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Monitoring and control processes within executive functions: Is post-error slowing related to pre-error speeding in children?

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A B S T R A C T

Both pre-error speeding and post-error slowing reflect monitoring and control strategies. Post-error slowing is relatively well-established in children, whereas pre-error speeding is much less studied. Here we investigated (a) whether kindergarten and first-grade children show pre-error speeding in a cognitive control task (Hearts and Flowers) and, if so, (b) whether post-error slowing is associated with pre-error speeding. We analyzed the data from 153 kindergartners and 468 first-graders. Both kindergartners and first-graders showed significant pre-error speeding and post-error slowing, with no differences between the two samples in the magnitude of each. The magnitude of pre-error speeding and post-error slowing was correlated within individuals in both samples and to a similar extent. That is, children who sped up more extremely toward an error also slowed down more extremely after an error. These findings provide evidence that pre-error speeding and post-error slowing are related in children as early as kindergarten age and may in concert reflect how optimal children's monitoring and control of their performance is in a cognitive control task.

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Introduction

When people are instructed to solve an easy multi-trial task as fast and accurately as possible, they do not commit errors out of the blue, but errors may indicate that people search for their speed limits (Laming, 1979; Rabbitt, 1966). In other words, people test how fast they can respond to give a correct answer and speed up their responses until they make an error. This leads to the so-called *pre-error speeding* (Brewer & Smith, 1989). Once they make an error, a likely response is to slow down afterward, what is termed as *post-error slowing,* to prevent future errors (Botvinick et al., 2001, but see also Notebaert et al., 2009, for a nonfunctional account). These phenomena are observable not only in the laboratory but also in adults' and children's everyday lives. For instance, when a child is practicing simple addition and subtraction, he or she may speed up on the single one-digit tasks. However, if the tasks get increasingly difficult (two digits), the individual will most likely slow down to secure accuracy. Similarly, if an error occurs when the task suddenly changes (e.g., from addition to subtraction), the individual should slow down. How these phenomena come into being and whether they are related are curious questions to answer to understand the problem-solving processes.

Both post-error slowing and pre-error speeding are interpreted as mirroring a strategy of how an individual approaches a task. In particular, both reflect monitoring strategies in a multi-trial simple choice reaction task where participants are asked to respond as accurately and as fast as possible (Brewer & Smith, 1989). In this context, both speeding up until one encounters an error (i.e., pre-error speeding) and slowing down the response speed after an error to avoid future errors (i.e. post-error slowing) are considered strategies to maintain an optimal speed–accuracy balance. Hence, for optimal performance, an individual may speed up on a run of correct trials, but not too much, to avoid errors and slow down after an error to avoid future errors, but not too much, to still be fast enough overall. Therefore, not only can a relationship between whether an individual exhibits pre-error speeding and post-error slowing be expected as a manifestation of monitoring and cognitive control but also a relationship between the magnitude of the two can be expected as an indication of how optimal the individual is in monitoring and cognitive control.[1]

So far, there is no research systematically examining whether these phenomena are linked within individuals, but only some studies found both phenomena to occur within the same simple choice reaction time (RT) task (Allain et al., 2009; Brewer & Smith, 1989; Dudschig & Jentzsch, 2009; Jackson & Balota, 2012; Shiels et al., 2012; Smith & Brewer, 1995) and a few found post-error slowing to occur without necessarily pre-error speeding (Laming, 1979; Smulders et al., 2016). The reasons for this inconsistency may lie in the ages of the samples, the nature of the tasks used, the stimulus–response intervals used, or the methods used to calculate pre-error speeding and post-error slowing.

Post-error slowing and pre-error speeding are relatively well-studied in adults but to a much lesser extent in children. Particularly in young children, although a growing body of research provides evidence that they do show post-error slowing (e.g., Dubravac et al., 2020; Ger & Roebers, 2023a,b; Gupta et al., 2009; Roebers, 2022; Smulders et al., 2016), pre-error speeding has received much less attention and is not well-understood (Pfister & Foerster, 2022). And in the scarce research that exists, there is no consensus regarding whether children speed up their responses toward an error. Smulders et al. (2016) did not find pre-error speeding in a choice discrimination task (CDT) in participants aged 5 to 25 years. Brewer and Smith (1989) found robust pre-error speeding in a CDT in adults and a similar but noisier pattern (i.e., more trial-to-trial variation) of pre-error speeding in children aged 5 to 15 years. Epstein et al. (2010) found trials prior to commission errors in an inhibition task (i.e., go/no-

[1] Here it is important to also note that, conceptually, the monitoring and control addressed in the cognitive control (or EF) literature are different than those addressed more commonly in the metacognition literature in terms of the consciousness involved in these processes (Roebers, 2017). Specifically, the type of monitoring and control researched under the metacognition literature is mostly conscious given that it is assessed by more explicit methods such as asking individuals about their confidence in their answers, which answers they would keep or discard, and how well they think they learned a task. In contrast, these processes under the cognitive control literature are mostly assumed implicitly and not tested directly. Yet, instead of being two different concepts under each literature, they may constitute a spectrum ranging from more transient in EF to more explicit in metacognition. Hence, although the specifics of these processes in terms of consciousness are beyond the scope of this article, pre-error speeding and post-error slowing addressed in the current study are presumably implicit processes reflecting individuals' monitoring and control.

go task) to have faster RTs than all other trials, indicating pre-error speeding, in 7- to 9-year-olds. Shiels et al. (2012) found pre-error speeding in 7- to 11-year-olds in both an inhibition task (i.e., stop signal task) and a CDT.

Previous research documents that young children show coarser monitoring and control in the form of both overspeeding before errors and slowing down extremely after errors (Brewer & Smith, 1989; Fairweather, 1978; Smulders et al., 2016; Thaqi & Roebers, 2020). This raises the possibility that, if not in adults, in children who do not yet master monitoring and control adjustments, an association between pre-error speeding and post-error slowing may exist as an indication of suboptimal orchestration of monitoring and control and coarser control adjustments. The three studies with children mentioned above documented both pre-error speeding and post-error slowing within the same task (Brewer & Smith, 1989; Epstein et al., 2010; Shiels et al., 2012). However, whether these two measures correlated within individuals in a given task was, unfortunately, not addressed. Given that the years of transitioning to school are critical in the development of cognitive control (Carlson, 2005; Davidson et al., 2006), we focused on kindergarten and first-grade children. Therefore, in this study we first examined whether kindergartners (6 years of age) and first-graders (7 years of age) show pre-error speeding and post-error slowing. Second, we examined whether pre-error speeding is associated with post-error slowing to see whether those who extremely speed up toward an error also more extremely slow down post-error. This would indicate a relatedness of the different monitoring and adaptation processes.

Regarding children's development of cognitive control, some argue that it is not limited to only quantitative change but also qualitative change toward more optimal control. Specifically, they propose two types of control processes, reactive and proactive control, whose employment and coordination appear to develop with increasing age (Braver, 2012; Chevalier, 2015; Chevalier et al., 2020; Roebers, 2022). Proactive control is fueled by anticipating and preparing for the upcoming task demands, whereas reactive control is employed in response to unexpected events such as an error. Accordingly, pre-error speeding could be suggestive of rather proactive control, whereas post-error slowing could be suggestive of rather reactive control (Thaqi & Roebers, 2020). Whereas young children are assumed to rely mostly on reactive control, children aged 6 years and over are assumed to increasingly shift to proactive control, and the coordination of control improves with age (Chevalier, 2015; Munakata et al., 2012). Older children compared with younger children may employ more or better proactive control in contrast to reactive control or may better coordinate the two types of control (Chevalier, 2015; Chevalier et al., 2020; Roebers, 2022). Hence, we might expect a link between pre-error speeding and post-error slowing that may get stronger with age.

