frontiers | Frontiers in Education

TYPE Brief Research Report
PUBLISHED 12 April 2023
DOI 10.3389/feduc.2023.1141586

OPEN ACCESS

EDITED BY
Anna Maria Re,
University of Turin,
Italy

REVIEWED BY
Laura Traverso,
University of Genoa,
Italy
Giulia Vettori,
University of Florence,
Italy

*CORRESPONDENCE
Christina Hubertina Helena Maria Heemskerk
✉ christina.heemskerk@unibe.ch

SPECIALTY SECTION
This article was submitted to
Educational Psychology,
a section of the journal
Frontiers in Education

RECEIVED 10 January 2023
ACCEPTED 23 March 2023
PUBLISHED 12 April 2023

CITATION
Heemskerk CHHM and Roebers CM (2023)
Executive functions and classroom behaviour
in second graders.
Front. Educ. 8:1141586.
doi: 10.3389/feduc.2023.1141586

Executive functions and classroom behaviour in second graders

Christina Hubertina Helena Maria Heemskerk* and
Claudia M. Roebers

University of Bern, Bern, Switzerland

Background: Executive functions along with on-task behaviour in the classroom relate to academic success. Examining the shared and non-shared variances in their relationships with academic achievement may lead to a better understanding of the contribution of executive functions to achievement and may uncover a mechanism to explain *why* they are so important for school success. Specifically, we investigated the extent to which executive functions and classroom behaviour offer different and similar perspectives on children's self-regulatory behaviour, and make unique contributions to academic achievement.

Method: Data were collected from 129 2nd grade students (M age=7.93years, SD=0.5; 44.2% female). Participants were observed for 25min during a 'business-as-usual' classroom lesson, following a momentary assessment protocol; we developed and used an openly available mobile application. Subsequently, participants completed an executive function task (Hearts and Flowers) in small groups on tablet computers. Teachers rated students' academic achievement in language and mathematics.

Results: We found unique contributions for on-task behaviour and executive functions to academic achievement in 2nd grade. Moreover, we found that 27–31% of the total effect of inhibition on language achievement was mediated through on-task behaviour.

Conclusion: We have shown that executive functions and on-task behaviour share variance in their relationship to academic achievement, as well as providing a unique perspective on children's self-regulatory behaviour. Thus, researchers might want consider the inclusion of both executive function tasks and ecologically valid measures such as the current, easy to apply behavioural observation in a naturalistic setting in their future work.

KEYWORDS

executive functions, primary school, academic achievement, observations, on-task behaviour

Introduction

One of the most often replicated finding in the contemporary developmental literature is that executive functions (EF) are predictive for school readiness, school grades, academic achievement, and the like (see Friso-van den Bos et al., 2013; Yeniad et al., 2013; Allan et al., 2014, for meta-analyses). EF describe a set of heterogeneous but interrelated higher-order cognitive abilities, including working memory (being able to hold some information in mind and work with it, e.g., as in addition and subtraction tasks), inhibition (e.g., being able to hesitate and reflect, rather than to shout into the classroom and give incorrect answers), and cognitive flexibility (e.g., being able to fast and efficiently redirect attention from one detail to another, finding a good focus of attention for the task at hand) (Miyake et al., 2000). These and other constructs (such as persistence, effortful control, and others) belong to the comprehensive terms of self-regulation (Zhou et al., 2012). Not only are individual differences in EF related to academic performance (e.g., Cortés Pascual et al., 2019; Spiegel et al., 2021), a lack of improvement in EF over time has also been shown to be predictive of academic difficulties in primary school children (e.g., Diamond, 2013; Morgan et al., 2019). Effects of EF on academic outcomes in primary school of around $r = 0.30$ have been reported, although these numbers vary depending on the subcomponent of EF and the academic domain (e.g., Cortés Pascual et al., 2019) and the age group included (e.g., Magalhães et al., 2020; Spiegel et al., 2021).

It seems obvious to assume that formal learning in a primary school classroom requires self-regulatory competences. Learning in the classroom context involves being able to adapt one's individual learning to teachers' standards, expectations, rules, and behavioural demands. It includes involvement and active participation in the classroom. That is, the teacher predetermines the focus of attention for the students, they expect the individual to ignore distractions, to get involved in teacher-defined learning activities and to participate and interact - at certain times and not at other times - with peers. Children who have problems with active participation and adequate classroom behaviour are known to fall behind as they miss many and increasing learning opportunities (Nesbitt et al., 2015; Kuutti et al., 2022; Nesbitt and Farran, 2022). However, there is only very limited evidence on how and to what extend EF are linked to participation, involvement, and/or learning-related behaviour in the classroom.

