Contextual adaptation of cognitive flexibility in kindergartners and fourth graders

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Abstract

The present study investigated the development of children's ability to find the optimal balance between flexibility and stability as a function of the frequency of required task switches. This question was addressed in two situations contrasting the dynamics of engagement of reconfiguration processes (reactive vs. proactive). A cued task-switching paradigm was presented to kindergartners and fourth graders, known to differ in their preferential mode of control engagement. Flexibility adaptation was examined through the modulation of switching costs by switch proportion, the so-called list-wide switch proportion (LWSP) effect. When the situation forced the use of reactive control (Experiment 1 – simultaneous presentation of the cue and the stimulus), we found the LWSP effect with a greater magnitude in kindergartners than in fourth graders. In the situation inducing proactive control (Experiment 2 – task cue presented before and until the stimulus), flexibility adaptation was obtained when error rates were considered but not RTs. By demonstrating that even young children are capable of flexibility adaptation to contextual demands, these findings support the hypothesis that implicitly triggered adaptation of control may develop as early as the end of preschool years, despite the immaturity of cognitive control during this period.

Keywords

Cognitive control; Flexibility; Metacontrol; Proactive control; Reactive control; Children

Highlights

- Flexibility adaptation was assessed through switch proportion effects
- We used a cued task-switching paradigm inducing either reactive or proactive control

- Flexibility adaptation to task demands is effective as early as 5-6 years of age.
- Switch proportion effects were larger in kindergartners than in fourth graders.
- Flexibility adaptation depends on the dynamics of reconfiguration processes.

Introduction

A critical component of cognitive control in regulating one's actions towards one's goals is cognitive flexibility. Flexibility refers to the ability to deliberately switch between goals as a function of internal or external cues. Finding the optimal balance between keeping focused on the current task goal and remaining sensitive to environmental cues that may suggest a relevant updating of goals involves continual adjustments (Siqi-Liu & Egner, 2020). These adjustments of one's level of flexibility, also called "adaptation of cognitive flexibility", correspond to a form of meta-control and are central to an optimal adaptation to various contexts. The present study aimed to investigate early manifestations of flexibility adaptation in children and their evolution across childhood.

Research has evidenced adults' ability to adapt their level of flexibility as a function of the frequency of required task switches (e.g., Bonnin et al., 2011; Kang & Chiu, 2021; Siqi-Liu & Egner, 2020). In children, a handful of recent studies assessing conflict processing suggest that some forms of control adjustments can be observed as early as 5, although they appear to depend on the nature of the conflicts (e.g., Ambrosi et al., 2016; Gonthier et al., 2021; Gonthier & Blaye, 2021; Liu et al., 2018; Smulders et al., 2018). To our knowledge, only two studies have examined adaptation of control in a context of flexibility tasks in preschoolers (Marcovitch et al., 2007, 2010), albeit using a task that requires only a single switch between two possible tasks (e.g., DCCS task, Zelazo, 2006) and that is passed by most 4- to 5-year-olds. In order to get a more fine-grained picture of the development of children's dynamic adjustments of cognitive flexibility, more switches have to be involved. Further, paradigms that imply many switches like the task switching paradigm used in adults highlight the protracted developmental trajectory of flexibility up to early adulthood (e.g., Cepeda et al., 2001; Davidson et al., 2006; Diamond, 2013; Reimers and Maylor, 2005). Indeed, flexibility is specifically cognitively demanding throughout childhood (for reviews, see

Buttelmann & Karbach, 2017, and Cragg & Chevalier, 2012). Hence, designing contexts that induce more or less stability could be even more critical for children than adults, and therefore, was the first aim of this study.

Engaging in task switching is based on the detection and processing of environmental cues that indicate when changing the goal is required. It is optimally efficient to get prepared for a task switch before having to process the target stimulus, in order to reduce responses conflicts due to uncertainty on which goal to pursue. This however involves engaging control proactively, a mode of control which becomes increasingly effective and voluntarily engaged throughout school years, while preschoolers foremost rely on a reactive form of control mobilized late, only when needed (Chatham et al., 2009; Chevalier et al., 2015; Gonthier et al., 2019; Lucenet & Blaye, 2014). The second aim of this study was then to examine the extent to which children's potential ability to adapt their level of flexibility as a function of task demands, would depend on whether or not they can rely on their preferential mode of control.

Control Adjustments to Contextual Variations

Research in adults suggests that cognitive control is not an all-or-none process, but rather involves dynamic adjustments of control engagement to different task demands and context conditions (for a recent review see Braem et al., 2019). Mostly investigated through the use of conflict tasks (Flanker, Simon or Stroop task), congruency effects (*i.e.*, the difference between performances in congruent and incongruent trials), taken as an index of conflict-processing efficiency, have been shown to be modulated based on variations of both local and more global contexts. For instance, item-specific proportion congruency effects, corresponding to a reduction in the congruency effect on items that are presented mostly in incongruent trials compared to the effect obtained on items presented mostly in congruent trials, have been widely observed in adults (e.g., Bugg & Hutchison, 2013; Jacoby et al., 2003). More global, list-level adjustments of control as a function of the proportion of conflicts in a series of trials have also been shown, as evidenced by the list-wide proportion congruency effect (LWPC effect; for a review, see Bugg & Crump, 2012).

