced task-set cost) or by a better response coordination ability (reduced dual-task cost). Moreover, in some studies, transfer effects seemed larger if the untrained tasks shared strong similarity with the training task with regards to input modality (e.g., both tasks involved visual input) and motor response modality (e.g., both tasks required motor responses). The present study was conducted to assess the extent to which cross-modality transfer effects can be expected after dual-task training in older and younger adults.

According to Barnett and Ceci's (2002) taxonomy (see also Zelinski, 2009), modality transfer refers to improvement observed in a new task that involves different stimuli, or input modality, than the one that has been trained (e.g., training with a visual task leads to improvement in an auditory task). Furthermore, modality transfer can be qualified as *near* or *far* depending on the distance between the modalities of the trained task and the transfer task. *Near modality transfer* refers to improvement on novel tasks that involve new stimuli but share the same stimulus and response modalities with the training task. The notion of near modality transfer is very close to the one of within-modality transfer used in some studies (Bherer et al., 2005). For the transfer to be qualified as *far modality transfer*, training-related improvement must be observed on tasks that involve different stimulus modalities (visual to auditory) and/or response modalities (manual tapping to foot tapping) than those used in training. The notion of far modality transfer is very close to the one of cross-modality transfer used in other studies (Bherer et al., 2005). Far modality transfer appears as an essential outcome for a cognitive training program to produce significant changes in activity of daily living. For example, if transfer is specific to the trained modality, one should not aim at improving driving performance or at improving balance while talking by training on computerized software that do not involve the same input or output modalities. Moreover, knowing the extent and limits of transfer would help creating new platform, or choosing among existing ones, when it comes to use video games devices (e.g., Wii's Wii Fit™, PlayStation's Eye™, Xbox's Voice Recognition™, etc.) in the context of cognitive rehabilitation with clinical populations.

Transfer effects reported so far in dual-task training studies appear limited to *near modality transfer*, or within-modality transfer. In a recent study in older adults, half of the trained participants practiced a visual number summing task while trying to detect peripheral visuals targets (flowers), while the other half practiced a visual letter-position subtraction task while also trying to detect peripheral targets (soccer balls). Both groups showed significant improvement in untrained version of the tasks after training as opposed to control groups (Mackay-Brandt, 2011). Similarly, increased ability to maintain and prepare multiple tasks (reduced task-set cost) and enhanced coordination of the two tasks (reduced dual-task cost) were observed on transfer dual-task conditions after training (Bherer et al., 2005, 2008). These results suggest that to some extent, near modality transfer effects (or within-modality transfer effects) can be expected after dual-task training. Interestingly, younger and older adults did improve to the same extent in the transfer tasks. However, far modality transfer or cross-modality transfer, after dual-task training only received partial support so far. Bherer et al. (2005) observed that training to perform simultaneously a visual and an auditory discrimination tasks can lead to enhanced performances in an untrained dual-task condition that involved two visual tasks, although improvement in task-set cost was not significant. In a more recent study (Bherer et al., 2008), older adults trained to perform two visual tasks did show improved task-set cost, but not dual-task cost, in cross-modality transfer tasks that involved performing a visual and an auditory transfer task concurrently. Although global performances in the transfer dual-task conditions suggest that training led to a generalizable improvement in the ability to perform concurrent tasks, these results suggest that there are some limits in the amount of cross-modality (far modality) transfer effects that can be expected after dual-task training. Hence, learning to coordinate two visual tasks might generalize to untrained visual tasks, but the amount of transfer would be reduced if at least one of the untrained tasks involved the auditory modality. According to this hypothesis, a transfer dual-task condition that involved two tasks in which the modality differs from the training task should show even less transfer effects, or none at all. In a recent set of studies (Liepelt et al., 2011; Strobach et al., 2012), young students practiced a visual task (discriminating circle locations by pressing keys on the keyboard) and an auditory task (discriminating low, middle, or high tones by answering "one," "two," or "three") simultaneously. A decreased of dual-task cost was observed in transfer conditions where either the visual or the auditory task was changed from practice. However, no decreased of dual-task cost was observed in transfer condition where both tasks changed from the practiced tasks. Authors concluded that task coordination skills are non-transferable and task-specific. However, it is important to note that, a decreased of error rates was observed on the auditory transfer task which indicated some level of transfer. Moreover, for the auditory task transfer condition, tones were the same but the mapping changed to "two," "one," or "three." This likely limits the transfer effects that could be expected since participants had to inhibit the mapping learned during training. Further studies are thus required to clarify whether transfer effects can be observed after dual-task training when the transfer dual-task condition involves two new and untrained concurrent tasks.

While stimulus modality transfer effects have received some support, the extent to which cross-modality transfer effects can be expected when the response modality differs from the training to the transfer tasks has not been systematically investigated. In Voelcker-Rehage and Alberts' (2007) study, older adults were trained on a motor control task, which was paired with an untrained cognitive task before and after training. Surprisingly, participants improved on the cognitive task but did not improve on the motor task. The authors suggested that motor supervision was highly demanding before training and that there were fewer resources available for the cognitive task. So far, studies that reported transfer effects after dual-task training in older and younger adults have used the same motor response modality (keyboard input) in training than in transfer tasks. There is thus no evidence of either near or far modality transfer involving a new set of response modalities. Transfer effects to new motor responses appear particularly relevant in the context of dual-task training in older adults. Indeed, Hartley (2001) showed that age-related deficits in dual-task performances were most likely to occur if the task combination involves two motor responses. The present study assessed whether dual-task training leads to some benefits in a new dual-task combination that involved new motor response modes and if transfer effects are equivalent amount older and younger adults.