Moreover, post-error slowing in children aged 4 years and over appears to be domain-general; namely, it manifests itself in various executive function (EF) tasks with different types of conflict and task demands (Dubravac et al., 2022; Ger & Roebers, 2023a). That is, children slow down after errors in different types of situations such as after committing an error by responding impulsively where they are required to inhibit themselves and after responding incorrectly based on an old rule where they were expected to respond based on a new rule. However, there are also some indications that post-error slowing is less robust in a more demanding EF task that mainly taxes shifting (in addition to inhibition) compared with the less demanding task that taxes only inhibition in 6-year-olds than in 7- and 8-year-olds (Roebers, 2022). Only one study looked at pre-error speeding in children in more than a single task, specifically in an inhibition task (i.e., stop signal task) and a general cognitive ability task (i.e., CDT) and found pre-error speeding in both (Shiels et al., 2012). In that regard, we also investigated whether pre-error speeding similarly occurs and/or correlates with post-error slowing in EF tasks that mainly tax different EF components, specifically inhibition and shifting (i.e., cognitive flexibility), the latter of which is more demanding. In the Hearts and Flowers task we used, the Flowers block requires children to inhibit the prepotent response to press on the same side where a flower stimulus appears and to press on the opposite side, thereby constituting the inhibition component. The Mixed block requires children to shift between pressing the same side when a heart stimulus appears and pressing the opposite side when a flower stimulus appears, thereby constituting the shifting component.

Finally, independent of the potential within-person association between pre-error speeding and post-error slowing, we expected the magnitude of both to be greater in the kindergarten sample compared with the first-grade sample given that these monitoring adjustments are documented to be coarser (i.e., more exaggerated) and noisier (i.e., more trial-to-trial variation) in younger children compared with older children (Brewer & Smith, 1989; Fairweather, 1978; Smulders et al., 2016; Thaqi & Roebers, 2020).

Our study also makes a novel contribution in the calculation of pre-error speeding. The pre-error speeding is a more gradual process distributed across several pre-error trials, whereas post-error slowing is restricted mainly to the trial immediately following the error trial (see Fig. 3 in Brewer & Smith, 1989). For that reason, we preferred to stick to the traditional calculation of post-error slowing while we thought a novel measure of pre-error speeding that takes into account not only the trial immediately preceding the error but all the preceding trials would be more representative of the phenomenon. The traditional calculation of post-error slowing is by subtracting the mean individual RT of correct post-correct trials from the mean individual RT of correct post-error trials (Dutilh et al., 2012). The higher this value, the greater the post-error slowing. Yet, there is no consensus in the literature on how to calculate pre-error speeding, and most restrict it to the trials immediately surrounding the error trial (Gehring & Fencsik, 2001; Jackson & Balota, 2012; Jentzsch & Leuthold, 2006; Pfister & Foerster, 2022; Shiels et al., 2012).

More recently, Murphy et al. (2016) looked at the trajectory of RTs of five correct trials preceding an error and conducted an analysis of variance (ANOVA) on these RTs with the trial position as the independent variable to detect whether there was significant pre-error speeding. We took a similar approach to Murphy et al. (2016) to quantify pre-error speeding in a more extended sequence of trials preceding an error. To be able to not only detect whether there is significant pre-error speeding but also quantify the magnitude of it, we calculated an unstandardized linear regression coefficient (i.e., slope) of RTs in the sequence of correct pre-error trials. We then averaged the coefficients derived from all sequences as an overall index of pre-error speeding for each child (negative values meaning speeding). Hence, we did not preselect only those sequences of a predetermined number of pre-error correct trials but included any sequence of at least three consecutive correct trials before any error. This way, we were not limited to only those sequences with a fixed number of correct pre-error trials but rather were able to better capture the entire performance.

In sum, we formulated the following four hypotheses. First, we expected both kindergartners and first-graders to show significant pre-error speeding and post-error slowing. Second, we expected the magnitude of both pre-error speeding and post-error slowing to be greater in kindergartners than in first-graders. Third, we expected that pre-error speeding is negatively associated with post-error slowing for both kindergartners and first-graders (negative values of pre-error speeding mean speeding, whereas positive values in post-error slowing mean slowing). Namely, we expected children who speed up more to also slow down more. Fourth, we expected that the association between pre-error speeding and post-error slowing would be greater in first-graders than in kindergartners.

We also explored whether children reduce the magnitude of their pre-error speeding and post-error slowing throughout a block to further support the thesis that both are strategies of monitoring that get more fine-tuned in the course of a task and explored how pre-error speeding and post-error slowing relate to accurate performance.

Method

Participants

The data came from the pretesting of two independent larger training studies. The data from 153 kindergarten children (49% female) and 468 first-grade children (43% female) were included in the analyses. The size of each of sample was determined based on the corresponding individual projects' time and personnel constraints. However, an a priori power analysis using the program G*Power (Faul et al., 2007) for detecting a small effect size of d = .25 on the alpha = .05 level for pre-error speeding for obtaining .90 power estimated a required sample size of 139 for a one-sample t test (mu = 0). A two-tailed correlation analysis for a low correlation coefficient of .25, alpha level of .05, and .90 power estimated a required sample size of 160. Hence, with our existing sample size, the study was sufficiently powered.

Kindergartners were aged 5.5 to 7 years with a mean age of 6.4 years (*SD* = 0.3). First-graders were aged 7 to 8.3 years with a mean age of 7.3 years (*SD* = 0.2). An additional 16 kindergartners were tested but excluded from the analyses because they did not complete the task ($n = 2$) or they had less than 50% correct in either the Flowers or Mixed block ($n = 14$), which is a common exclusion criterion in the literature using the Hearts and Flowers task to ensure that children have understood the task (e.g., Camerota et al., 2019; Roebers, 2022). An additional 85 first-graders were tested but excluded from the analyses because they did not complete the task ($n = 44$), they had less than 50% correct in either the Flowers or Mixed block ($n = 37$), or they did not make any mistakes in either the Flowers or Mixed block (in which we calculated post-error slowing), for whom post-error slowing therefore could not be calculated ($n = 4$).

Participating children came from urban and rural areas of central Switzerland, from lower- to upper-middle-class families. Excluding 10 children's missing information, 77% of children had one of the official languages as their mother tongue. Participants were recruited by contacting kindergarten teachers who showed interest in participating. Participating children's parents provided informed consent. The study was approved by the local ethics committee and was carried out in accordance with the Declaration of Helsinki.

Task and procedure

Children were tested in small groups in a quiet room in their kindergartens or schools. Children sat in front of a tablet computer, which was connected to headphones and a pair of external response buttons. Children received instructions and feedback during practice trials from a taped audio via the headphones. These audio tapes were made appropriate for children of the tested age and had been piloted intensively.

We used an adapted version of the Hearts and Flowers (HF) task (Diamond et al., 2007). A schematic of the Mixed block of the HF task is illustrated in Fig. 1. In this task, children were presented with either a heart or flower image. They needed to press an external button at the congruent side where the heart appeared, and at the opposite side where the flower appeared, as quickly but also as accurately as possible. A total of three blocks were presented in a fixed order. First a congruent block with 24 heart trials (Hearts block), then an incongruent block with 36 flower trials (Flowers block), and finally a Mixed block with 48 heart and 12 flower trials were presented. The Hearts block served to establish a prepotent response (i.e., pressing on the same side of the stimulus). The Flowers block served to impose conflict given that the prepotent response needed to be inhibited. In the Mixed block, heart (congruent) and flower (incongruent) trials were presented in a pseudo-randomized order, whereby a flower trial was followed and preceded by a heart trial. This block required children to flexibly switch between rules (i.e., press on the same side vs. press on the opposite side). Before starting with test trials in each block, children received instructions and solved four practice trials. Stimuli were presented for 750 ms, and the trial ended as soon as children gave a response. A fixation cross was presented for 500 ms between trials. The accuracy and RT of the responses were obtained.