In preschool children, both local and more global adjustments have been observed (e.g., Ambrosi et al., 2016; Erb et al., 2017; Gonthier et al., 2021; Gonthier & Blaye, 2021; Liu et al., 2018; Rueda et al., 2004; Wilk & Morton, 2012). As an example of global adjustment, Gonthier et al. (2021) found that even preschoolers had their congruence effect significantly reduced in a Stroop-like task when stimuli were presented in blocks containing mainly incongruent stimuli as compared to mostly congruent stimuli. This finding suggests that children are able to incidentally learn associations between contexts and control settings, and benefit from this information to adjust their level of control to the actual demand of each context. However, the question of whether this competence is specific to conflict processing or can generalize to other control processes remains open. In particular, can children achieve a contextually adapted balance between flexibility and stability, and is it the case regardless of the dynamics of reconfiguration processes induced by the sequence of information display?

Flexibility Adaptation to Contextual Variations

As already mentioned, very few studies have provided evidence of control adjustments in young children in the context of flexibility tasks. Marcovitch et al. (2007, 2010) used a variant of the DCCS task (Zelazo, 2006) with 4- and 6-year-old children. Participants completed two blocks of trials in which they had to match test cards with one of two target cards (e.g., a blue rabbit and a red boat). They were instructed to sort test cards according to one dimension in a pre-switch block (e.g. color) and then to the other in a post-switch block (e.g., shape). Contextual variations were based on the proportion of test cards (80% vs 20%): in the post-switch block the test cards were entirely redundant with the target cards (i.e; identical) resulting in more or less conflict cards (i.e., cards that match one target card on one dimension and the other based on the other dimension). Children's efficiency in applying the new sorting criterion in the post-switch block was significantly improved when most cards where conflictual. These results provide evidence for some form of contextual influences on children's flexibility, being based on a single task switch; However, they do not allow any generalization to situations where switching back and forth between two tasks is required, known to be particularly demanding for children. Indeed, the context variations introduced by Marcovitch et al's (2007, 2010) are operationalized through the manipulation of the proportion of trials where responses depend -or not- on the sorting criterion at hand, and as such do not provide direct evidence on children's ability to adjust their switch readiness to changing task demands in the form of having to switch tasks. The present study addressed this last question.

Flexibility adaptation has been initially investigated in adults using the cued task-switching paradigm. This paradigm requires participants to switch between tasks (*e.g.*, categorizing bivalent stimuli according to their shape or their color) as a function of task cues that unpredictably change -or not- across trials (for reviews, see Kiesel et al., 2010; Koch et al., 2018; Monsell, 2003). Participants are presented with mixed-task blocks including nonswitch (task repetition) and switch (task change) trials, the latter resulting in slower responses and more errors than the former, an effect referred to as the switching cost. This cost is assumed to mostly reflect the requirement of a reconfiguration of the previously relevant task-set on switch trials (i.e., of an updating of the set of stimulus-response rules guiding processing within each task; Kiesel et al., 2010). Developmental studies have reported a drastic reduction in switching costs across childhood (e.g., Cepeda et al., 2001; Chevalier et al., 2015; Chevalier & Blaye, 2009; Reimers & Maylor, 2005), relying, at least in part, on an increasing cue-based reconfiguration of the task-set in advance of the target stimulus when possible (e.g., Chevalier et al., 2015; Chevalier & Blaye, 2016; Lucenet & Blaye, 2019; Niebaum et al., 2021). Variations of switching costs as a function of manipulations of the proportion of switch trials are used to assess adjustments of the flexibility level. Parallel to the proportion congruency effects, the list-wide switch proportion (LWSP) effect corresponds to a reduction in switching costs as the proportion of switch trials increases (Bonnin et al., 2011; Dreisbach & Haider, 2006; Dreisbach et al., 2002; Duthoo et al., 2012; Kang & Chiu, 2021; Mayr, 2006; Meiran et al., 2000; Monsell & Mizon, 2006, Exp 4.; Siqi-Liu & Egner, 2020). Such modulations of switching costs based on the experience of variations of the frequency of task switches appear to be an adjustment of the level of switch readiness (Kang & Chiu, 2021). Although both flexibility adaptations in adults, and conflict-processing adjustments in adults and children now appear to be well established, the question of flexibility adjustments in children in response to variations of the probability of switches remains unexplored.

Critically, investigating control adaptation in the form of flexibility adjustments offers an opportunity to explore further the potential dissociation between the developmental trajectories of control itself and of meta-control. Indeed, the adaptation of control in conflict-processing situations does not appear to increase with age and may even diminish (Gonthier et al., 2021; Li et al., 2019; Smulders et al., 2018). This developmental trajectory stands in contrast with the dramatic changes found between preschool and school-age periods in terms of efficiency of intentional control (Chevalier et al., 2015; Marcovitch et al., 2010; Munakata et al., 2012). Different control strategies have themselves staggered developmental paths; this is the case of reactive and proactive control. Interestingly, a key feature of the task-switching paradigm lies in the possibility it offers to orient participants towards engaging either a proactive or a reactive strategy of control.

Braver's "dual mechanisms of control" theory (DMC; Braver, 2012; Braver et al., 2007) distinguishes a proactive mode of control from a reactive one. Proactive control is engaged in advance, before the occurrence of critical stimuli, preventing interference from irrelevant task information. On the contrary, reactive control is engaged "only as needed", which, in a task-switch paradigm corresponds to late task-set reconfiguration once the participant is presented with the target stimulus. In children, the use of proactive and reactive modes of control evolves from preschool to school years, with children before 6 preferentially engaging reactive control whereas both modes of control become increasingly used across childhood as a function of task demands (Chatham et al., 2009; Chevalier et al., 2015; Gonthier et al., 2019; Killikelly & Szűcs, 2013; Lorsbach & Reimer, 2010; Lucenet & Blaye, 2014).