The main objective of the present study was to explore further the limits of transfer effects that can be expected after dual-task training. For the first time, cross-modality transfer effects were systematically assessed by using three dual-task conditions; a dual-task condition in which the stimuli modality differed in both tasks from the tasks used in training, a dual-task condition in which the response modality differed from the training tasks in both untrained tasks, and a third transfer condition in which both the stimuli and the output modality were new in both tasks. In all three transfer-task conditions the amount of change in task-set and dual-task costs was also measured in order to assess whether transfer effect were supported by increased preparation for multiple tasks or enhanced ability to coordinate the two concurrent tasks. Another goal of the present study was to assess whether age-related differences exist in the amount of cross-response and cross-stimulus modality transfer effects.

MATERIALS AND METHODS

PARTICIPANTS

Twenty-three older adults and 23 younger adults participated in the study. All participants were healthy community-dwellers who provided informed consent to participate in the study. The older adults group was composed of 18 women and 5 men (age: $M = 68.5 \pm 7.1$ years; education: 14.4 ± 3.4 years). The younger adults group was composed of 13 women and 10 men (age: $M = 23.7 \pm 3.0$ years; education: 15.3 ± 1.7 years). Participants were excluded if they had depressive disorder, neurological disorders, uncorrected or impaired vision or audition and a history of stroke or general anesthesia in the past 6 months. On the first session, older participants completed the Mini-Mental State Examination (Folstein et al., 1975). Participants having a score below 26/30 were excluded. Participants were then randomly assigned to training or control group. Participants were blinded to the existence of different groups. The training group was composed of 13 younger and 13 older adults while the control group was composed of 10 older and 10 younger adults.

Prior to assessment of dual-task performances, both experimental and control groups were compared through an assessment of several neuropsychological tests: verbal abstraction (Similarity test; Wechsler, 1997), verbal fluency (P-T-L phonetic fluency), mental reasoning (matrix; Wechsler, 1997), processing speed (Digit Symbol Substitution; Wechsler, 1997), short-term and working memory (Digit span forward and backward; Wechsler, 1997), and attention and executive functions (Stroop Color Test and Trail Making Test A and B (Reitan, 1958; Bohnen et al., 2002; Chatelois et al., unpublished data). For a detailed description of each test, see Lezak et al. (2004). ANOVAs performed on neuropsychological tests performances as dependent variables and training group as between group factor (training vs. control) indicated that in both younger and older adults, there was no significant difference between training and control groups (see **Table 1**).

THE DUAL-TASK PARADIGM

The dual-task paradigm runs on E-prime 2.0 from Psychology Software tools. Participants started each trial by pressing the space bar or by pressing a button on the wheel depending on the response modality. Then, a fixation point (an asterisk) appeared in the middle of the screen for 500 ms followed by stimuli presentation, which lasted until participants provided a response. Participants controlled the length of the inter-stimulus interval by triggering the next trial, but a minimum inter-stimuli interval of 750 ms was set. Participants were asked to respond as quickly and accurately as possible. A visual warning appeared when participants committed errors ("wrong answer" in red).

Each dual-task condition involved pure and mixed blocks. In pure blocks, participants performed only one of the two tasks at a time (*single-pure trials*). In mixed blocks, participants either performed the two tasks concurrently (*dual-mixed trials*) or just one of the two tasks (*single-mixed trials*). Therefore, single-mixed trials differed from dual-mixed trials simply in the presentation of one or two stimuli, with no further indication given to the participants. The order of the single- and dual-mixed trials within the mixed blocks was unpredictable. Participants were instructed to give equal priority to both tasks.

Comparisons between the different trial types provide valuable information with regard to the potential mechanisms involved in dual-task performances. Performances on single-pure trials can be viewed as an indicator of general processing speed, while comparison between single-pure and single-mixed trials (referred to as task-set cost) provides a measure of processing required to prepare and maintain multiple task sets. Difference between performances in single-mixed and dual-mixed trials can be viewed as a measure of the ability to perceive multiple stimuli and coordinate the execution of two motor responses. This measure is referred to as the dual-task cost. While a decrease of the task-set cost is interpreted as an improvement of the ability to prepare and maintain in working memory multiple stimulus–response alternatives, a decrease of the dual-task cost can be considered as an indicator of improved task coordination abilities require in executing multiple tasks.

STIMULI AND MOTOR RESPONSES

The training dual-task condition involved two visual identification tasks. Stimuli appeared in the middle of a 19″ flat screen, on

Table 1 | Demographic Data and Performance Scores on the Tests Measuring Cognitive Functions.