Data analysis

All analyses were carried out in R (Version 4.0.2; R Core Team, 2020). We used the packages "lme4" (Bates et al., 2015), "lmerTest" (Kuznetsova et al., 2017), and "sjPlot" (Lüdecke, 2024) for mixed models, the package "rstatix" (Kassambara, 2023) for correlation, Wilcoxon, and *t* tests, and the package "cocor" (Diedenhofen & Musch, 2015) for Fisher's *z* test. The current approach is a secondary analysis of the Flowers and Mixed blocks of the HF task data obtained from two larger training datasets. The errors from all trial types in the Mixed block were included in the current analyses; that is, no differentiations between a switch or non-switch trial were made. The preregistration can be found at https://osf.io/uns84. The anonymized data and analysis script can be found at https://osf.io/yqabt/. Reaction time and accuracy measures (percentage correct) were used. Trials with an RT longer than 2500 ms were removed for being outliers based on the maximum RT allowed commonly used in

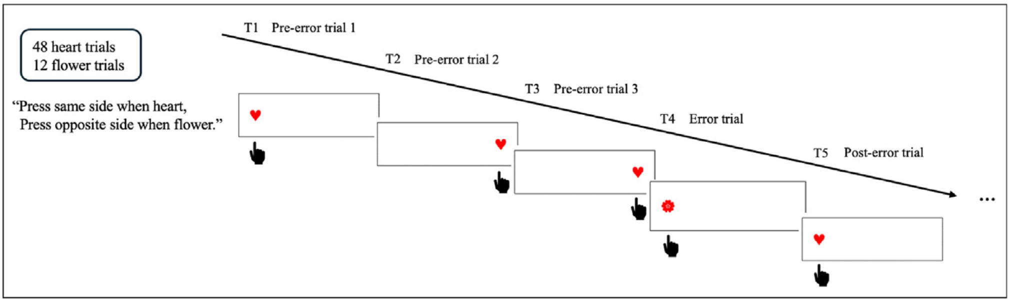

Fig. 1. Schematic of the Hearts and Flowers task (Mixed block). The order of the stimuli is made up for illustration purposes.

the literature, and trials with an RT shorter than 250 ms were removed for being too fast to be a response to the stimuli (Davidson et al., 2006; Wright & Diamond, 2014). Table 1 shows the number and percentage of removed trials for both samples. After these removals, a total of 70,917 trials were analyzed.

At this point, we should note that we did not set an exclusion criterion for minimum number of errors for participants to be included in the analyses of error processing. There is no consensus in the literature regarding this criterion, especially in research with children. The number of errors per participant included in the current analyses for both pre-error speeding and post-error slowing is presented in Fig. 2.[2] As can be seen here, the number of errors is rather normally distributed in the Mixed block, whereas it is positively skewed in the Flowers block. This uneven distribution in the number of error trials, contributing to the calculation of error processing measures such as post-error slowing and pre-error speeding, may bias and inflate the size of the effects of interest. More specifically, there is a piling up of children with a single error in the Flowers block, and children who rarely make errors may show a larger surprise response to a single error, thereby inflating the average magnitude of post-error slowing. Therefore, relying on the literature on adults, where a minimum of 10 errors is a common criterion (e.g., Ehlis et al., 2018), we also repeated the correlation analyses with minimum error criteria ranging from 2 to 10 and report these results in the Supplementary Material. These analyses show that the trend for a significant negative relationship between pre-error speeding and post-error slowing did not change with a minimum error criterion ranging from 2 to 10 errors. One caveat is that for the Flowers block, where the average error rate was not so high, the criterion of analyzing only those children who had at least 6 to 10 errors drastically reduced the number of children with analyzable data, thereby reducing the power to calculate meaningful correlation statistics. Even in this case, the negative pattern remained the same. Given that the relationship between the estimated pre-error speeding and post-error slowing remains robust to the different number of minimum errors, we reasoned that analyzing children's data without applying any such exclusion criteria, where naturally occurring error rates of just 1 or 2 errors are included, adequately reflects the true nature of children's error-related adjustments.

Preregistered hypotheses

To test Hypothesis 1—that kindergartners and first-graders would show significant pre-error speeding—we carried out one-tailed one-sample *t* tests comparing pre-error speeding with 0 to see whether it is significantly below 0. To test Hypothesis 2—that the magnitude of both pre-error speeding and post-error slowing would be greater in kindergartners than in first-graders—we ran one-tailed between-participants *t* tests comparing pre-error speeding and post-error slowing magnitude between kindergartners and first-graders. To test Hypothesis 3—that pre-error speeding would be negatively associated with post-error slowing for both kindergartners and first-graders—we carried

[2] Note that some of the errors were not included in the analyses of pre-error speeding and post-error slowing because they did not meet requirements such as following at least 3 consecutive correct trials for pre-error speeding or preceding a correct trial for post-error slowing. In Table 4 (see Results), error positions greater than the maximum number of errors in these graphs are listed. This is possible, for instance, when a child's error in position 11 is included, but 3 errors in other positions needed to be excluded due to these requirements.

Table 1
Removed trials

Grade	Number (and %) of trials > 2500 ms	Number (and %) of trials < 250 ms
Kindergarten	832 (4.5%)	315 (1.7%)
First grade	1564 (2.8%)	892 (1.6%)

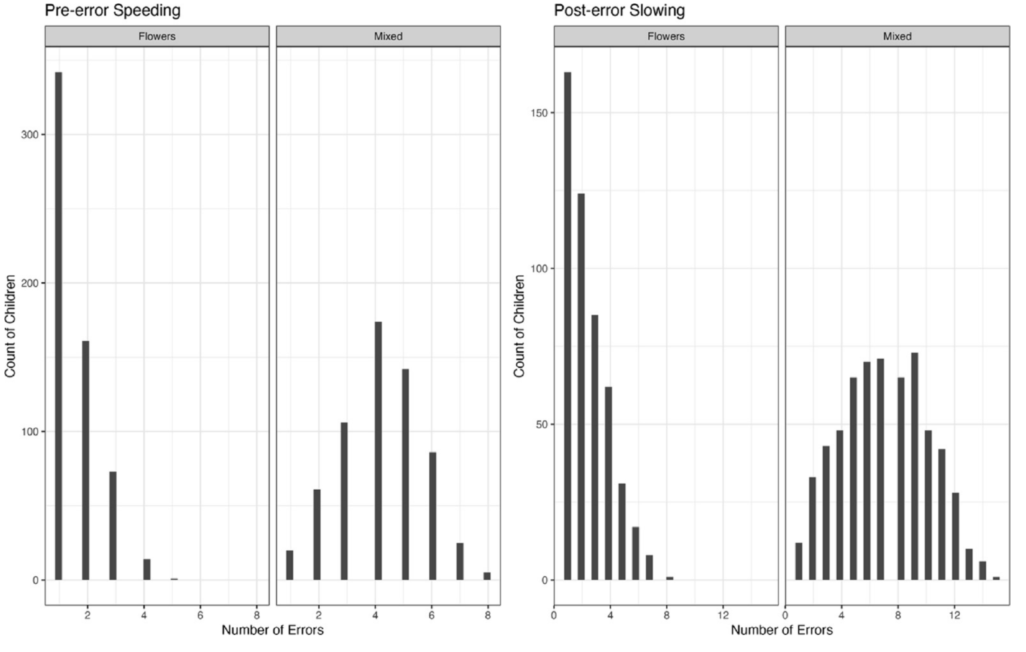

Fig. 2. Number of errors per participant included in the analyses.

out Spearman correlation tests between pre-error speeding and post-error slowing because the normality assumptions were violated in both pre-error speeding and post-error slowing in both blocks and both age groups, mainly due to some children with outlying values. We also ran partial correlations controlling for accuracy and processing speed. To test Hypothesis 4—that the association between pre-error speeding and post-error slowing would be greater in first-graders than in kindergartners—we compared the correlation coefficients between the kindergarten and first-grade samples using a Fisher's *z* test. Given that there is sparse empirical evidence on the nature of post-error slowing, and specifically pre-error speeding across different EF demands (i.e., inhibition and shifting) that also seem to depend on age, we explored whether our hypotheses hold for both EF demands, that is, in both blocks of the HF task. Therefore, we report all our analysis results separately for both blocks of the HF task.