Flexibility Adaptation in Situations Favoring Reactive and Proactive Control

It is worth noting that in adults the LWSP effect has been shown to be sensitive to the possibility of preparing stimulus processing based on early displayed task cues. More specifically, the effect was obtained in situations involving no – or extremely short (less than 200 ms) – cue-stimulus intervals, inductive of reactive engagement of control. It was not evidenced in situations involving ample time between the task cue and the stimulus to prepare for the upcoming task, thereby favoring proactive control (Bonnin et al., 2011; Monsell & Mizon, 2006; Siqi-Liu & Egner, 2020; for reviews see Kiesel et al, 2010; Monsell, 2003; Vandierendonck et al., 2010). In other words, flexibility adaptation is evidenced only when participants are constrained to engage control reactively. However, whereas adults are known to benefit from longer CSI to engage task-set reconfiguration in advance, thereby masking any control adjustment, this is much less true for young children (Chevalier et al., 2010, 2015, 2018; Chevalier & Blaye, 2016), leaving alternative hypotheses open.

The Present Study

This study addressed the question of whether young children can adapt their level of flexibility to task demands (in terms of variations of proportions of switches), using a cued-task switching paradigm. Children were required to categorize stimuli according to their shape or their color as a function of task cues, in two conditions varying in terms of switch proportion (frequent task changes vs. frequent task repetitions). We investigated the development of flexibility adaptation by examining this form of meta-control in two situations inducing respectively reactive and proactive reconfiguration of task sets, and in two groups of children differing in their level of mastery of proactive control: kindergartners known to rely exclusively on reactive control, and fourth graders who already use proactive control quite effectively. In Experiment 1, task cues and stimuli were presented simultaneously, leading to the use of reactive control. In Experiment 2, task cues were presented ahead of stimuli and disappeared at stimulus onset, eliciting the engagement of proactive control. Findings in conflict tasks suggest that adaptations of cognitive control are functional from 5-6 years of age. The lack of evidence of any improvement in adaptation between 5 and 10 years suggests that control adaptation may mature earlier than conflict processing, known to improve across this age range. Based on findings on the adaptation of conflict processing in children, flexibility adaptation could also be independent of age in this age range despite important changes in explicit control, in particular in the efficient use of proactive control along with an overall reduction in switching costs. Further, as evidenced in adults, adjustment should be optimal in a situation where task-set reconfiguration has to be engaged reactively due to the synchronous display of the task cue and the target stimuli (Experiment 1). Contrastingly, in a situation where a proactive reconfiguration of the task-set before target onset is encouraged by a display of the task cue in advance and its disappearance at target onset (Experiment 2), alternative hypotheses can be proposed. In light of the literature on adults, this situation is expected to reduce or even eliminate flexibility adaptation. However, if kindergartners do not engage proactive control despite being strongly encouraged to do so by the sequence of task cues and display of stimuli, they may still evidence flexibility adaptation in this situation.

Experiment 1

The purpose of Experiment 1 was to compare kindergartners' and fourth graders' ability to adjust flexibility in a situation offering no preparation time between task cue and target, thereby allowing only reactive, post-target reconfiguration of task-set.

Method

Participants

Studies on control adaptation in conflict processing tasks in children are usually based on sample sizes of 30 to 45 participants per age group (Ambrosi et al., 2016; Gonthier & Blaye, 2021). Data collection was planned for about 50 children per age group. A sample of 50 kindergartners (M_{age} = 5.79 years, SD_{age} = 0.39, 23 females) and 47 fourth graders (M_{age} = 9.98 years, SD_{age} = 0.26, 23 females) participated in the current experiment. Children were all native French speakers. They were recruited from two preschools and primary schools in the south of France and were tested individually in a quiet room at their school. The children were predominantly Caucasian from middle-class families reflecting the characteristics of the local community. All parents and participants gave their consent, and children received a small age-appropriate prize (i.e., stickers) and a "young scientist" certificate at the end of the experiment.

Materials and Procedure

Each participant performed a child-friendly, cued task-switching paradigm adapted from the "Santa Claus Game" (Chevalier et al., 2015), and presented on a DELL computer with E-Prime 2 (Psychology Software Tools, Pittsburgh, PA). Children had to help Santa Claus to sort toys by either their shape or their color.

In each trial, a 2 × 2 cm brown wrapped box presented within a black circle appeared at the top middle of the screen, and an 8 × 8 cm bidimensional stimulus (e.g., a blue car) was presented at the center of the screen within a black ring. Depending on whether shape or color was the relevant sorting criterion, 12 gray geometrical shapes or 12 patches of different colors (task cues) were distributed along the ring at the onset of stimulus display. Bivalent stimuli consisted of 64 line drawings of four different dogs and four different cars displayed in four different shades of orange and four different shades of blue (i.e., from light to dark). In the shape task, participants had to categorize the stimulus as a dog or a car. In the color task, participants were asked to categorize the stimulus as orange or blue. The responses for both shape and color tasks were mapped onto four buttons on an AZERTY keyboard (s-key for dogs, x-key for orange, j-key for cars, and n-key for blue). Children were asked to keep their four fingers (index and middle fingers of each hand) on the response keys, which were identifiable by four stickers corresponding to each of the four possible response options, and to respond by pressing the correct response button. Before the experiment, the stimuli were presented individually to the children to ensure that they were able to correctly identify each shape and then each color used in the experiment. All the children succeeded. The display of response options remained constant across subjects and conditions.