Rutherford et al. (2018) describe EF as an 'underlying competency' for self-regulated learning (SRL), although it has not been established if EF truly is a prerequisite for SRL, or if they are related, concurrently developing constructs (Davis et al., 2021). The concept of SRL includes academic behaviour but is much broader than behaviour alone. It includes monitoring, goal setting, planning, and persistence, to name a few of the aspects covered (e.g., Duckworth et al., 2014; Nigg, 2017). The monitoring of goals, behaviour, and time allocation is highlighted in Pintrich's general framework of SRL (Pintrich, 2000). This requires, on the one hand, an awareness of one's academic behaviour in an overarching, mostly retrospective or prospective way ("How much time did I need to complete this task?," "How difficult is this task? How much time will I need?"). Being and remaining on-task during a lesson, on the other hand, requires a moment-to-moment awareness of behaviour. This implies the ability to filter out irrelevant stimuli and thoughts, to keep task assignments in mind and to flexibly change the attentional focus - which is where EF may play a more prominent role. To date, very little is known about the exact contributions of EF subcomponents to classroom behaviour. And even less is known about possible indirect effects of EFs on academic achievements through classroom behaviour. Therefore, this study investigates how EF relates to moment-to-moment task-behaviour during classroom lessons in second graders, and how both EF and task-behaviour relate to academic achievement in second graders.

The majority of the current literature focuses on very young children (pre-K and kindergarten (e.g., Nesbitt et al., 2015)). The conventional approach to measuring EF is to quantify children's performance in terms of accuracy, reaction times, or a combination of both under highly controlled settings (quiet room, standardized instructions, encouragement provided by the experimenter). Yet, it remains unclear to what degree such direct assessments, considered as the "gold standard" for measuring EF, reflect the complexities of a classroom. These include, for example, the ability to stay focused on a task without encouragement, to initiate and complete learning efforts, to persist on academic challenges, and to ignore the many distractions and behavioural options in the classroom setting (with and without peers).

Not surprisingly, the few existing studies report only weak to moderate correlations between EF and teachers' ratings of self-regulation in the classroom (ranging from 0.10 to 0.35; Neuenschwander et al., 2012; Fuhs et al., 2015; Schmitt et al., 2015; Finders et al., 2021), and even weaker associations between EF and observational data of on-task classroom behaviour, involvement, or disruptive/unoccupied behaviour (McCoy et al., 2022; Nesbitt and Farran, 2022). Research attempts to adapt "classical" EF task to group-based measurements and to simulate classroom settings when measuring EF have shown that EF tasks and these adaptations already share only moderate amounts of variance. This underlines that the different tasks have different demands, call for the deployment of different self-regulatory but also non-self-regulatory skills, and have different sources of measurement error (Obradović et al., 2018; Ahmed et al., 2021). Together, these findings suggest that each measurement offers distinct information and captures different observable and unobservable cognitive processes.

Investigating the shared and non-shared variances of different methods may lead to a better understanding of the often narrowly defined EF (McCoy et al., 2022). While teachers' ratings of learning-related behaviour in the classroom have provided valuable yet retrospective and possibly biased information (Bonefeld et al., 2020), observational data during normal school lessons offer a unique perspective on naturally occurring classroom behaviour and have very recently proven to provide objective, reliable and valid information (Nesbitt et al., 2015; McCoy, 2019; McCoy et al., 2022; Heemskerk et al., 2022a,b). Moreover, for very young children, Nesbitt et al. (2015) were able to show that the effect of EF on achievement gains in math and literacy were indirect, that is, mediated through different aspects of learning-related behaviour observed in regular school lessons. This finding is important as it uncovers one mechanism to explain *why* EF are so important for school success.

We aimed to further our understanding of how and to what extent EF impact children's behaviour and learning opportunities in the classroom for older children (2nd grade). These children have spent more time in formal school settings, with opportunities to adjust to the behavioural expectations, build on their EF in class, and learn to ignore the distractions inherent in completing learning tasks alongside a room full of peers. Specifically, we investigated the extent to which EF and observed classroom behaviour offer different and similar perspectives on children's self-regulatory behaviour, and make unique and indirect contributions to academic performance, with both EF measures and observational data having pros and cons.

Method

Sample and procedure

The ethics committee at the University of Bern Institute of Psychology gave permission for this study to be carried out. Data were collected in second grade classes (n = 13) of primary schools during the autumn semester. Teachers from schools within a 1-h travel distance from the university were invited via email and telephone to participate in the study with their classes. From the participating classes, children with informed parental consent were allowed to take part. Valid data from 129 children (44.2% females, M age = 7.93 years, SD = 0.5 years) were included for analysis. More details about the sample can be found in Table 1.