	Older				Younger			
	Trained (N = 13)		Control (N = 10)		Trained (N = 13)		Control (N = 10)	
	M	SD	M	SD	M	SD	M	SD
DEMOGRAPHICAL DATA								
Age(years)	68.5	6.9	68.5	7.6	24.1	3.9	23.1	2.8
Gender (# of women)	11		7		7		6	
Education (years)	14.9	1.7	13.7	4.0	14.9	1.7	15.7	1.8
IQSP	10.8	3.3	13.6	5.7	9.7	6.1	6.7	5.5
GENERAL COGNITION								
Mini Mental State Examination	28.3	1.2	28.8	0.8				
ABSTRACTION								
Similarity (WAIS-III)	24.0	4.1	24.9	4.2	27.0	3.7	24.6	3.7
Matrix (WAIS-III)	15.4	4.4	15.7	4.2	21.9	1.6	21.2	2.0
SHORT-TERM AND WORKING MEMORY								
Digit span forward	9.3	1.8	9.5	1.6	11.0	1.8	10.3	1.9
Digit span backward	6.9	2.2	7.2	3.9	7.9	1.9	7.9	2.5
PROCESSING SPEED								
Digit coding (score)	63.7	13.0	58.5	17.6	82.7	15.4	86.3	21.1
Stroop-word (ms)	42.6	5.0	43.8	5.5	37.4	6.4	40.3	4.9
Stroop-color (ms)	70.4	11.8	65.7	11.1	55.7	11.8	63.8	11.4
Trail A (ms)	37.0	10.8	41.0	14.5	23.5	7.0	27.3	7.8
VERBAL FLUENCY								
Verbal fluency P-T-L	47.5	13.3	51.3	12.6	50.9	8.8	49.3	6.6
ATTENTION AND EXECUTIVE FUNCTIONS								
Stroop-interference (ms)	120.8	23.3	113.9	21.8	87.8	15.5	92.7	18.9
Stroop-switching (ms)	137.6	29.3	137.0	30.6	107.0	21.2	115.2	30.2
Trail B (ms)	85.8	31.5	87.0	23.7	54.5	19.7	49.8	12.0

a black background. Viewing distance was approximately 45 cm. At this distance, visual stimuli subtended a vertical visual angle of 1.15° and a horizontal visual angle of 0.76°. One task required identifying the direction of a white arrow (left or right) by pressing "A" or "S" on the keyboard with the index or the middle finger of the left hand. The other task was to identify the color of a square (red or green) by pressing "K" or "L" keys with their right hand index or middle finger.

Three transfer dual-tasks conditions were designed for this study. The stimulus modality transfer (S-MT) dual-task combination involved two auditory discrimination tasks: to judge if a pure sound (990 Hz) was coming from the left or right headphone speakers and to discriminate the words "GO" or "STOP" presented in stereo in the headphone. Participants could adjust sound volume as needed and responses were provided using the same keys as in the training dual-task condition. In the response modality transfer (R-MT) condition, the participant had to turn the wheel in the direction of the arrow and had to press the accelerator or the brake depending on the color of the square, red or green. Stimuli were identical to the ones used in training dual-task condition. Finally, the stimuli–response modality transfer (SR-MT) condition used the same stimuli than the S-MT and the same responses than the R-MT.

PRE- AND POST-TRAINING PROCEDURES

In the pre- and post-training sessions, participants completed four dual-task combinations; the training task as well as the three transfer dual-task combinations. Each dual-task combination lasted around 20 min during which participants started with two pure blocks (20 single-pure trials), followed by two mixed blocks (40 single-mixed and 40 dual-mixed trials), and two pure blocks (20 single-pure trials). No feedback on speed was provided. **Table 2** resumes the blocks structure of pre and post-training evaluations.

TRAINING PROCEDURE

Less than 1 week separated training from the pre- or post-training sessions. The training regimen was composed of five training sessions of approximately 1 h each. Participants were asked to attend to two or three sessions a week but they had to wait a minimum of 1 day between each session. Training was performed in a computer room allowing 10 participants to train simultaneously. Participants from the control group did not receive the training but had to wait an equal lapse of time before being invited on the post-training evaluation.

The dual-task training condition differed from pre- and post-dual-task training conditions on several aspects. First, in each training session, participants completed two pure blocks (20 trials

Table 2 | Content (blocks and trials) of the evaluation and training sessions.

PRE- AND POST-TRAINING SESSIONS							
Overall time	80 min approx. (20 min per conditions)						
Conditions	Visual stimuli + keyboard responses, visual stimuli + wheel and brakes responses, auditory stimuli + keyboard responses, auditory stimuli + wheel and brakes responses						
	Block 1	**Block 2**		**Block 3–4**		**Block 5**	**Block 6**
Type of trials	Single-pure	Single-pure	Single-mixed	and	Dual-mixed	Single-pure	Single-pure
No of trials	20	20	40		40	20	20
Task	A	B	A or B	or	A and B	A	B
TRAINING SESSIONS							
Overall time	55 min. approx.						
Conditions	Only visual stimuli + keyboard responses						
	Block 1	**Block 2**		**Block 3–10**		**Block 11**	**Block 12**
Type of trials	Single-pure	Single-pure	Single-mixed	and	Dual-mixed	Single-pure	Single-pure
No of trials	20	20	80		80	20	20
Task	A	B	A or B	or	A and B	A	B

each) followed by eight mixed blocks (80 trials each), and two other pure blocks (20 trials each). Participants completed five training sessions, for a total of 400 single-pure trials (5 × 4 × 20), 1600 single-mixed trials (5 × 8 × 40), and 1600 dual-mixed trials (5 × 8 × 40).

Second, during training sessions a continuous, individualized adapted feedback was displayed on the computer screen. Feedback indicators were presented continuously on a histogram in the top-left portion of the screen and depicted speed performance for the dual-mixed trials. The histogram contained two bars, each one giving feedback for a specific hand. The heights indicated participants' performances (speed) in dual-mixed trials. The bars first appeared as small and red. As performances progressively got faster, the graph bars grew taller and simultaneously changed to yellow or green. The bars automatically became red when an error was made. Performances were estimated through a comparison between dual-mixed trials and single-mixed trials. The criterion for optimal performance was reached when the mean RT for the last three dual-mixed trials was smaller or equal to the median of the RT distribution for all previous single-mixed trials in a given training session.