Each trial began with a fixation cross within a black circle, appearing for 1000 ms at the top middle of the screen, followed by a gift within a black circle (containing brown dots) for 1500 ms until simultaneous cue and stimulus onset. Then, cue and stimulus remained displayed on the screen until a response was entered (see Figure 1). The time interval between the response and the next fixation cross was 25 ms. Participants were instructed to respond as quickly and as accurately as possible.

All children were tested in two switch proportion contexts including single-task blocks[1] and mixed-task blocks. In the low switch proportion condition (LSW), mixed task blocks contained 75% nonswitch trials and 25% switch trials, thereby representing a context list with a low switch proportion. The proportion of trial types was reversed in the high switch proportion context (HSW), where mixed task blocks included 75% switch trials and 25% nonswitch trials, thereby representing a context list with a high switch proportion. The order of switch proportion presentations was counterbalanced between participants. Children were not informed of the change in switch proportion when they started a new condition.

All participants were tested in two consecutive sessions corresponding to each proportion condition, lasting approximately 15 min and including a short training phase, followed by an experimental phase. The training phase consisted of two single-task blocks of six trials each (shape task, then color task), followed by one mixed-task block of 17 trials (75% nonswitch trials or 75% switch trials, for the LSW and HSW condition, respectively) where children were asked to switch between color and shape tasks depending on the task cue. The experimental phase consisted of two series, each including two single-task blocks (shape task, then color task) of 17 trials, followed by two mixed blocks of 17 trials separated by short breaks. In total, each proportion condition included 4 mixed blocks of 17 trials, and the first trial of each block was excluded, yielding a total of 64 critical trials per condition. The single and mixed-task blocks consisted of an equal number of four stimulus types (dog/in orange, dog/in blue, car/in orange, car/in blue). In the mixed-task blocks (2 blocks per series, leading to 4 mixed task blocks), the shape and color tasks were alternated pseudo-randomly

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[1] In the two experiments, single task blocks provided a baseline performance for understanding of instructions when no task-switch was involved, as well as for testing order group equivalence between switch proportion presentations through student t analyses, in each level group (all *p*s > .14). Given that they were non-critical considering the aims of the current study, single task blocks from the experimental phase were not analyzed further.

(with no more than three response repetitions in a row), so that there were 75% nonswitch trials and 25% switch trials in the LSW proportion (12 nonswitch trials and 4 switch trials), and 75% switch trials and 25% nonswitch trials in the HSW proportion (12 switch trials and 4 switch trials); the first trial cannot be classified as either switch or nonswitch. Except during the training trials, no feedback was delivered. Verbal instructions were provided before each of the experimental blocks, indicating whether the shape task, the color task, or both tasks had to be performed. No information about the switch proportion was given. After 1 series of 4 blocks, subjects had a short break of 5 min.

[Insert Figure 1 approximately here]

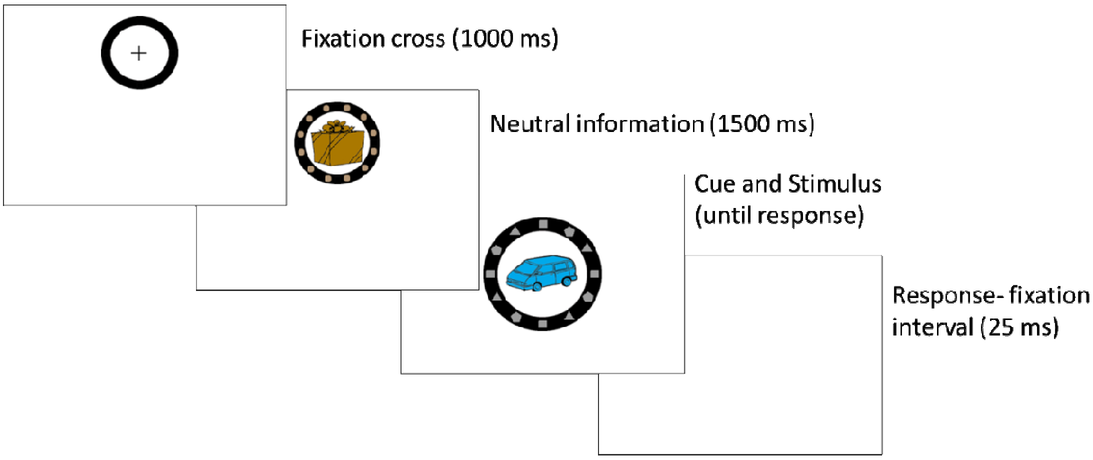

Figure 1. Illustration of a within-trial sequence (here, shape task) in the reactive situation.

Results

The first trial of each block was excluded from the analysis. Trials with correct response times (RTs) lower than 200 ms or above 3 standard deviations from each participant's mean response time for each trial type were also discarded from the analyses (for the LSW and HSW proportions, respectively: 1.76% and 1.66% of trials for kindergartners; 1.35% and 1.10% of trials for fourth graders). Four kindergartners and 6 fourth graders were excluded due to failure in more than 30% of the training trials (1 kindergartner and 2 fourth graders), and error rates beyond three standard deviations from the mean of their age group in at least one trial type (3 kindergartners and 4 fourth graders). Thus, the final sample included 46 kindergartners (M_{age} = 5.79 years, SD_{age} = 0.40, 21 females) and 41 fourth graders (M_{age} = 9.98 years, SD_{age} = 0.27, 22 females). Because children were discarded after testing, this led to similar, but not equal, group sizes.