Each class was visited by the trained research team once, during the morning. The visit started with an introduction of around 10 minutes, during which the research team introduced themselves, explained to the children what research is, and explained that those who had permission from their parents would complete a task after their normal lesson would finish. The class was also told that, during the next lesson, the research team would have a look at what this lesson was like and would take some notes, but that the children did not need to do anything in particular for it and could just ignore the researchers. Then, the research team spread themselves around the outside of the classroom and after a few minutes started a 25-min observation of pupils' task-related behaviour, using a momentary observation scheme. The teachers were asked to teach the usual timetabled lesson during the observation period. After the observation period, the participants completed the Hearts and Flowers task (Davidson et al., 2006) on a tablet. The task was administered to small groups of up to 10 pupils, in a room where no other teaching activities were carried out at the time. After completion of the task, the children were thanked for their participation and returned to their class to carry on with their lessons as normal.

TABLE 1 Sample descriptives.

Variable	Categories	n	M / %	SD	Min	Max
Age		129	7.93	0.50	6.83	10.00
Sex	Girl	57	44.2%			
	Boy	72	55.8%			
On-task behaviour		129	81.0%	10.0%	48.0%	98.0%
Language achievement	1	3	2.3%			
	2	27	20.9%			
	3	59	45.8%			
	4	29	22.5%			
	5	11	8.5%			
Maths achievement	1	17	13.2%			
	2	41	31.8%			
	3	40	31.0%			
	4	17	13.2%			
	5	14	10.8%			
Hearts & Flowers						
Accuracy	Hearts	129	0.97	0.05	0.68	1
	Flowers	124	0.90	0.13	0.09	1
	Mixed	124	0.78	0.16	0.22	1
Reaction time	Hearts	129	489.9	101.9	328.9	1111.5
	Flowers	124	686.9	124.2	444.2	1074.4
	Mixed	124	696.7	104.2	433.0	1039.5

Teachers provided ratings of the children's academic performance in language and maths, as well as two aspects of self-regulated learning; their ability to work independently and to gauge their own strengths and weaknesses. All teacher reports (four single ratings) were provided on a 5-point Likert scale (1 = well below age-related expectation, 2 = below age-related expectation, 3 = at age-related expectation, 4 = above age-related expectation, 5 = well above age-related expectation).

Executive functions task

The Hearts and Flowers task (Davidson et al., 2006; Diamond et al., 2007) was used to assess EF. The task was programmed using the open source mobile application development platform Ionic (Version 5, 2020) and carried out on Samsung Galaxy Tab A7® tablets (running on Android), using external response buttons (Buddy Buttons of Ablenet Inc.) placed to the left and right of the tablet and connected via a response box ("Immo-Reaction Response Box," available from Immo-Electronics Inc.). All instructions were given via audio recordings embedded in the programme, over headphones. The task consists of three blocks: congruent (hearts, 24 trials), incongruent (flowers, 36 trials), and mixed (60 trials, 80% congruent, 20% incongruent). Each block is preceded by a practice section to ensure the participants understand the task. Stimulus presentation time was 600 ms, with an inter-stimulus interval of 500 ms.

This task taps into all three of the basic domains of EF (working memory to keep the various rules of the task in mind, inhibition to prevent dominant responses in the incongruent trials, and switching in the mixed block when the rule to be applied changes between congruent and incongruent trials) (Diamond et al., 2007). The accuracy and RT in the flowers and mixed blocks can be used as measures of inhibition and switching, respectively (Diamond et al., 2007).

On-task behaviour observations

Children were observed every 30 s for 25 min (yielding max. 50 observations per participant). Researchers followed a momentary observation protocol and used the 'SchoolBehaviour' app to record their observations. During the 30-s interval between each participant's observations, the researchers observed other participants (a maximum of 6 participants per researcher). Thus, each recorded behaviour was a snapshot of the behaviour at the moment of observation, and not an aggregate of the 30 s interval.

At every observation, the researchers gave a rating of 'on-task', 'passive off-task', 'active off-task', or 'other'. Goal-directed behaviour for carrying out the set task, without disrupting other students, was coded 'on-task'. Staring, yawning, stretching, or sleeping, in the absence of goal-directed behaviour, was coded 'passive off-task'. Moving or talking, when not task-related, was coded 'active off-task'. If a participant was obscured from the researcher's view, or if their behaviour was ambiguous, a rating of 'other' was recorded.

Inter-rater reliability for the four observers was good (Light's κ = 0.76). The 'SchoolBehaviour' app is an easy-to-use app, which is free to download from the app stores for iOS and Android. Training material including video is obtainable from the first author.

Analytic procedures

Variable creation

For the Hearts and Flowers task, we excluded anticipatory trials (reaction time (RT) ≤ 200 ms; 4.8% of trials) and trials with RT > 2000 ms (2.8% of trials). We excluded participants with an overall mean accuracy below 50% (less than chance, $n = 0$). After data cleaning was complete, we calculated the mean RT and accuracy (percentage correct trials) separately for the incongruent block (inhibition accuracy and RT) and the mixed block (shifting accuracy and RT).