ANALYSIS

ANOVAs were performed on RT (ms) and accuracy (% of correct responses) with Age (older vs. younger) and Group (trained vs. control) as between-subjects factors, and Session and Trial type (single-pure – single-mixed – dual-mixed) as within-subject factors. Significant interactions were decomposed with simple effects. However, in the case of a significant interaction with more than two levels of a repeated factor (e.g., Trial types), repeated contrasts were used. Such analyses provide a comparison of RT differences between two consecutive levels of a repeated factor. Statistical analyses of the data were performed on SPSS 17. An effect was reported significant according to the adjusted alpha level (Greenhouse–Geisser) when required – that is, when the Mauchly's test of sphericity was significant. Effect sizes (eta squared) are also reported. In the event of a significant effect of Age, age-related slowing was controlled for by conducting analyses of covariance (ANCOVAs) with baseline RT in the single-pure trials averaged for the two tasks of a given condition. Performances of the training group through the five training sessions will be described first. Then, performance of training and control groups will be compared from pre-test to post-test in the training dual-task condition and the three transfer dual-task conditions.

RESULTS

All participants demonstrated very high accuracy on the four dual-task combinations used at pre and post-test (training task: 98%, S-MT: 98%, R-MT: 97%, SR-MT: 97%). Variations from pre-test to post-test never exceeded 1%, which shows that accuracy remained considerably high throughout all the sessions. **Table 3** shows detailed results of the analyses on accuracy data. These results are not further described here due to absence of significant training effect or interaction. The following sections report results observed in RT data only.

TRAINING SESSIONS

An ANOVA was performed on RT with Age as between-subjects factor, and Session (1–5) and Trial type as within-subject factors. As shown in **Figure 1**, RT decreased with training, $F(4, 96) = 75.48$, $p < 0.001$, $\eta^2 = 0.76$. A Session × Trial type interaction, $F(8, 192) = 42{,}96$, $p < 0.001$, $\eta^2 = 0.64$, was also observed due to a significant decrease in task-set cost after the first, $F(1, 24) = 12.76$, $p < 0.005$, $\eta^2 = 0.35$, and the fourth session, $F(1, 24) = 4{,}50$, $p < 0.05$, $\eta^2 = 0.15$, while dual-task cost decreased after the first, $F(1, 24) = 31.37$, $p < 0.001$, $\eta^2 = 0.57$, the second, $F(1, 24) = 6.27$, $p < 0.05$, $\eta^2 = 0.20$, and the fourth sessions, $F(1, 24) = 11.39$, $p < 0.005$, $\eta^2 = 0.32$. There was also an Age × Session interaction, $F(4, 96) = 3.80$, $p < 0.01$, $\eta^2 = 0.14$. A larger improvement was observed in younger adults between session one and two, $F(1, 24) = 4{,}50$, $p < 0.005$, $\eta^2 = 0.16$. There was no age-related difference in training after session two.

Table 3 | Results of the analyses of variance performed on accuracy for the training and transfer tasks conditions used in the pre-training and post-training session.

	Training task				Transfer tasks									
	Visual-keyboard				Response-MT				Stimuli-MT			Stimuli and response-MT		
	df	*F*	*p* <	η^2	df	*F*	*p* <	η^2	*F*	*p* <	η^2	*F*	*p* <	η^2
Age (younger-older)	1.41	6.43	0.05*	0.13	1.42	1.22	n.s.	0.03	3.71	n.s.	0.08	0.13	n.s.	0.00
Group (trained-control)	1.41	2.56	n.s.	0.06	1.42	3.98	n.s.	0.08	1.32	n.s.	0.03	5.93	0.05*	0.12
Type of trial (SP, SM, DM)	2.82	49.57	0.001*	0.54	2.84	35.00	0.001*	0.46	44.73	0.001*	0.51	45.49	0.001*	0.52
Age × type	2.82	1.05	n.s.	0.02	2.84	0.13	n.s.	0.00	0.44	n.s.	0.01	0.24	n.s.	0.01
On task-set cost	1.41	0.44	n.s.	0.01	1.42	0.26	n.s.	0.00	0.70	n.s.	0.02	0.44	n.s.	0.01
On dual-task cost	1.41	0.74	n.s.	0.02	1.42	0.06	n.s.	0.00	0.23	n.s.	0.01	0.33	n.s.	0.01
Age × session	1.41	8.97	0.05*	0.18	1.42	4.08	0.05*	0.09	20.40	0.001*	0.32	2.49	n.s.	0.06
Group × session	1.41	0.65	n.s.	0.02	11.42	0.03	n.s.	0.00	5.16	0.05*	0.11	2.33	n.s.	0.05
Group × session × type of trial	2.82	3.10	n.s.	0.07	21.84	0.80	n.s.	0.02	2.44	n.s.	0.05	0.72	n.s.	0.02
On task-set cost	1.41	2.02	n.s.	0.05	11.42	0.32	n.s.	0.01	1.30	n.s.	0.03	1.08	n.s.	0.03
On dual-task cost	1.41	0.84	n.s.	0.02	11.42	0.39	n.s.	0.01	0.81	n.s.	0.02	1.19	n.s.	0.03