Based on the literature on children's adjustments of control (e.g., Ambrosi et al., 2016; Gonthier et al., 2021; Gonthier & Blaye, 2021), both RTs and error rates measures were considered for testing the LWSP effect. Two analyses of variance (ANOVA) were run on log-transformed correct response times (RTs) and error rates, respectively, with Grade Level (kindergartners, fourth graders) as a between-subject factor, and Switch Proportion (LSW, HSW) and Trial Type (nonswitch, switch) as within-subject factors. Flexibility adaptation was analyzed by examining switching cost modulation as a function of switch proportion by planned contrasts. For the sake of clarity, we reported both log-transformed and raw values (see Table 1 in Appendix for the error rates and RT means from all proportions and trial types of the two grade levels). The order of Switch Proportions (LSW first, HSW first) did not interact with other variables of interest in any of the following analyses (all *p*s > .260) and was therefore not considered further.

For RTs, analyses revealed the expected main effects of the trial type, and switch proportion, $F(1,85) = 62.65$, $p <. 001$, η^2p= .42, and respectively $F(1, 85) = 6.87$, $p = .010$, η^2_p = .074, indicating significant switching costs (0.08 ln ms, 191 ms), and an overall RTs advantage for the LSW proportion (7.62 ln ms, 2443 ms) as compared to the HSW proportion (7.67 ln ms, 2508 ms). Critically, Switch Proportion × Trial Type interaction was significant, $F(1, 85) = 28.71$, $p <. 001$, η^2p = .25, evidencing a LWSP effect, with lower switching costs for the HSW proportion (0.03 ln ms, 99 ms) than for the LSW proportion (0.11 ln ms, 283 ms). A significant main effect of grade level was found, $F(1, 85) = 185.72$, $p <. 001$, η^2p = .68, with slower RTs in kindergartners (7.98 ln ms, 3350 ms) than in fourth graders (7.31 ln ms, 1601 ms). There was also an interaction between trial type and grade level $F(1, 85) = 8.30$, $p = .005$, $\eta^2 p = .088$, corresponding to a significant decrease in switching cost from preschool to fourth grade (0.10 ln ms, 324 ms and 0.05 ln ms, 58 ms, respectively), these costs being significant for each grade level (all *p*s < .001). Further, a tendential three-way interaction Switch Proportion × Trial Type × Grade Level was obtained, $F(1,85) = 3.84$, $p = .053$, $\eta^2 p = .043$. The LWSP effect described above was observed in both grade levels (see Figure 2a), but was more pronounced in kindergartners (0.10 ln ms, 306 ms effects) than in fourth graders (0.06 ln ms, 63 ms effects). Testing the LWSP effect in the two grade levels separately confirmed that it was significant in both kindergartners, $F(1, 45) = 23.13$, $p <. 001$, $\eta^2 p = .33$, and fourth graders, $F(1, 40) = 7.35$, $p = .009$, $\eta^2 p = .15$. No other effect was significant (all *p*s > .78).

For error rates, a significant main effect of the trial type was found, $F(1,85) = 39.15$, $p < .001$, $\eta^2 p = .31$, with larger error rates for switch trials (9%) than nonswitch trials (5.2%), yielding significant switching costs (3.8%). The main effect of the switch proportion was significant, $F(1, 85) = 4.09$, $p = .046$, $\eta^2 p = .04$; error rates were higher in the LSW (7.8%) than in the HSW proportion (6.4%). Most importantly, a LWSP effect was found, as revealed by an interaction between trial type and switch proportion, $F(1,85) = 25.02$, $p < .001$, $\eta^2 p = .22$, with higher switching costs in the LSW proportion (6.4%) than in the HSW proportion (1.2%). The main effect of grade level was significant, $F(1, 85) = 17.80$, $p < .001$, $\eta^2 p = .17$, showing that kindergartners (9.5%) made more errors than fourth graders (4.7%), but this factor did not interact with trial type, $F(1, 85) = 1.94$, $p = .16$, $\eta^2 p = .022$. The three-way interaction among trial type, switch proportion and grade level was significant, $F(1,85) = 5.75$, $p = .018$, $\eta^2 p =.06$: Although descriptively present in both grade levels and larger in kindergartners (7.6% effect) than in fourth graders (2.7% effect), the LWSP effect was significant in the younger age group, $F(1, 45) = 25.21$, $p < .001$, $\eta^2 p = .35$, and tendential in fourth graders, $F(1,40) = 3.86$, $p = .056$, $\eta^2p = .088$ (see Figure 2b). The analysis revealed no other significant main effects or interactions (all *ps* > .16).