Because we had a considerably greater sample size for the first-grade children, we also ran a simulation where we subsampled 100 times the size of the kindergarten sample (n = 153) out of the first-grade sample (n = 468) without replacement and ran the analyses in each of these subsamples to determine the percentage of times we get similar significance (i.e., significant or not, with the same < .05 cutoff), similar to a power calculation. For instance, for Hypothesis 1, we randomly selected 153 children's data out of the 468 first-grade children's data, carried out the one-sample *t* test on pre-error speeding, and checked whether it was significant. We repeated this 99 more times and calculated how many times out of 100 it turned out significant. This was done to make sure that we do not have artificially higher chances of finding significance in the first-grade sample just due to its larger sample size compared with the kindergarten sample.

Exploratory analyses

We also explored whether children reduce the magnitude of their pre-error speeding and post-error slowing throughout a block, as a potential indication that they get better in monitoring, and whether that is similar or different in the different blocks and in kindergarten versus first-grade children. To this end, we ran separate linear mixed-effects models for pre-error speeding and post-error slowing and separately for the Flowers and Mixed blocks. For pre-error speeding, we had the slope estimate of pre-error speeding as the outcome variable, the position of the pre-error chunk, the sample (kindergarten or first grade), and their two-way interaction as the fixed effects, and participants as the random intercept. We included participant as a random intercept because the multiple observations from each participant are not independent. For post-error slowing, we calculated another index for each error by subtracting the average RT of the correct post-correct trials within the block from the RT of that error. We then entered this index as the outcome variable, the position of the error within the block (first error, second error, etc.), the sample (kindergarten or first grade), and their two-way interaction as the fixed effects, and participants as the random intercept. In both models (for pre-error speeding and post-error slowing), we removed the sample variable from the model if the comparisons between models with and without the sample in the two-way interaction were not significant. We ran further simple slope analyses when interactions were significant and used the Benjamini–Hochberg procedure for *p* value adjustment, which controls for false discovery rate. We reported the effect size of the final models using the *tab_model* function of the "sjPlot" package, which gives marginal and conditional R^2 values following Nakagawa and Shielzeth's (2013) recommendations for linear mixed-effects models.

We also explored, in each block, the prediction of overall accuracy by pre-error speeding, post-error slowing, age, and all three-way and two-way interactions, with the aim to elucidate their role for high accuracy. To this end, we first ran a separate linear regression model for each block, predicting accuracy from the standardized pre-error speeding, standardized post-error slowing, age, and all interactions. In a hierarchical fashion, higher-order interactions that were not significant were removed in a subsequent model. We reported the results of the final models using the *tab_model* function.

Results

Descriptive statistics for the accuracy and RTs in each block, and the pre-error speeding and post-error slowing in the Flowers and Mixed blocks, are reported separately for both samples in Table 2. Numbers of children was reduced for pre-error speeding because children did not have any pre-error chunk with at least 3 trials (22 first-graders and 8 kindergartners in the Flowers block and 1 first-grader in the Mixed block) or did not have any pre-error chunk where all the trials were within the included RT window of 250 to 2500 ms (1 first-grader in the Mixed block). Number of children was reduced for post-error slowing because they did not have any errors in that block (23 kindergartners and 83 first-graders in the Flowers block and 1 first-grader in the Mixed block) or had the only error in the last trial (2 first-graders in the Flowers block), which did not allow calculating any post-error slowing, or did not have any post-error trial within the included RT window of 250 to 2500 ms (9 kindergartners and 13 first-graders in the Flowers block and 2 kindergartners and 3 first-graders in the Mixed block). Preliminary analyses showed no sex differences in pre-error speeding or post-error slowing; hence, analyses were carried out on the collapsed sample.

Preregistered hypotheses

Regarding Hypothesis 1, results showed that both kindergarten and first-grade children showed significant pre-error speeding in both the Flowers block [kindergartners: $t(144) = -4.17$, $p < .001$; first-graders: $t(445) = -6.39$, $p < .001$] and the Mixed block [kindergartners: $t(152) = -4.20$, $p < .001$; first-graders: $t(465) = -5.33$, $p < .001$]. That is, in the run of correct trials before an error, children sped up their responses (14 and 13 ms per trial in the Flowers block and 17 and 12 ms per trial in the Mixed block, respectively, for kindergarten and first-grade children).

Table 2
Descriptive statistics of measured variables

Variable	Kindergarten			First grade		
	n	Mean	*SD*	*n*	Mean	*SD*
Accuracy: Hearts	153	.97	.048	468	.96	.048
Accuracy: Flowers	153	.91	.11	468	.92	.091
Accuracy: Mixed	153	.83	.092	468	.83	.098
RT: Hearts	153	598	131	468	628	165
RT: Flowers	153	828	155	468	856	194
RT: Mixed	153	784	166	468	833	183
Post-error slowing: Flowers	121	272	296	370	230	266
Post-error slowing: Mixed	151	125	212	464	86	184
Pre-error speeding: Flowers	145	−14	42	446	−13	44
Pre-error speeding: Mixed	153	−17	49	466	−12	49

Note. Accuracy represents percentage correct answers. Reaction times (RTs) are in milliseconds. The pre-error speeding values are children's average slope coefficients (unstandardized) of their pre-error chunk RTs. It represents the average change in RT in milliseconds from one trial to the next in a pre-error trial chunk. The post-error slowing values are the mean RT difference between children's correct post-correct trials and correct post-error trials.

Regarding Hypothesis 2, the magnitude of post-error slowing or pre-error speeding was not found to be greater in kindergartners compared with first-graders in either of the blocks (all *ps* > .16). We also ran correlation analyses with age in the collapsed data of both age groups, and no significant correlations emerged (ρs = −.02, −.07, .00, and −.01 and *ps* = .67, .10, .94, and .82, respectively, between age and post-error slowing in the Flowers block, age and post-error slowing in the Mixed block, age and pre-error speeding in the Flowers block, and age and pre-error speeding in the Mixed block).

Regarding Hypothesis 3, pre-error speeding was negatively associated with post-error slowing for kindergartners in both the Flowers block (ρ = −.28, p < .01; Fig. 3A) and the Mixed block (ρ = −.33, p < .001; Fig. 3B) as well as for first-graders in both the Flowers block (ρ = −.23, p < .001; Fig. 3C) and the Mixed block (ρ = −.38, p < .001; Fig. 3D). All these significant correlations held even after controlling for accuracy in the corresponding sample and block or controlling for the mean RT in the Hearts block as an index of children's general processing speed (Table 3). Namely, children who sped up more toward an error also slowed down more after an error. As can be probed further from the distribution of children on the slowing–speeding axis in all plots in Fig. 3, speeding and slowing appeared to be dependent. That is, it seemed more likely that if children noticeably speed up (speeding < 0), they also noticeably slow down (slowing > 0), and vice versa. In the graphs in Fig. 3, one can see a clustering in a vertical stack around the zero point on the x-axis (pre-error speeding). We did not apply further trimming for the post-error slowing and pre-error speeding values because we already trimmed the data per individual based on overall accuracy and per trial based on RT cutoffs. However, to ensure the reliability of the correlations, we carried out additional correlation analyses after removing outlying post-error slowing and pre-error speeding data points, namely data points outside 1.5 times the interquartile range (IQR). The IQRs for post-error slowing were 351 and 183 ms in the Flowers and Mixed blocks, respectively. The IQRs for pre-error speeding were 29 and 44 ms in the Flowers and Mixed blocks, respectively. All the significant correlations held even after this removal. The resulting scatterplots and the correlation statistics (both Pearson and Spearman correlations) are reported in the Supplementary Material.