Observations concurrently coded 'other' for both the task and behaviour were removed from the data set. Only participants with 40 or more valid observations were included in analyses. We then created the 'on-task' variable: the percentage of valid observations rated as on-task.

Teacher ratings of academic achievement had a high intra-class correlation ($ICC_{Maths} = 0.311$; $ICC_{Language} = 0.183$) and were centred within classes.

Analyses

Using RStudio (RStudio Team, 2022), we analyzed Spearman correlations between the measures of EF (accuracy and RT for both inhibition and switching), the prevalence of on-task behaviour, and the teacher ratings of academic achievement and study behaviour. Correlations were considered small if they were < 0.3, moderate if they were 0.3–0.49 and large if they were ≥ 0.5. The significance level was set at $\alpha < 0.05$. We then specified path models using the lavaan package (Rosseel, 2012) to investigate possible indirect effects of EF on achievement via on-task behaviour. To assess the meaningfulness of indirect paths, we calculated the effect ratio: $P_M = \frac{indirect\ effect}{total\ effect}$ (Shrout and Bolger, 2002). An effect ratio of 1 indicates full mediation, whereas a ratio of 0 indicates no mediation.

Results

Table 1 displays the sample descriptives, including on-task behaviour, academic achievement, and the accuracy and RT from the Hearts and Flowers task. As expected, accuracy was lower in the third block (switching) than in the first (baseline) and second (inhibition) block. RT was longer for both switching and inhibition than for baseline.

Correlations between executive functions, on-task behaviour, and academic achievement

On-task behaviour correlated significantly with RT in the inhibition block ($r = -0.18$, $p = 0.024$), indicating that children who responded faster in the incongruent block also were more on-task during the preceding lesson. Teacher-rated achievement in maths and language correlated with each other ($r = 0.46$, $p < 0.001$). Maths achievement also correlated with inhibition accuracy ($r = 0.25$, $p = 0.006$), whereas language achievement correlated with on-task behaviour ($r = 0.23$, $p = 0.009$). The full correlation matrix can be found in Table 2.

Indirect effects of executive functions on academic achievement in 2nd grade students

The path models (see Figure 1) showed that for both inhibition and switching, accuracy was related to on-task behaviour, but only for inhibition was it also related to academic achievement in maths. RT only showed a significant relationship for inhibition.

In model A, inhibition accuracy and RT are included. We see that accuracy is related to on-task behaviour ($\beta = 0.16$, $p = <0.001$) and academic achievement in maths ($\beta = 0.27$, $p = <0.001$). Moreover, the relationship between on-task behaviour and language achievement is significant, creating two indirect paths: from inhibition accuracy to language achievement via on-task behaviour ($\beta = 0.04$, $P_M = 0.31$) and from inhibition RT to language achievement via on-task behaviour ($\beta = -0.04$, $P_M = 0.27$). The indirect relationship from inhibition RT to maths achievement via on-task behaviour had an effect ratio of $P_M = 0.05$, indicating that almost no mediation takes place in the relationship between inhibition accuracy and maths achievement.

In model B, which includes switching accuracy and RT, no direct effects of switching on academic achievement were found, but an effect of switching accuracy on on-task behaviour ($\beta = 0.17$, $p = 0.031$), and an effect of on-task behaviour on language achievement ($\beta = 0.24$, $p = 0.003$). No significant indirect paths led from switching via on-task behaviour to academic achievement.

Discussion

This study aimed to investigate the relationships between EF and on-task behaviour, and their unique contributions to academic achievement in maths and language in 2nd grade students. We found that EF only explained part of the variance in on-task behaviour (inhibition: 5.8%; switching 5.5%), and that behaviour did not fully explain the link between EF and achievement, as evidenced by the significant direct effect of inhibition accuracy on maths achievement. This is in line with findings by Brock et al. (2009), who found that behaviour did not account for the EF-achievement link in their sample of kindergarten pupils. We found partial mediation for the effect of inhibition on language, but not maths achievement, and no mediation or direct effects for switching. The fairly small proportion of variance in behaviour explained by EF may mean that other concepts, such as SRL, self-control, or motivation play additional roles in shaping task-behaviour (e.g., Pintrich and Zusho, 2002; Zimmerman and Kitsantas, 2014; Cirino et al., 2016; Rutherford et al., 2018; Davis et al., 2021).