*$p < .05$

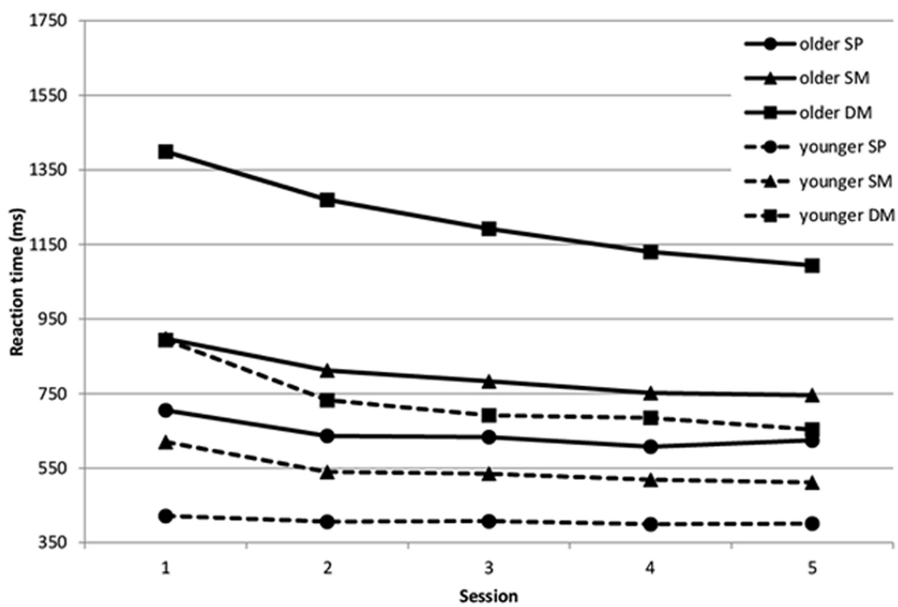

FIGURE 1 | Mean reaction time (ms) for older and younger adults in the three trial types [single pure (SP), single mixed (SM), and dual mixed (DM)], as a function training sessions.

PRE VS. POST-TRAINING SESSIONS

For each of the dual-task condition (training, S-MT, R-MT, SR-MT), an ANOVA was performed with Group (trained vs. control participants) and Age as between-subjects factors, and Session (pre and post-training) and Trial type as within-subject factors. Results are presented in **Table 4**. The main results are summarized here to address three main questions. First, did training lead to significant improvement in dual-task performances compared to the control condition? Second, is there any age-related difference in training effects? Third, did training lead to cross-modality transfer effects and if so, were transfer equivalent among older and younger adults?

First, with regards to training effect, as can be seen in **Figure 2** (top-left panel) RT improvement in training dual-task condition was larger in the training group (−326 ms) than in the control group (−169 ms), and this effect was also characterized by a Group × Session × Trial type interaction. Repeated contrasts indicated that both the task-set cost (trained: −217 ms; control: −48 ms) and the dual-task cost (trained: −356 ms; control: −97 ms) decreased

Table 4 | Results of the analyses of variance performed on reaction time for the training and transfer conditions used in the pre-training and post-training sessions.

	Training task				Transfer tasks									
	Visual-keyboard				Response-MT				Stimuli-MT			Stimuli and response-MT		
	df	*F*	*p* <	η^2	df	*F*	*p* <	η^2	*F*	*p* <	η^2	*F*	*p* <	η^2
Age (younger-older) session	1.41	80.62	0.001*	0.66	1.42	37.56	0.001*	0.47	37.52	0.001*	0.47	18.27	0.001*	0.30
Group (trained-control)	1.41	4.43	0.042*	0.10	1.42	0.08	n.s.	0.00	0.28	n.s.	0.01	0.01	n.s.*	0.00
Type of trial (SP, SM, DM)	2.82	503.52	0.001*	0.93	2.84	325.98	0.001*	0.89	601.46	0.001*	0.94	512.07	0.001*	0.92
Age × type of trial	2.82	35.43	0.001*	0.46	2.84	26.20	0.001*	0.38	13.66	0.001*	0.25	11.16	0.001*	0.21
On task-set cost	1.41	16.37	0.001*	0.29	1.42	11.75	0.001*	0.22	12.45	0.001*	0.23	8.34	0.006*	0.17
On dual-task cost	1.41	43.38	0.001*	0.51	1.42	28.35	0.001*	0.40	11.37	0.002*	0.21	9.55	0.004*	0.19
Age × session	1.41	21.30	0.001*	0.34	1.42	12.51	0.001*	0.23	2.64	0.112	0.06	4.84	0.033*	0.10
Group × session	1.41	72.84	0.001*	0.64	11.42	13.54	0.001*	0.24	17.43	0.001*	0.29	4.93	0.032*	0.16
Age × group × session	1.41	11.72	0.001*	0.22	11.41	0.64	n.s.	.0.01	2.64	n.s.	0.06	0.582	n.s.	0.01
Group × session × type of trial	2.82	37.58	0.001*	0.48	21.84	11.45	0.001*	0.21	6.71	0.001*	0.14	2.64	n.s.	0.06
On task-set cost	1.41	28.22	0.001*	0.41	1.42	2.40	n.s.	0.05	0.90	n.s.	0.02	3.39	n.s.	0.08
On dual-task cost	1.41	27.55	0.001*	0.40	1.42	14.49	0.001*	0.26	8.37	006*	17	0,88	n.s.	35