[Insert Figure 2a and Figure 2b approximately here]

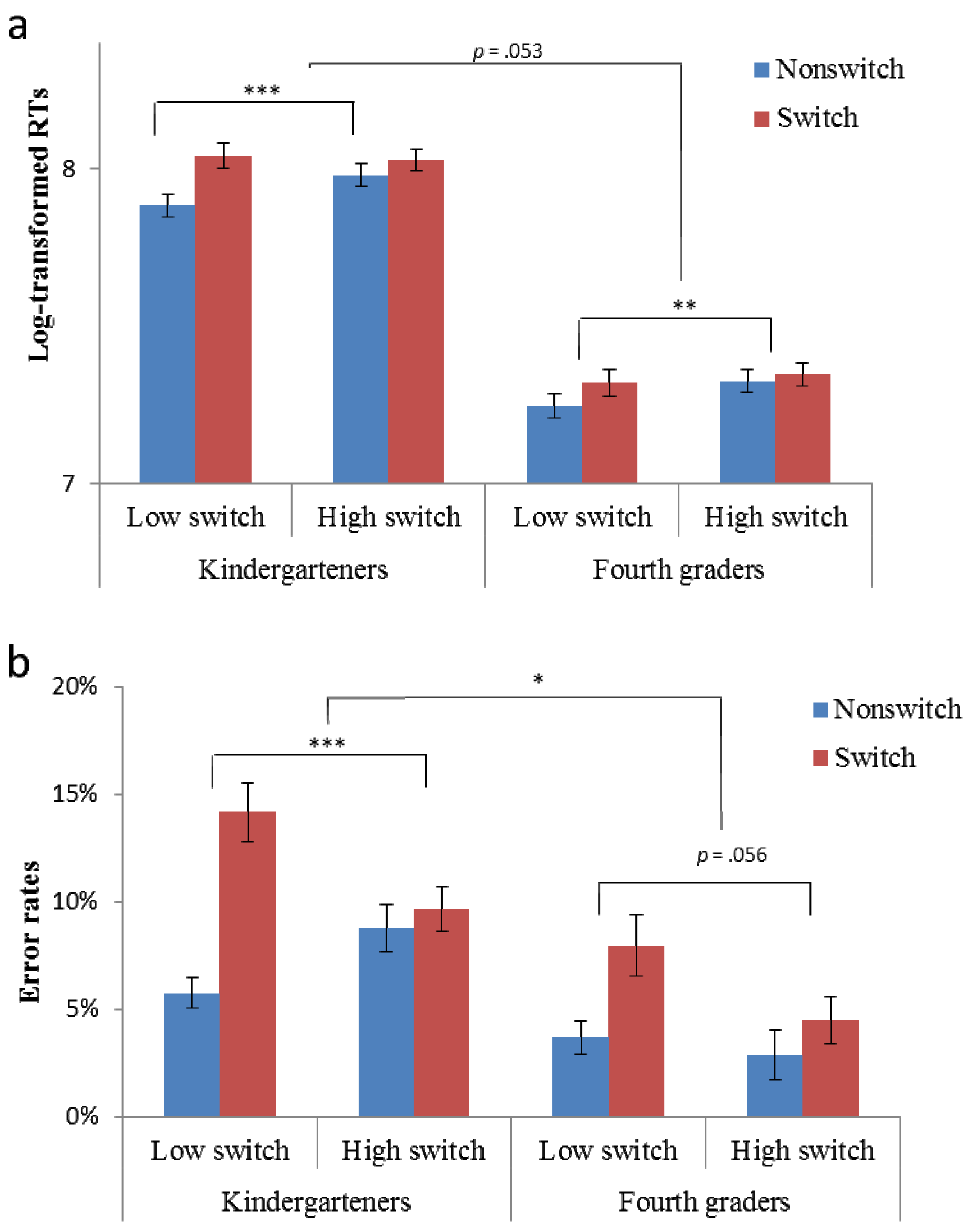

Figure 2. (a) Log-transformed response times and (b) error rates and as a function of Trial Type (nonswitch, switch), Switch Proportion (low switch, high switch) and Grade Level (kindergartners, fourth graders). (b) Switching costs on log-transformed reaction times and

error rates as a function of Switch Proportion (low switch, high switch) and Grade Level (kindergartners, fourth graders). Error bars refer to the standard errors of the means.

* *p* <.05, ** *p* <.01, *** *p* <.001.

Discussion

Experiment 1 showed children's flexibility adaptation as a function of switch proportion for both RTs and error rates. Switching costs were reduced in a context of HSW proportion when compared to LSW proportion. The present results support previous findings demonstrating control adaptation in children as young as 5 years old when processing conflicts, and extend them to another, under-explored, field namely task switching. This adaptation however occurred in a situation requiring the use of reactive control, the mode that preschoolers preferentially engage. Would this adaptation be obtained in a situation making reactive control costly and less efficient? Experiment 2 addressed this question.

Experiment 2

Experiment 2 was designed along the same lines as Experiment 1 except for the display sequence of task cues and target stimuli. To test whether an adaptation of children's level of flexibility can be obtained in a situation encouraging a proactive control reconfiguration of task sets, task cues were presented ahead of the stimuli and disappeared at stimuli onset. This sequence requiring preparation in advance of the target is known to be particularly challenging for kindergartners (Chatham et al., 2007; Chevalier et al., 2015; Elke & Wiebe, 2017; Gonthier et al., 2019; Lucenet & Blaye, 2019).

Method

Participants

Data collection was planned for the same sample size as in Experiment 1 (which included 50 participants per group). Consent was obtained for a new sample of 48 kindergartners (M_{age} =

5.72 years, SD_{age} = 0.29, 27 females) and 43 fourth graders (M_{age} = 9.88 years, SD_{age} = 0.23, 22 females). Children were all native French speakers and were recruited from three preschools and primary schools in France. The recruitment conditions and characteristics of the sample were identical to those in Experiment 1.