On the whole, our findings align with findings by Nesbitt et al. (2015), who found that learning gains during the pre-K year were predicted by EF and mediated by classroom behaviour. However, our findings differ from those of Nesbitt and colleagues in several aspects. Firstly, for inhibition, we found relationships between the accuracy (percentage of correct answers) as well as RT, and on-task behaviour and academic achievement. For switching, we only found one

TABLE 2 Spearman correlations and partial correlations of measures of inhibition with observed task-related behaviour and academic achievement.

	Inhib acc	Inhib RT	Shift acc	Shift RT	On-task beh	Maths	Language
Inhibition accuracy		**0.19***	**0.41*****	**−0.18***	0.03	**0.24****	−0.01
Inhibition RT	0.09		**−0.26****	**0.69*****	−0.08	−0.15	−0.09
Shifting accuracy	**0.18***	−0.10		**0.37*****	**0.19***	−0.18	−0.05
Shifting RT	0.13	**0.66*****	0.10		−0.07	0.14	0.09
On-task behaviour	0.14	**−0.18***	0.16	−0.15		−0.10	**0.33*****
Maths teacher rating	**0.25***	−0.12	−0.02	−0.02	−0.02		**0.37*****
Language teacher rating	0.10	−0.15	−0.17	0.03	**0.23****	**0.46*****	

Partial correlation above the diagonal (gray shade), zero-order correlations below the diagonal. Partial correlations of behaviour controlled for EF, partial correlations of EF controlled for behaviour. (Partial) correlations significant at $p < 0.05$ in bold print. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. For RT smaller numbers indicate better performance.

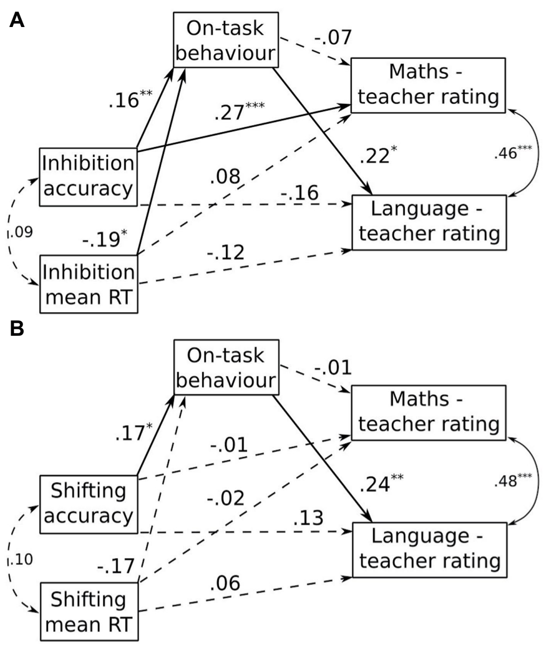

FIGURE 1
Path models of the indirect effects of **(A)** inhibition and **(B)** shifting on academic achievement. Note: All path coefficients are standardised. Significance set at $p<0.05$. *$p<0.05$, **$p<0.01$, ***$p<0.001$. Significant paths are drawn in solid lines.

relationship with on-task behaviour for accuracy, and none for RT. This is in line with suggestions that until accuracy scores are high (e.g., > 80%), RT is a less informative measure of EF than accuracy (Zelazo et al., 2013; Camerota et al., 2019). In our sample, mean accuracy was >80% for inhibition (89.9%), but not for switching (78.1%). Thus, in 2nd graders inhibition *and* switching accuracy are associated with on-task behaviour, but only inhibition RT.

On-task behaviour was related to inhibition accuracy and RT, and indirect effects of inhibition on language achievement via behaviour were found. The effect ratios were considerably larger than those in the study by Nesbitt et al. (2015), who found both language and maths gains were predicted by EF, and mediated by classroom behaviours (0.27 and 0.31, in our study; 0.10–0.13, for Nesbitt and colleagues). The difference in effects ratio may be related to the age of the children in the respective samples. Our sample of 2nd graders has had more time to develop their EF and learn to adjust to the demands of completing learning tasks in a dynamic classroom environment than the pre-K children in the Nesbitt study. This could be a reason that the effect ratio for the mediation effect was greater in our sample, as consistent on-task behaviour and active participation in learning activities is crucial to maximising a child's learning (Nesbitt et al., 2015; Kuutti et al., 2022; Nesbitt and Farran, 2022).

In the switching path model (Figure 1B), only accuracy and not RT was related to on-task behaviour, and neither related directly to academic achievement. Shifting typically develops later than inhibition does (Diamond, 2013), and it may be that in our sample of 2nd graders, shifting was not yet sufficiently developed to significantly relate to their behaviour and achievement. This is also supported by the considerably lower mean accuracy in the shifting block than in the inhibition block (see Table 1) and corresponds with findings by Magalhães et al. (2020) that second grade achievement in maths and literacy is predicted by inhibition, but not switching.