**p* < .05*

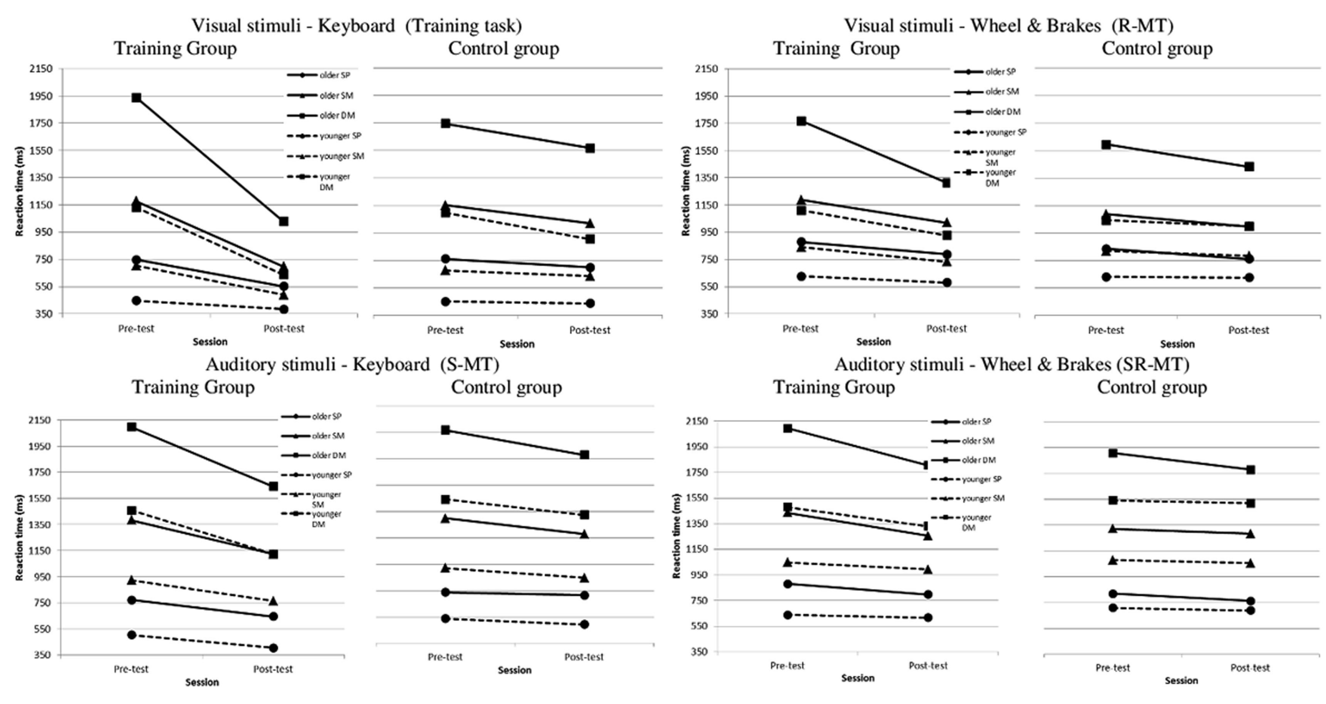

FIGURE 2 | Mean reaction time (ms) for older and younger adults in the three trial types [single pure (SP), single mixed (SM), and dual mixed (DM)], as a function of pre- and post-test sessions, for the trained dual-task condition (first panel), the response modality transfer (R-MT) dual-task condition (second panel), the stimulus modality transfer dual-task condition (S-MT) (third panel), and the stimuli–response modality transfer (RS-MT) dual-task condition (last panel).

to a greater extent in training group than in control group.

Second, an Age × Group × Session × Trial types interaction, $F(2, 82) = 6.52$, $p < 0.01$, $\eta^2 = 0.13$, was observed and the interaction remained significant after controlling for general slowing, $F(2, 80) = 6.34$, $p < 0.005$, $\eta^2 = 0.14$. Age-related differences in training were further explored by examining the Group × Session × Trial type interaction separately