Finally, regarding Hypothesis 4, the association between pre-error speeding and post-error slowing was not found to be greater in first-graders than in kindergartners in either the Flower block (z = −0.27, p = .605) or the Mixed block (z = −0.65, p = .741). The simulations with a smaller subsample of the first-grade sample yielded the same significance decision 76% to 100% of the time for Hypotheses 1 to 4.

Exploratory analyses

Next, we turn to the exploratory analyses' results regarding the magnitude of children's pre-error speeding and post-error slowing in the course of a block.

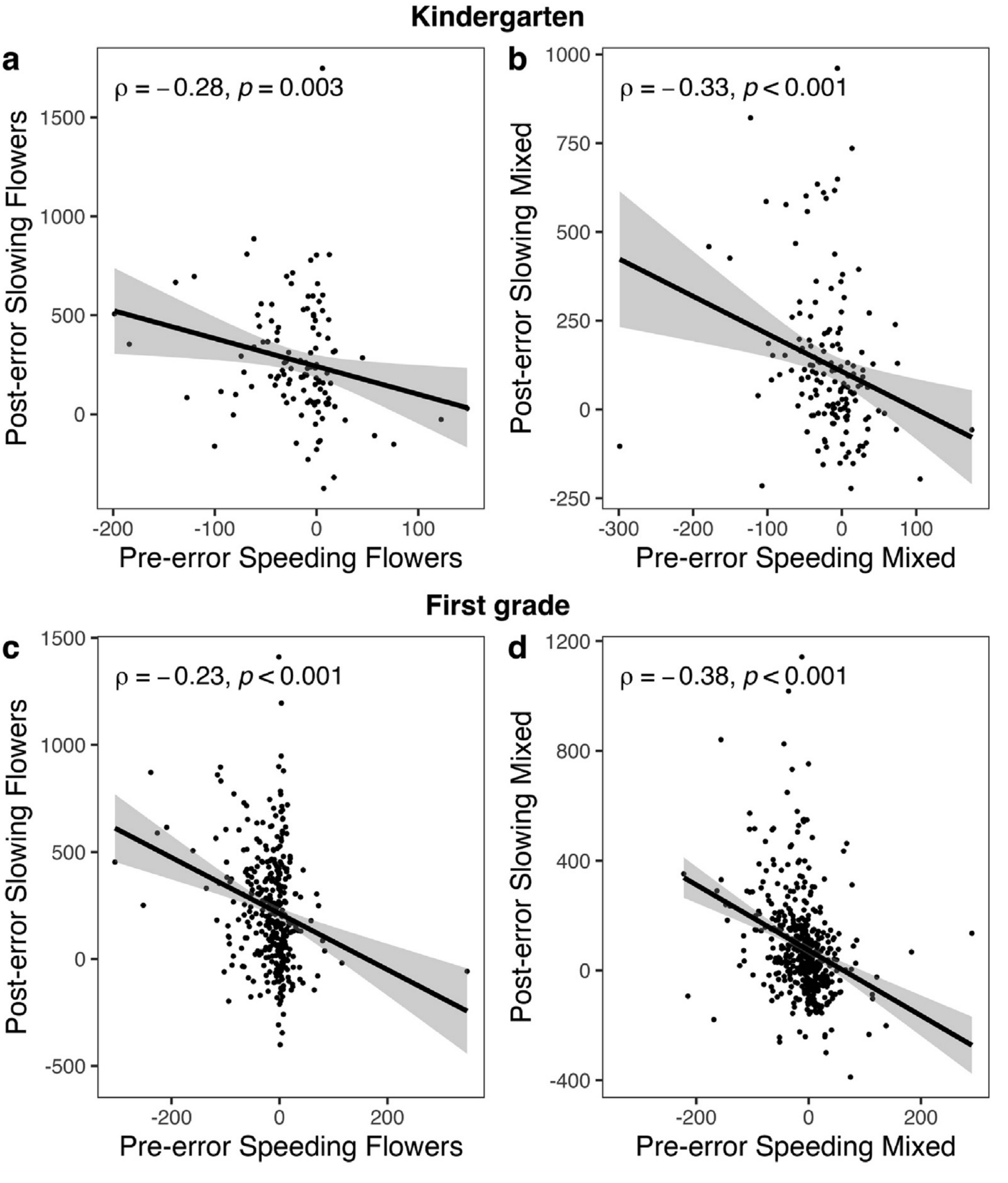

Fig. 3. Correlation between pre-error speeding and post-error slowing in kindergartners and first-graders.

Pre-error speeding

For pre-error speeding, the model with the grade in the interaction proved better for the Flowers block, $\chi^2(1) = 5.39$, $p = .020$, whereas the model without the grade in the interaction proved better for the Mixed block, $\chi^2(1) = 0.00$, $p = .956$. Hence, kindergarten and first-grade children diverged in their pre-error speeding trajectory in the Flowers block, whereas they showed similar patterns in the Mixed block. The effect sizes (marginal R^2/conditional R^2) for the final models were .014/.082 for the Flowers block and .013/.023 for the Mixed block.

Table 3
Correlation between pre-error speeding and post-error slowing, controlling for accuracy or processing speed

Grade	Flowers		Mixed	
	ρ	p	ρ	p
	Controlling for accuracy			
Kindergarten	−.33	<.001	−.35	<.001
First grade	−.29	<.001	−.39	<.001
	Controlling for processing speed			
Kindergarten	−.27	.003	−.33	<.001
First grade	−.23	<.001	−.38	<.001

In the Flowers block, as mentioned above, there was a significant interaction between the sample and the position of the pre-error chunk, $\chi^2(1) = 5.39$, $p = .020$. Kindergarten children's speeding did not change (estimate [unstandardized] = 2.49, *SE* = 3.89, confidence interval (*CI*) = [−5.13, 10.11], $p = .522$; Fig. 4A), whereas first-grade children's speeding increased in the course of the task block (estimate [unstandardized] = −7.93, *SE* = 2.25, *CI* = [−12.34, −3.51], $p < .001$; Fig. 4A). Namely, in each consecutive run of correct trials leading to an error, first-grade children's speeding toward an error increased by 7.93 ms per trial. For instance, if a first-grader answered the first trial correctly in 500 ms and answered the next trial correctly in 480 ms and the next in 460 ms and then made a mistake on the 4th trial, the estimated speeding in this first chunk of 3 correct trials is 20 ms per trial [=(500 − 460)/2]. In the second chunk of correct trials, let's say from the 5th trial onward, the speeding is estimated to be 7.93 ms greater. That is, if the child answers the 5th trial correctly again in 500 ms, the child is expected to answer the next trial correctly in 472.07 ms, 27.93 ms faster per trial. Kindergarten children were estimated to show pre-error speeding until about the 3rd error (i.e., third pre-error chunk), which can be observed where the upper bound of the ribbons representing the 95% confidence intervals crosses the 0 lines in Fig. 4A. First-grade children were estimated to show pre-error speeding until the last error, which can be observed by the fact that the upper bound of the ribbons representing the 95% confidence intervals does not cross the 0 line in Fig. 4 (which does so only for the Mixed block).

In the Mixed block, as mentioned above, there was no significant interaction between the sample and the position of the pre-error chunk, $\chi^2(1) = 0.00$, $p = .956$. Hence, both kindergarten and first-grade children's speeding decreased in the course of the task block (estimate [unstandardized] = 4.06, *SE* = 0.72, *CI* = [2.65, 5.48], $p < .001$; Fig. 4B). Children were estimated to show pre-error speeding until about the 6th error (i.e., sixth pre-error chunk), which can be observed where the upper bound of the ribbons representing the 95% confidence interval crosses the 0 line in Fig. 4B.

Post-error slowing

For post-error slowing, the models without the grade in the interaction proved to be better for both the Flowers block, $\chi^2(1) = 0.26$, $p = .607$, and the Mixed block, $\chi^2(1) = 0.78$, $p = .377$. Hence, kindergarten and first-grade children showed similar patterns in the post-error slowing trajectory in both blocks. The effect sizes (marginal R^2/conditional R^2) for the final models were .015/.208 for the Flowers block and .014/.101 for the Mixed block.