In our study, we found indirect paths between EF and language achievement, but not maths, despite the current literature generally reporting stronger links between maths and EF than between language and EF (e.g., Spiegel et al., 2021, for a meta-analysis), although the differences are not large. In their meta-analysis, Spiegel et al. (2021) report effect sizes of $r = 0.29$ for inhibition on maths and $r = 0.26$ on reading. For switching, they report $r = 0.28$ and 0.24 for maths and reading, respectively. However, we found that maths, but not language, related *directly* to inhibition accuracy ($\beta = 0.27$). This may indicate that EF makes a greater unique contribution to maths achievement – as also reflected by the small effect ratio for the indirect effect of inhibition accuracy via on-task behaviour. Moreover, regarding the relationships between maths and EF/on-task behaviour, Ahmed et al. (2021) suggest that maths achievement is mostly affected by working memory. This is also supported by meta-analyses reporting effects of $r = 0.35$ to 0.39 for working memory (Cortés Pascual et al., 2019; Spiegel et al., 2021) compared to effects of less than $r = 0.30$ for inhibition and shifting (Spiegel et al., 2021). The present study focused on inhibition and switching, whereas the EF measure used by Nesbitt et al. (2015) did include working memory.

Finally, we used the participants' current academic achievement as the dependent variable, rather than their learning gains. This difference in outcome variable could affect the strength of associations. For example, a child with low achievement may make large learning gains through attentive classroom behaviour and good task-focus, but still have lower achievement than would be typically expected for his or her age, or low achievement in comparison to their peers. Thus, a child may score highly on one metric whilst scoring poorly on the other.

Strengths and limitations

This study used direct observation as well as objective tests of EF. Observations followed a momentary time sampling protocol, taking a snapshot every 30 s. Although observations always come with the risk of bias, the research team was trained until interrater agreement exceeded $\kappa = 0.70$. Using a set protocol means that as the observation interval is predetermined and systematic, any under- or overestimation of certain behaviours would occur in an unbiased way (Meany-Daboul et al., 2007). The observation tool used in the present study (SchoolBehaviour) is easy to learn, easy to apply, and has already proved in other studies to provide a useful perspective on children's behaviour in the classroom. It is openly available on app stores for iOS and Android and may be of interest to many other researchers. Finally, a comparison of momentary time sampling with continuous observation concluded that a 30-s sampling interval had good correspondence with continuous protocols ($r = 0.78$; Zakszeski et al., 2017), especially for high-frequency behaviour such as on-task behaviour in primary school classrooms (Pearson Assessments, 2013; Zakszeski et al., 2017).

A strength of our study is that the Hearts and Flowers task has most widely been used in laboratory settings, or away from the laboratory in 1–2–1 settings. We applied this task in schools, in small groups of up to 10 students at a time. This setting more accurately reflects a classroom situation and provides more ecologically valid measures of EF (Obradović et al., 2018; McCoy, 2019).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CH: data curation, formal analysis, investigation, project administration, and writing - original draft. CR: conceptualization, project administration, methodology, and writing - original draft. CH and CR: writing – revisions. All authors contributed to the article and approved the submitted version.

Funding

Open access funding by University Of Bern.

Acknowledgments

The authors would like to acknowledge and thank Stefan Kodzhabashev from the faculty's technology platform for programming the apps used in this study, and the participating teachers and children for their time and effort.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Ahmed, S. F., Grammer, J., and Morrison, F. (2021). Cognition in context: validating group-based executive function assessments in young children. *J. Exp. Child Psychol.* 208:105131. doi: 10.1016/j.jecp.2021.105131

Allan, N. P., Hume, L. E., Allan, D. M., Farrington, A. L., and Lonigan, C. J. (2014). Relations between inhibitory control and the development of academic skills in preschool and kindergarten: a meta-analysis. *Dev. Psychol.* 50, 2368–2379. doi: 10.1037/a0037493

Bonefeld, M., Dickhäuser, O., and Karst, K. (2020). Do preservice teachers' judgments and judgment accuracy depend on students' characteristics? The effect of gender and immigration background. *Soc. Psychol. Educ.* 23, 189–216. doi: 10.1007/s11218-019-09533-2

Brock, L. L., Rimm-Kaufman, S. E., Nathanson, L., and Grimm, K. J. (2009). The contributions of 'hot' and 'cool' executive function to children's academic achievement, learning-related behaviors, and engagement in kindergarten. *Early Child. Res. Q.* 24, 337–349. doi: 10.1016/j.ecresq.2009.06.001

Camerota, M., Willoughby, M. T., and Blair, C. B. (2019). Speed and accuracy on the hearts and flowers task interact to predict child outcomes. *Psychol. Assess.* 31, 995–1005. doi: 10.1037/pas0000725