Materials and Procedure

The materials, procedure, design, and data processing in Experiment 2 were identical to those of Experiment 1, except that in each trial, the task cue (a black circle of 12 gray geometrical shapes indicating that shape was relevant vs. 12 patches of different colors indicating that color was relevant) was presented for 1500 ms around the gift box and disappeared at stimulus onset (see Figure 3), thereby encouraging participants to process the cue proactively, that is, to identify and set the relevant task goal ahead of the stimulus presentation.

[Insert Figure 3 approximately here]

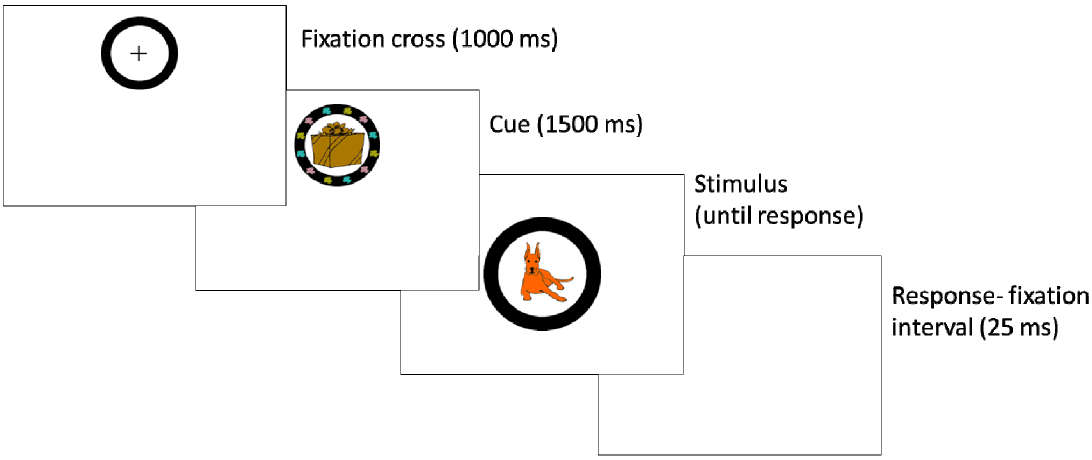

Figure 3. Illustration of a within-trial sequence (here color task) in the proactive situation.

Results

The data were analyzed as for Experiment 1 (with 1.61% and 1.85% of trials with correct response times excluded for kindergartners for the LSW and HSW proportions, respectively; and 1.64% and 1.85% of trials for fourth graders). After testing, 7 kindergartners and 6 fourth graders were excluded due to failure in more than 30% of the training trials (1 kindergartner and 1 fourth grader), and error rates beyond three standard deviations from the mean of their age group in at least one trial type of each switch proportion (6 kindergartners and 5 fourth graders). Thus, the final sample included 41 kindergartners (M_{age} = 5.68 years, SD_{age} = 0.27, 24 females) and 37 fourth graders (M_{age} = 9.90 years, SD_{age} = 0.22, 19 females). Error rates and RT means for the two proportions of switches and trial types in the two grade levels are reported in Table 1 of the Appendix. The order of the switch proportions did not interact with other variables of interest in any of the following analyses (all *p*s > .071).

Regarding RTs, as revealed by a main effect of trial type, $F(1,76) = 43.20$, $p < .001$, $\eta^2p = .36$, latencies were faster on nonswitch trials (7.19 ln ms, 1557 ms) than on switch trials (7.26 ln ms, 1639 ms), yielding significant switching costs (0.07 ln ms, 82 ms). There was also a significant main effect of the switch proportion, $F(1, 76) = 15.53$, $p < .001$, $\eta^2_p = .16$, indicating faster responses in the LSW proportion (7.19 ln ms, 1530 ms) than in the HSW proportion (7.27 ln ms, 1666 ms). However, the trial type did not interact with the switch proportion $F(1,76) = 1.22$, $p = .27$, $\eta^2p = .015$, thereby failing to demonstrate the LWSP effect in a context encouraging proactive control within the trial (i.e., with time to prepare for the upcoming task and disappearance of the task cue at stimulus onset), in line with findings in adults demonstrating the LWSP effect only for short or null, but not long, CSIs (Bonnin et al., 2011; Monsell & Mizon, Experiment 4, 2006; Siqi-Liu & Egner, 2020). A main effect of grade level was obtained, $F(1, 76) = 99.72$, $p < .001$, $\eta^2p = .56$, showing that fourth graders (6.92 ln ms, 1116 ms) were faster than kindergartners (7.53 ln ms, 2079 ms), but this variable did not interact with the other ones (all *p*s > .11).

The results for error rates evidenced a main trial type effect, $F(1,76) = 93.64$, $p < .001$, $\eta^2p = .55$, showing lower error rates on nonswitch trials (7.3%) than on switch trials

(14.9%), yielding significant switching costs (7.5%). A main effect of switch proportion was also obtained, $F(1,76) = 16.27$, $p < .001$, $\eta^2 p = .17$, with lower error rates in the HSW proportion (9.2%) than in the LSW proportion (13%). The most critical questions were whether switching costs would vary according to switch proportion, and whether this modulation would depend on grade level given the challenging nature of proactive control in kindergartners. Importantly, the Trial Type × Switch Proportion interaction was significant $F(1,76) = 18.50$, $p < .001$, $\eta^2 p = .19$, demonstrating the LWSP effect (see Figure 4), expressed through significantly smaller switching costs at the HSW proportion (3.7%) compared with the LSW proportion (12.7%). A main effect of grade level was found, $F(1,76) = 28.41$, $p < .001$, $\eta^2 p = .27$, revealing that kindergartners made significantly more errors (14.1%) than fourth graders (8.1%). An interaction between trial type and grade level was found, $F(1,76) = 4.14$, $p = .045$, $\eta^2 p = .051$, showing a significant decrease from kindergartners to fourth graders in switching costs (from 9.1% to 5.9%). However, the interaction between trial type, grade level and switch proportion was not significant, $F(1,76) = 0.62$, $p = .43$, $\eta^2 p = .008$, failing to demonstrate a modulation of the LWSP effect by grade level. No other effect was significant (all *p*s > .18).