Children decreased their slowing in both the Flowers block (estimate [unstandardized] = −26.47, *SE* = 6.28, *CI* = [−38.79, −14.15], $p < .001$; Fig. 5A) and the Mixed block (estimate [unstandardized] = −11.87, *SE* = 1.64, *CI* = [−15.09, −8.65], $p < .001$; Fig. 5B). Namely, after each consecutive error, children decreased their slowing by 26.47 ms in the Flowers block and by 11.87 ms in the Mixed block. Children were estimated to show post-error slowing until about the 8th error in the Flowers block and until about the 11th error in the Mixed block, which can be observed where the lower bound of the ribbons representing the 95% confidence intervals crosses the 0 lines in Fig. 5. The number of children contributing to this calculation is reported in Table 4.

As can be seen in Table 4, for further error positions, data from a smaller number of participants are being included in the estimations of the models. Based on these numbers, we also repeated the anal-

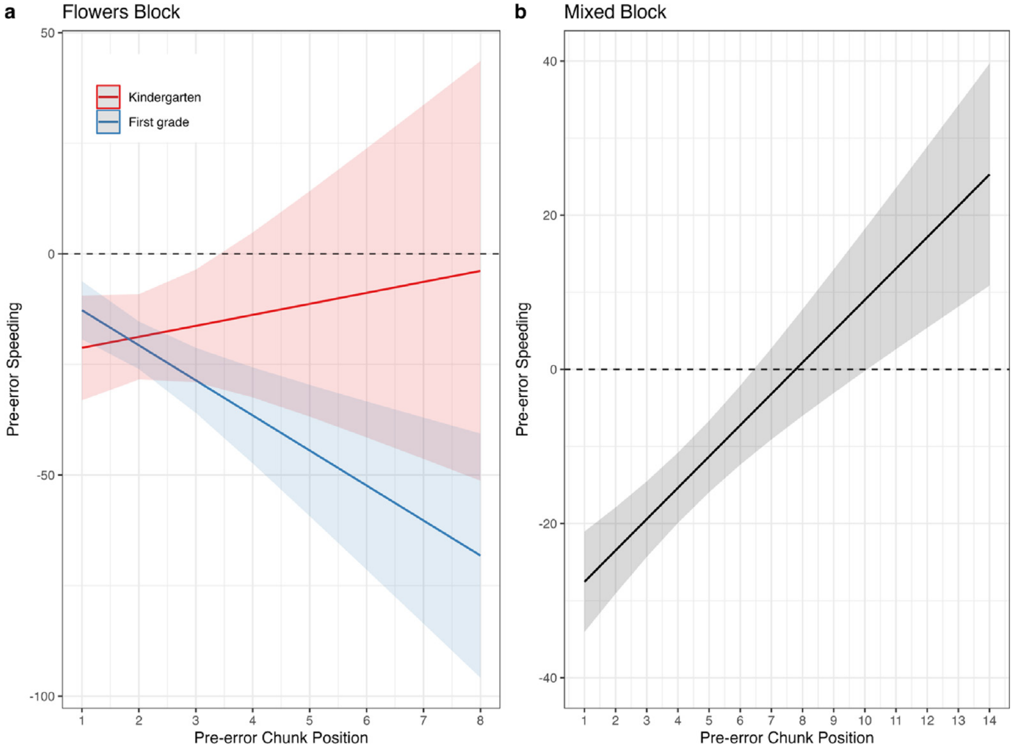

Fig. 4. Pre-error speeding in the Flowers block (A) and the Mixed block (B). The y-axis reflects children's average of the slope (unstandardized regression coefficient) of speeding where the slope reflects the reaction time change per trial. For example, on average, first-graders responded about 12.5 ms faster per trial in the first chunk of correct trials before an error (the blue [lowest] line at pre-error chunk position 1 in Panel A). Panel B reflects the predicted values averaged over kindergarten and first-grade children.

yses by including until the error position where more than 15 children are contributing (error position 7 for the Flowers block and error position 14 for the Mixed block). These analyses revealed very similar patterns of results (see Supplementary Material).

Predicting accuracy from pre-error speeding and post-error slowing

The linear regression models predicting accuracy from pre-error speeding, post-error slowing, age, and their interactions revealed no significant interactions in either block. Following this, models with only main effects of pre-error speeding, post-error slowing, and age were tested. This model was significant for both the Flowers block, $F(3, 459) = 13.14$, $p < .001$, $R^2 = .08$, adjusted $R^2 = .07$, and the Mixed block, $F(3, 609) = 19.14$, $p < .001$, $R^2 = .09$, adjusted $R^2 = .08$. Regarding predictors, there was no significant effect of age, but there were significant main effects of pre-error speeding and post-error slowing. Table 5 shows the estimates (standardized betas) from each model. Less pre-error speeding and greater post-error slowing predicted higher accuracy.

Discussion

This study investigated whether kindergarten and first-grade children show pre-error speeding and post-error slowing in an EF task and whether post-error slowing is associated with pre-error speeding. Results revealed that both kindergartners and first-graders showed significant pre-error speeding and post-error slowing in both blocks of an EF task that mainly taxed inhibition and shifting. In both blocks and age groups, pre-error speeding and post-error slowing were correlated. That is, children who sped

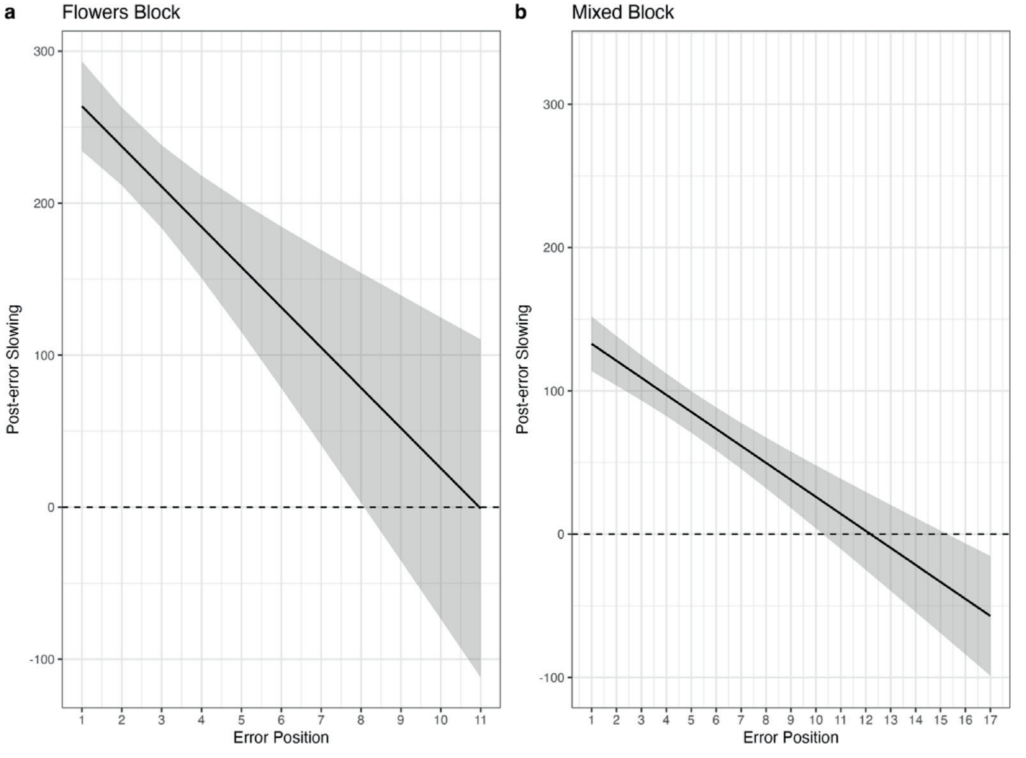

Fig. 5. Post-error slowing as a function of error position in the Flowers block (A) and the Mixed block (B). The y-axis reflects children's average of post-error slowing, which is the reaction time (RT) of the error in that position subtracted from the average RT of the correct post-correct trials within that block. For example, on average, children will respond about 125 ms slower than the average of all correct post-correct trials on their first error in the Mixed block (error position 1 in Panel B).