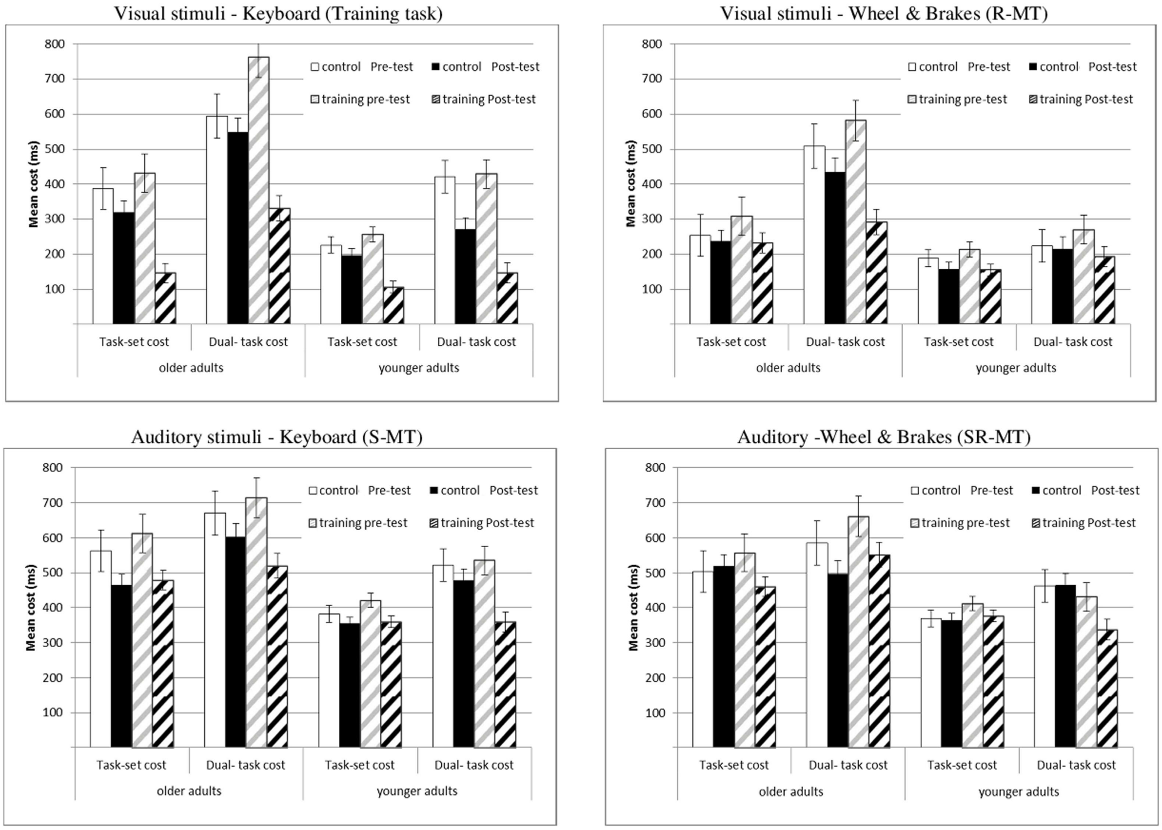

FIGURE 3 | Mean task-set cost and dual-task cost in older and younger adults at pre-test and post-test sessions, for the trained dual-task condition (first panel), the response modality transfer (R-MT) dual-task condition (second panel), the stimulus modality transfer (S-MT) dual-task condition (third panel), and the stimuli–response modality transfer (SR-MT) dual-task condition (last panel).

for younger and older adults. In older adults, a significant Group × Session × Trial type interaction was observed, $F(2, 40) = 31.29$, $p < 0.001$, $\eta^2 = 0.61$. **Figure 3** illustrates the changes in task-set and dual-task costs. Repeated contrasts showed a Group × Session interaction in task-set cost $F(1, 20) = 12.84$, $p < 0.005$, $\eta^2 = 0.39$. Simple effect analyses indicated that this interaction was due to a significant drop of task-set cost in the training group (−284 ms), $F(1, 11) = 43.81$, $p < 0.001$, $\eta^2 = 0.80$, which was not observed in the control group (−67 ms), $F(1, 9) = 2.63$, *ns*, $\eta^2 = 0.23$. A significant Group × Session interaction was also observed in dual-task cost, $F(1, 20) = 29.81$, $p < 0.001$, $\eta^2 = 0.60$. Dual-task cost decreased in the training group (−430 ms), $F(1, 11) = 106.42$, $p < 0.001$, $\eta^2 = 0.91$, but not in the control group (−45 ms), $F(1, 9) = 0.59$, *ns*, $\eta^2 = 0.06$. In younger adults, a significant Group × Session × Trial type interaction, $F(2, 42) = 8.03$, $p < 0.001$, $\eta^2 = 0.28$, was also observed. Alike older adults, repeated contrasts showed a Group × Session interaction in task-set cost, $F(1, 21) = 28.27$, $p < 0.01$, $\eta^2 = 0.57$. Simple effect analyses showed a significant drop in task-set cost in the training group (−150 ms), $F(1, 12) = 73.06$, $p < 0.001$, $\eta^2 = 0.86$, and a somewhat smaller decrease in the control group (−28 m), $F(1, 9) = 5.36$, $p < 0.05$, $\eta^2 = 0.37$. Moreover, the reduction in dual-task cost was not significantly different among trained and control participants, $F(1, 21) = 3.70$, $p = 0.068$, $\eta^2 = 0.15$. Improvement in dual-task cost was significant in both training (−282 ms), $F(1, 9) = 12.86$, $p < 0.01$, $\eta^2 = 0.59$, and control group (−149 ms), $F(1, 12) = 30.29$, $p < 0.001$, $\eta^2 = 0.72$.).

Third, regarding transfer effects, results showed an overall improvement in all three transfer dual-task conditions, as indicated by a Group × Session interaction. In all conditions, improvement was larger in training group (S-MT: −239 ms; R-MT: −175 ms; SR-MT: −122 ms) than in control group (S-MT: −93 ms; R-MT: −67 ms; SM-RT: −51 ms). However, improvement in task-set and dual-task costs depends upon transfer condition. A Group × Session × Trial type interaction was observed in the S-MT and the R-MT. Repeated contrasts showed that dual-task cost decreased more in training group (S-MT: −181 ms; R-MT: −187 ms) than in control participants (S-MT: −58 ms; R-MT: −34 ms) in both condition, but there was no group difference in change in task-set cost. In the SR-MT condition, neither task-set nor dual-task cost showed group difference in change from pre-test to post-test. Finally, the absence of Age × Group × Session or Age × Group × Session × Trial Type interaction in the three transfer dual-task combinations suggest that training-related changes in performance were equivalent among older and younger adults.

DISCUSSION

The present study assessed the limits of cross-modality transfer effects after dual-task training in older and younger adults. Participants completed 5 h of dual-task training with a dual-task combination that involved two visual discrimination tasks and both tasks were answered manually through keyboard keys. The main objectives of the present study were to determine (a) if far modality transfer effects occur on tasks with untrained stimuli and/or motor responses modalities, (b) if transfer effects are due to specific improvements on task-set cost or dual-task cost, (c) if there are age-related differences in dual-task transfer effects. Participants were assessed before and after training on several dual-task conditions; (1) auditory stimuli and keyboard responses (S-MT), (2) visual stimuli and wheel and brakes responses (R-MT), (3) auditory stimuli and wheel and brake responses (SR-MT).