Cirino, P. T., Miciak, J., Gerst, E., Barnes, M. A., Vaughn, S., Child, A., et al. (2016). Executive function, self-regulated learning, and Reading comprehension: a training study. *J. Learn. Disabil.* 50, 450–467. doi: 10.1177/0022219415618497

Cortés Pascual, A., Moyano Muñoz, N., and Quílez Robres, A. (2019). The relationship between executive functions and academic performance in primary education: review and meta-analysis [systematic review]. *Front. Psychol.* 10:1582. doi: 10.3389/fpsyg.2019.01582

Davidson, M. C., Amso, D., Anderson, L. C., and Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia* 44, 2037–2078. doi: 10.1016/j.neuropsychologia.2006.02.006

Davis, H., Valcan, D. S., and Pino-Pasternak, D. (2021). The relationship between executive functioning and self-regulated learning in Australian children. *Br. J. Dev. Psychol.* 39, 625–652. doi: 10.1111/bjdp.12391

Diamond, A. (2013). Executive functions. *Annu. Rev. Psychol.* 64, 135–168. doi: 10.1146/annurev-psych-113011-143750

Diamond, A., Barnett, W. S., Thomas, J., and Munro, S. (2007). Preschool program improves cognitive control. *Science* 318, 1387–1388. doi: 10.1126/science.1151148

Duckworth, A., Gendler, T., and Gross, J. (2014). Self-control in school-age children. *Educ. Psychol.* 49, 199–217. doi: 10.1080/00461520.2014.926225

Finders, J. K., McClelland, M. M., Geldhof, G. J., Rothwell, D. W., and Hatfield, B. E. (2021). Explaining achievement gaps in kindergarten and third grade: the role of self-regulation and executive function skills. *Early Child. Res. Q.* 54, 72–85. doi: 10.1016/j.ecresq.2020.07.008

Friso-van den Bos, I., van der Ven, S. H. G., Kroesbergen, E. H., and van Luit, J. E. H. (2013). Working memory and mathematics in primary school children: a meta-analysis. *Educ. Res. Rev.* 10, 29–44. doi: 10.1016/j.edurev.2013.05.003

Fuhs, M. W., Farran, D. C., and Nesbitt, K. T. (2015). Prekindergarten children's executive functioning skills and achievement gains: the utility of direct assessments and teacher ratings. *J. Educ. Psychol.* 107, 207–221. doi: 10.1037/a0037366

Heemskerk, C. H. H. M., Strand, S., and Malmberg, L. E. (2022a). Physical activity predicts task-related behaviour, affect and tiredness in the primary school classroom: a within-person experiment. *Br. J. Educ. Psychol.* e12523. doi: 10.1111/bjep.12523

Heemskerk, C. H. H. M., Sumatic, M., Strand, S., and Malmberg, L. E. (2022b). Individual differences in the effects of physical activity on classroom behaviour [original research]. *Front. Educ.* 6:571. doi: 10.3389/feduc.2021.812801

Kuutti, T., Sajaniemi, N., Björn, P. M., Heiskanen, N., and Reunamo, J. (2022). Participation, involvement and peer relationships in children with special educational needs in early childhood education. *Eur. J. Spec. Needs Educ.* 37, 587–602. doi: 10.1080/08856257.2021.1920214

Magalhães, S., Carneiro, L., Limpo, T., and Filipe, M. (2020). Executive functions predict literacy and mathematics achievements: the unique contribution of cognitive flexibility in grades 2, 4, and 6. *Child Neuropsychol.* 26, 934–952. doi: 10.1080/09297049.2020.1740188

McCoy, D. C. (2019). Measuring young Children's executive function and self-regulation in classrooms and other real-world settings. *Clin. Child. Fam. Psychol. Rev.* 22, 63–74. doi: 10.1007/s10567-019-00285-1

McCoy, D. C., Koepp, A. E., Jones, S. M., Bodrova, E., Leong, D. J., and Deaver, A. H. (2022). An observational approach for exploring variability in young children's regulation-related skills within classroom contexts. *Dev. Sci.* 25:e13250. doi: 10.1111/desc.13250

Meany-Daboul, M. G., Roscoe, E. M., Bourret, J. C., and Ahearn, W. H. (2007). A comparison of momentary time sampling and partial-interval recording for evaluating functional relations. *J. Appl. Behav. Anal.* 40, 501–514. doi: 10.1901/jaba.2007.40-501

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., and Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. *Cogn. Psychol.* 41, 49–100. doi: 10.1006/cogp.1999.0734

Morgan, P. L., Farkas, G., Wang, Y., Hillemeier, M. M., Oh, Y., and Maczuga, S. (2019). Executive function deficits in kindergarten predict repeated academic difficulties across elementary school. *Early Child. Res. Q.* 46, 20–32. doi: 10.1016/j.ecresq.2018.06.009