Table 4
Number of children with errors in different positions

Error position	Number of children	
	Flowers	Mixed
1	467	545
2	322	552
3	200	522
4	125	504
5	64	466
6	33	423
7	16	360
8	5	288
9	1	233
10	1	175
11	1	122
12		77
13		34
14		18
15		4
16		1
17		1

up more extremely toward an error also slowed down more extremely after an error. In both blocks, the magnitude of both pre-error speeding and post-error slowing and the strength of their association were similar in kindergartners and first-graders.

Regarding the first question of whether children show pre-error speeding, our findings are in line with the few previous studies that found pre-error speeding in children as young as 5 years (Brewer & Smith, 1989; Epstein et al., 2010; Shiels et al., 2012; but see Smulders et al., 2016). Although Brewer and Smith (1989) found the pattern to be the noisiest in 5-year-olds and gets less noisy in 7-year-olds and older children, we did not find a different pattern in our kindergartners (6-year-olds) and first-graders (7-year-olds). One should note, however, the very low sample sizes in Brewer and Smith's study. This discrepancy could also be related to some differences in the characteristics of the tasks used. Among others, we used a different type of task (inhibition and shifting tasks vs. CDT), a lower number of response choices (two vs. four), and a different modus of stimulus presentation (tablet computers vs. live presentation).

Regarding the second question, to our knowledge this is the first study to show that pre-error speeding and post-error slowing are correlated intra-individually in two task blocks, one demanding inhibition and one demanding inhibition and shifting, in kindergartners and first-graders. These findings suggest adjustments in children's performance in a cognitive control task that introduces a speed–accuracy trade-off. The speeding up of children's responding on a run of correct trials until an error may be an indication of monitoring correct answers, and slowing down their responding after committing an error may be an indication of monitoring errors, which enables returning to a safer RT band that secures subsequent accuracy (Brewer & Smith, 1989; Rabbitt, 1966). More important, children's adjustments after correct responses were associated with their adjustments after errors. Within the same task block, if children sped up more extremely, they also slowed down more extremely, suggesting that both adjustments may be related components of the same overarching monitoring and cognitive control mechanism (Thaqi & Roebers, 2020).

Exploring the trajectory of pre-error speeding and post-error slowing yielded further insights into what these phenomena tell us about children's monitoring and control behavior and revealed some interesting differences between the blocks. In the Flowers block (i.e., inhibition), first-grade children's pre-error speeding increased, whereas kindergarten children's pre-error speeding did not change. In the Mixed block (i.e., shifting), however, both first-grade and kindergarten children's pre-error speeding decreased throughout the block. Each run of correct trials ending with an error is, so to say, an opportunity for returning to a safe RT band of responding (Brewer & Smith, 1989; Rabbitt, 1966). Hence, if the increasing number of such runs helps in adjusting the speeding accordingly, we would expect a decrease in the amount of speeding with each episode of such a run of correct trials leading to an error, especially in a more demanding block with more errors. This is exactly what we observed in the Mixed block of the HF task we used, which required children to not only inhibit themselves but also shift between two rules. Interestingly, however, children's speeding either did not change (kindergarten children) or kept on increasing (first-grade children) in the Flowers block, which required children to inhibit themselves. One interpretation could be that in the less demanding Flowers block, which only required inhibiting the prepotent response from the previous Hearts block, children might have been globally more overconfident in their ability (Roebers et al., 2007). This overconfidence might have resulted in speeding adjustments' falling out of the optimal safe range over the course of the block. In contrast, in the subsequent more demanding Mixed block, which required shifting between rules on top of inhibiting the irrelevant rule, children might have come to realize the greater demand of this block, which may have resulted in the optimization of speeding by reducing it as the trials went ahead. This is also in line with the self-directed goal identification framework delineated by Frick and Chevalier (2023). This framework posits that children identify goals by tracking contextual information, which can also stem from past events and actions and the prediction of future events and actions. In the case of the Mixed block, the experience in the earlier phases of the block might have led children to adjust themselves for engaging in more stringent control with the expectation of increasing task demands. Moreover, the unpredictable sequence in the Mixed block, namely not knowing when a flower trial will appear after a number of heart trials, might have called for more overcaution. This overcaution in turn may have led to a better global control or block-wise proactive control with decreasing pre-error speeding.

Table 5
Linear regression results predicting accuracy in the flowers and mixed blocks

Variable	Estimate (and *SE*)	*t*	*p*
	Flowers		
Intercept	−0.75 (0.68)	−1.11	.267
Pre-error speeding	0.23 (0.04)	5.43	<.001
Post-error slowing	0.20 (0.05)	4.27	<.001
Age	0.01 (0.01)	0.79	.432
	Mixed		
Intercept	0.12 (0.58)	0.21	.835
Pre-error speeding	0.14 (0.04)	3.42	<.001
Post-error slowing	0.29 (0.04)	7.41	<.001
Age	−0.00 (0.01)	−0.22	.829

Note. Estimates are standardized beta values.

In both the Flowers and Mixed blocks, both kindergarten and first-grade children's post-error slowing decreased throughout the block. As children make further errors, the magnitude of the reaction to the error in the form of slowing down response time might downregulate. This may suggest that children might be learning and adapting to the task demands over time. That is, they may become more efficient in recovering from an error, requiring less additional time to adjust their behavior after making a mistake.

In terms of the RT optimization for accurate performance, we explored the prediction of overall accuracy by pre-error speeding and post-error slowing. In the Flowers block, pre-error speeding had a greater influence on accuracy than post-error slowing. A lower magnitude of pre-error speeding and a greater magnitude of post-error slowing predicted higher accuracy. This is also in line with our other finding that children did not change or kept on increasing their speeding throughout the Flowers block. Perhaps for this less demanding block children felt more overconfident and did not monitor their speeding well enough to optimize it. In that regard, those children who did show an overall lower level of speeding might have taken advantage of more or better proactive control to avoid errors and maintain high accuracy. In contrast, those who were less in control of their speeding might have used an alternative reactive control by which they slowed down in great magnitudes after a mistake to avoid future errors. In the Mixed block, the pattern was reversed; that is, post-error slowing had a greater influence on accuracy than pre-error speeding. Although similar to the Flowers block, a lower magnitude of pre-error speeding and a greater magnitude of post-error slowing predicted higher accuracy. For this more demanding task block, children were perhaps challenged enough from the outset to not increasingly speed up their responses. Hence, slowing down after an error might have been more predictive of good overall accuracy in the face of not enough room for variation in speeding. Remember also the finding that children reduced their pre-error speeding and post-error slowing throughout the Mixed block. Together, it seems that in the course of this more demanding block, children already aligned their proactive and reactive control better by monitoring both their pre-error speeding and post-error slowing better. Coordinating control, for instance, between reactive and proactive control based on task demands is a crucial ability for optimal performance (Chevalier, 2015). The children in our study appeared to successfully coordinate cognitive control based on task demands to a certain extent. Children's individual tendencies such as overconfidence may play a role in these processes. Given that young children are usually overconfident, and this decreases as they age (van Loon et al., 2017), an important future direction is to address the potential influence of overconfidence on monitoring and control processes in developmental time.