As expected, the training effectiveness was confirmed as both younger and older adults showed improved performance after training, but training effects differed among age groups. In older adults, the training group showed improved task-set and dual-task costs compared to controls, while in younger adults, only task-set cost showed significant improvement. In younger adults, both training and control groups showed improved dual-task cost. This suggests that in younger adults' minimal exposition to the dual-task condition (test–retest effect) leads to significant improvement in task coordination. Overall, these results on training effects are highly consistent with previous findings using the same training paradigm (Bherer et al., 2005, 2008).

The specific contribution of the present study was to test the limits of modality transfer effects induced by dual-task training. Results of the present study indicated that participants that completed the training showed larger improvement in all three transfer-task combinations compared to control participants. Therefore, results support the existence of far modality transfer effects since training led to significant improvements in conditions in which both input and output modalities changed from training to transfer tasks conditions. Moreover, training led to significant improvements in dual-task cost in both S-MT and R-MT. These findings are of major importance since they demonstrate that training effects can be observed after dual-task training despite the fact that stimuli or motor response modalities differed from training. This suggests that training leads to greater learning than a specific stimuli/response association and that this learning can be generalized to new situations. However, since task-set cost did not decrease after training, it is unlikely that the improvement observed in the S-MT and R-MT dual-task conditions arose from better preparation of stimulus–response mapping or from a decrease of the task load on working memory. The present results thus suggest that transfer effects are supported by an improvement in executive control required to coordinate two concurrent tasks. However, the results observed in the SR-MT dual-task conditions brought limited support to this conclusion. In fact, in this condition, attentional costs did not improve, which suggests that performance improvement was merely supported by a general improvement in processing speed.

Liepelt et al. (2011) and Strobach et al. (2011) observed transfer in novel tasks of the same modalities and concluded that transfer in dual-task was relatively robust. In line with this, results of the present study suggest that training did improve a set of skills that are independent of the specific modality characteristics of the training program. However, past studies did not assess transfer effect when both input and output modalities differ from training. Results of the present study suggest that transfer effects can be limited when both stimuli and response modalities differed from the training conditions.

The improvement observed here in a dual-task condition that involved visual stimuli or motor responses has strong theoretical and practical implications. In fact, it has been reported that age-related dual-task deficits are larger when both tasks involve a visual input and a similar motor outputs (Hartley, 2001; Hein and Schubert, 2004). The present findings suggest that after dual-task training participants tend to overcome input and output interference, which leads to better coordination of two concurrent tasks and that this improvement is equivalent among younger and older adults. With regards to potential application in the context of cognitive rehabilitation, results of the present study suggest that a patient trained on a visual balance multitask would also improve on an auditory balance multitasks. This supports the uses of computerized software and videogames devices in modalities that are not exactly the same as the activities of daily living that they aimed to improve.

The present findings also suggest that there are some limits in the extent to which transfer occurs after dual-task training. When both input stimuli and response mode changed in the SR-MT condition, improvements of task-set cost and dual-task cost were equivalent among training and control groups, despite a larger gain overall in the training group. This suggests that transfer may be limited to an increase of general speed when the transfer condition shares neither stimuli nor motor response modality with the training dual-task condition. Together with the results observed in the S-MT and R-MT dual-task conditions, these results suggest that learning to coordinate two concurrent tasks is relatively modality specific and would not lead to improvement in coordinating sets of new stimuli with new responses modality. It thus seems that the general improvement observed in the SR-MT condition may, in fact, be caused by a familiarization toward the dual-task environment. It may also be that only the training group was exposed to a feedback on speed, which would have led to enhanced motivation to provided faster responses with training.

With regard to potential age-related differences in transfer effects, results of the present study suggest quite consistently age-equivalent generalizable gains. Among all the three transfer dual-task combinations, transfer effects were equivalent between older and younger participants. These results bring further support to the notion that cognitive plasticity is preserved in advance age (Verhaeghen, 2000; Basak et al., 2008). Improvements induced by cognitive training, as observed in the present study, can be attributed to cognitive plasticity. In fact, neural correlates of dual-task performance improvement have been observed in studies using a dual-task paradigm very similar to the one used in the present study (Erickson et al., 2005, 2007). According to Lovden et al. (2010), two phenomena can induce improvement of performance after training: *flexibility* which denotes the capacity to optimize the brain's performance within the limits of the current state of functional supply and *plasticity* which denotes the acquisition of new knowledge and change of the current state of functional supply. Future studies would be require to specify whether transfer effects observed in the present study are due to improved flexibility (e.g., better coordination strategies) or neural plasticity (wider or more efficient neuronal recruitment).

The present study has some limits. In order to consolidate present findings, one should verify that the patterns of effects observed here are not specific to the training protocol that was used. For example, it would be interesting to examine if training with auditory stimuli and verbal responses induces transfer effects in dual-task condition that combines visual stimuli and manual responses. Future studies should also assess the maintenance of transfer effects by re-evaluating subjects after a few months. Finally, more attention should be given to training components that enhance transfer. For example, varying task priorities and individualizing feedback might be among the determining components that support transfer.

Little is known about the extent and limits of transfer effects following cognitive training. The present study innovates by supporting far transfer modality to untrained stimuli and untrained response modalities. While a few studies have investigated transfer to untrained stimulus modality, none had systematically examined transfer to untrained motor responses. In the present study, transfer effects were notably large even though the training lasted only 5 h distributed on 2–3 weeks. Considering the growing interest in cognitive interventions that include dual-task training in order to preserve older adults gait and balance (Li et al., 2010), as well as driving abilities (Cassavaugh and Kramer, 2009), it appears important to identify the mechanisms by which transfer effects occur and to better understand the extent and limits of transfer effects that can be expected after dual-task training. Such knowledge could support development of new training paradigms that target real-life situations.

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