Nesbitt, K. T., and Farran, D. C. (2022). Executive function skills and classroom behaviors of U.S. Prekindergartners with special needs [original research]. *Front. Educ.* 7:447. doi: 10.3389/feduc.2022.944224

Nesbitt, K. T., Farran, D. C., and Fuhs, M. W. (2015). Executive function skills and academic achievement gains in prekindergarten: contributions of learning-related behaviors. *Dev. Psychol.* 51, 865–878. doi: 10.1037/dev0000021

Neuenschwander, R., Röthlisberger, M., Cimeli, P., and Roebers, C. M. (2012). How do different aspects of self-regulation predict successful adaptation to school? *J. Exp. Child Psychol.* 113, 353–371. doi: 10.1016/j.jecp.2012.07.004

Nigg, J. T. (2017). Annual research review: on the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. *J. Child Psychol. Psychiatry* 58, 361–383. doi: 10.1111/jcpp.12675

Obradović, J., Sulik, M. J., Finch, J. E., and Tirado-Strayer, N. (2018). Assessing students' executive functions in the classroom: validating a scalable group-based procedure. *J. Appl. Dev. Psychol.* 55, 4–13. doi: 10.1016/j.appdev.2017.03.003

Pearson Assessments. (2013). *BOSS User's Guide*. Bloomington: Pearson Publisher.

Pintrich, P. R. (2000). "Chapter 14 - the role of goal orientation in self-regulated learning" in *Handbook of Self-Regulation*. eds. M. Boekaerts, P. R. Pintrich and M. Zeidner (San Diego: Academic Press), 451–502.

Pintrich, P. R., and Zusho, A. (2002). "Chapter 10 - the development of academic self-regulation: the role of cognitive and motivational factors" in *Development of Achievement Motivation*. eds. A. Wigfield and J. S. Eccles (San Diego: Academic Press), 249–284.

Rosseel, Y. (2012). Lavaan: an R package for structural equation modeling. *J. Stat. Softw.* 48, 1–36. doi: 10.18637/jss.v048.i02

RStudio Team (2022). *Rstudio: Integrated Development Environment for R. in (version 4.2.0)*. Boston, MA: RStudio PBC.

Rutherford, T., Buschkuehl, M., Jaeggi, S. M., and Farkas, G. (2018). Links between achievement, executive functions, and self-regulated learning. *Appl. Cogn. Psychol.* 32, 763–774. doi: 10.1002/acp.3462

Schmitt, S. A., McClelland, M. M., Tominey, S. L., and Acock, A. C. (2015). Strengthening school readiness for head start children: evaluation of a self-regulation intervention. *Early Child. Res. Q.* 30, 20–31. doi: 10.1016/j.ecresq.2014.08.001

Shrout, P. E., and Bolger, N. (2002). Mediation in experimental and nonexperimental studies: new procedures and recommendations. *Psychol. Methods* 7, 422–445. doi: 10.1037/1082-989X.7.4.422

Spiegel, J. A., Goodrich, J. M., Morris, B. M., Osborne, C. M., and Lonigan, C. J. (2021). Relations between executive functions and academic outcomes in elementary school children: a meta-analysis. *Psychol. Bull.* 147, 329–351. doi: 10.1037/bul0000322

Yeniad, N., Malda, M., Mesman, J., van Ijzendoorn, M. H., and Pieper, S. (2013). Shifting ability predicts math and reading performance in children: a meta-analytical study. *Learn. Individ. Differ.* 23, 1–9. doi: 10.1016/j.lindif.2012.10.004

Zakszeski, B. N., Hojnoski, R. L., and Wood, B. K. (2017). Considerations for time sampling interval durations in the measurement of young Children's classroom engagement. *Top. Early Child. Spec. Educ.* 37, 42–53. doi: 10.1177/0271121416659054

Zelazo, P. D., Anderson, J. E., Richler, J., Wallner-Allen, K., Beaumont, J. L., and Weintraub, S. (2013). Ii. NIH toolbox COGNITION battery (CB): measuring executive function and attention. *Monogr. Soc. Res. Child Dev.* 78, 16–33. doi: 10.1111/mono.12032

Zhou, Q., Chen, S. H., and Main, A. (2012). Commonalities and differences in the research on Children's effortful control and executive function: a call for an integrated model of self-regulation. *Child Dev. Perspect.* 6, 112–121. doi: 10.1111/j.1750-8606.2011.00176.x

Zimmerman, B. J., and Kitsantas, A. (2014). Comparing students' self-discipline and self-regulation measures and their prediction of academic achievement. *Contemp. Educ. Psychol.* 39, 145–155. doi: 10.1016/j.cedpsych.2014.03.004