Younger children are documented to show coarser monitoring reflected in both speeding more extremely before an error and slowing down more extremely after an error (Brewer & Smith, 1989; Fairweather, 1978; Smulders et al., 2016; Thaqi & Roebers, 2020). In light of this, we expected the magnitude of both pre-error speeding and post-error slowing to be greater in our kindergartners than in our first-graders, and vice versa for the strength of their association. Both our kindergartners and first-graders showed substantial post-error slowing and pre-error speeding. However, the magnitude of either or the strength of their association was not found to differ between kindergartners and first-graders. Note that as we carried out Spearman correlations, the strength of the association refers to the strength of the monotonic relationship and not the linear relationship. There was about a 1-year difference in the mean age of the two groups, which could have been too small to capture any developmental differences. Yet, our correlation analyses with age in the whole sample, whose ages ranged from 5.5 to 8.3 years, also revealed no significant relations with age. Previous findings documenting coarser adjustments by younger children had focused on children older than our target age (Thaqi & Roebers, 2020), compared groups of children with wider age ranges (Smulders et al., 2016), or did not report pairwise comparisons between the different age groups (Fairweather, 1978) except for Brewer and Smith (1989), who found different patterns in 5- and 7-year-olds, but with both showing a noisier pattern than 9-year-olds and adults. In parallel, it is still likely that developmental differences in these monitoring and control strategies and how well they are coordinated might emerge later than 7 years of age. A crucial future direction is to compare these phenomena between kindergartners and older school-aged children.

Nevertheless, the exploratory analyses revealed one difference between the kindergarten and first-grade children in the trajectory of pre-error speeding in the Flowers block. First-grade children's pre-error speeding increased, whereas kindergarten children's pre-error speeding was not found to change in the course of the block, although no difference emerged in their post-error slowing. Considering the descriptive values that the average accuracy and RT were very similar in the Flowers block in both samples, this difference may suggest that, in the course of the block, first-graders and kindergartners may have taken a different adjustment approach. Coordinating control is assumed to improve and become more optimal with age, especially after 6 years (Chevalier, 2015). Accordingly, first-graders may demonstrate a more active and adaptive approach, adjusting their behavior based on experience and learning from errors. Kindergarten children, in contrast, might not show the same level of adaptive pre-error adjustments. The fact that this difference between the samples emerged only in the Flowers block may again be related to the overall perceived low demand of the task block, which may have especially led the younger children to feel more overconfident and relatedly to exhibit a lower level of flexibility or readiness to modify their responses proactively. Further exploration, potentially incorporating additional cognitive measures and considering individual differences, can provide a more comprehensive understanding of the differences in these patterns.

Monitoring and controlling performance is critical in academic settings as well as in everyday activities. For example, at school, children should become able to track how quickly and how well they are doing simple arithmetic calculations. If they are progressively doing a good job, they can get faster to save time. Once they happen to miscalculate if they were too quick in doing so, they need to adjust their speed to ensure getting the correct number on the next calculation. On the playground, in a similar vein, if while playing hopscotch children are stepping right in, target after target, they may get faster. Yet, especially if stepping in the target gets more and more challenging with a tired leg, they may need to downregulate their speed of jumping to stay on target. In the current study, we showed that children engage in monitoring and control adjustments in a cognitive task and that a certain coordination of these adjustments predicts more accurate performance. However, it is not clear whether these adjustments are under conscious control of children and how they may extend to everyday activities. Building on this foundation that these adjustments are observed in young children, future studies may focus on the exact mechanisms by which children are engaging in these adjustments. Moreover, future studies can focus on training young children in monitoring and control strategies to achieve better success in the relevant tasks at hand.

As a general note, our findings might be of relevance in the discussion of how to best quantify EF in children, especially beyond 5 or 6 years of age, when accuracy in these simple multi-trial tasks is typically at ceiling. There is still a lot of work to be done to better understand pre-error speeding and post-error slowing, but monitoring might be an aspect of performance in these tasks that has so far been overlooked. In other words, researchers might consider not only integrating speed (of correct trials only) and accuracy but also using monitoring measures to support the measure of EF more broadly.

Our study has several limitations. First, we tested only two adjacent age groups. Testing an additional older age group may give further insights into how the monitoring and control processes may develop with age and how pre-error speeding and post-error slowing may present in this development. Second, we did not have an exclusion criterion based on a minimum number of errors in the calculation of pre-error speeding and post-error slowing. Although our post hoc examinations showed that our findings are rather robust to such different exclusion criteria, one should note that the number of errors may have an influence on pre-error speeding and post-error slowing. For instance, for a child who does not commit many errors overall, an error might trigger a larger surprise response and hence a larger post-error slowing compared with a child who commits many errors. In studies with adults examining these phenomena, it is common to use tasks with many more trials and hence more opportunities for more errors and set a minimum number of error criteria (e.g., 400 trials and a minimum of 10 errors in Ehlis et al., 2018). Given that children have a shorter attention span, it is difficult to test them with this many trials. As one consequence, of the limited number of trials, such as 60 trials in our case, it is not feasible to set such a high minimum number of errors as 10 in calculating pre-error speeding or post-error slowing, which may theoretically be necessary to obtain a more realistic picture of these phenomena. One possible solution could be to test children in several blocks or sessions to reach a higher number of trials. Third, regarding the post hoc checks with the criterion of minimum number of errors ranging from 2 to 10, although mainly consistent, significant correlations between pre-error speeding and post-error slowing disappeared for the Flowers block at a minimum of 7 errors and above for kindergarten children and at a minimum 9 or 10 errors for first-grade children. On the one hand, this may be due to the susceptibility of this association to the number of committed errors, especially for younger children and in the less demanding block of the EF task we used. It may indicate that in a less demanding task block where there is not as high a demand for adjusting performance, the different monitoring and control processes might not be as related, especially for younger children. On the other hand, it may be a consequence of the smaller sample size in kindergarten children and especially in the Flowers block (see Table 2). The criterion for including only children with a certain number of errors reduced the sample size and thus the power of the supplementary correlation analyses further, which may have also contributed to the disappearing significance of effects. Perhaps a better solution for studying error processing in children in an inhibition task is to use a task that is more likely to naturally result in a greater number of errors for not needing to exclude many children based on the number of errors. Hence, efforts to replicate the current results in future work is crucial. Fourth, there were children excluded for not making any errors. Although pre-error speeding or post-error slowing cannot be calculated for these children, they may nevertheless show other RT adjustments that may be reflective of their monitoring and control and may relate to their ceiling performance. Further investigations could explore the potential cognitive mechanisms underlying the performance of children who show no errors, focusing on alternative measures of RT adjustments. Finally, although the primary focus of this study was not on conflict or switch effects, it is important to acknowledge that the collapsing of switch and non-switch trials in the Mixed block may introduce a potential confounding factor given that both errors and conflicts result in subsequent slowing in children (Dubravac et al., 2020). Future research could investigate whether error adjustments differ between switch and non-switch trials, and caution is warranted in interpreting the current findings in light of these co-occurring effects.

In conclusion, this study documented the presence of at least two monitoring and control adjustments kindergarten and first-grade children employ in a cognitive control task that poses inhibition and shifting demands, namely pre-error speeding and post-error slowing. More important, these adjustments appeared to be related within individuals, suggesting that children coordinate their monitoring and control adjustments. This coordination also seems to depend on task demands. In a less demanding task block, children's responding sped up about the same (kindergartners) or increasingly more (first-graders) before an error, and the efficiency in speeding (i.e., keeping it sufficiently low) played a more decisive role for an individual's overall accuracy. In the following more demanding task block, children's coordination was better marked by both progressively reducing speeding before an error and progressively reducing slowing after an error, and the efficiency in slowing (i.e., keeping it sufficiently high) played a more deciding role in maintaining good overall accuracy. Future studies should investigate a wider age range to shed more light on the developmental progression in the ways in which these adjustments are employed and coordinated and should examine what role the development of cognitive control adjustments plays in the measurement of EFs.

CRediT authorship contribution statement

Ebru Ger: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis. **Claudia M. Roebers:** Writing – review & editing, Resources, Project administration, Methodology, Investigation, Funding acquisition.

Data availability

Anonymized data is available at https://osf.io/yqabt/.

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Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.jecp.2024.105975.

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