[Insert Figure 4 approximately here]

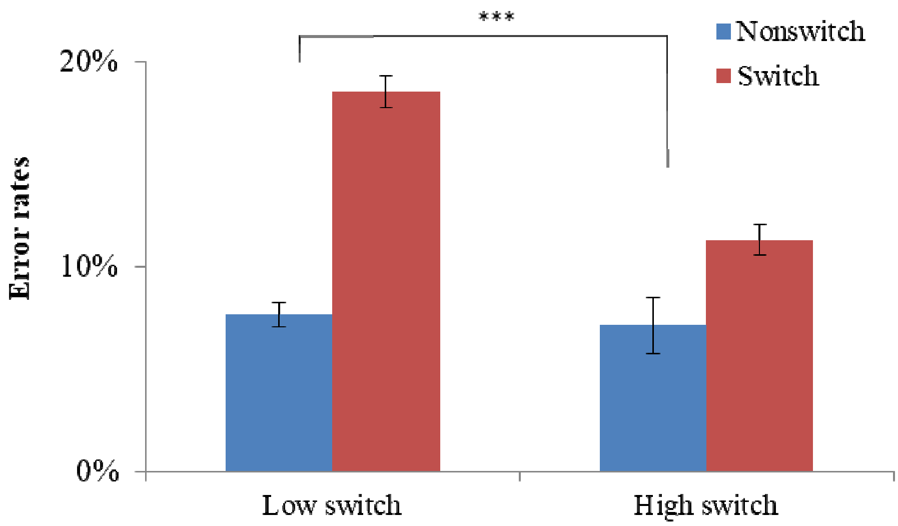

Figure 4. Error rates as a function of Trial Type (nonswitch, switch) and Switch Proportion (low switch, high switch). Error bars refer to the standard errors of the means.

*** p <.001.

Discussion

Experiment 2 failed to demonstrate a LWSP effect for RTs in a context encouraging proactive control within a trial; similar to adults who demonstrate this effect only for short or null CSIs but not long ones, encouraging reactive vs. proactive control, respectively (Bonnin et al., 2011; Monsell & Mizon, Experiment 4, 2006; Siqi-Liu et al., 2020). However, a LWSP effect was obtained for error rates and was significant for both age groups, thereby revealing flexibility adaptation in preschool years in this proactive situation, known to be particularly costly for young children.

General discussion

This study had two main goals. Firstly, we assessed adaptation of children's level of flexibility, at ages where control processes are not yet fully mature. Secondly, we investigated whether this form of meta-control would depend on children's possibility of preparing for the upcoming task. Such a possibility determines whether or not task-set reconfiguration can be engaged reactively or proactively: Whereas reactive control is mastered by both age groups, only fourth graders are known to already engage proactive control quite effectively. In a situation eliciting reactive control, Experiment 1 revealed a significant LWSP effect in children, with a larger magnitude in kindergartners than in fourth graders. By placing children in a situation encouraging proactive control, Experiment 2 revealed a different pattern of adaptation depending on the measure considered: Whereas no adaptation was found on RTs, error rates revealed smaller switch costs in the context of high switch proportion.

Age-Related Changes in Adaptation of Flexibility Level

Evidence of flexibility adjustments, based on experiences of contrasted proportions of switches in kindergartners, extends previous research that has revealed their control adaptation in contexts of conflict processing (Ambrosi et al., 2016; Erb et al., 2017; Gonthier et al., 2021. Gonthier & Blaye, 2021; Liu et al., 2018; Rueda et al., 2004; Wilk & Morton, 2012). As flexibility is still highly challenging in this age group, this finding provides new support for the conclusion that young children are capable of fine-grained modulation of cognitive control, although this control in itself is still partially immature. It then adds to the growing evidence suggesting that the adaptation of control recruitment to task demands may develop earlier than cognitive control itself. Among the reasons that may account for this lag is the implicit vs. explicit nature of the cues, which induce the engagement of control adaptation processes when implicit, and of control processes when explicit. Adaptation of control is triggered by the experience of contrasted proportions of control-demanding trials (proportion of switches or conflicts). Evidence of the implicit nature of these experiential cues is found in the very poor awareness of such variations of frequencies in both adults and children (Blais et al., 2012; Crump et al., 2006; Crump & Logan, 2010; Gonthier & Blaye, 2021; Gonthier et al., 2021). Conversely, cognitive control processes are engaged on the basis of explicit cues in control tasks be they explicit verbal instructions or task cues. On the one hand, processing of explicit cues may be more demanding than implicit control as it requires the intentional engagement of control processes and, on the other hand, implicit adaptation of control may reflect in part, consequences of conditions that more or less support processes underlying efficient control. Indeed, this last aspect could account for a somehow surprising finding which is the reduction of flexibility adaptation in the older group of children. Although a similar age effect has been obtained in recent studies investigating the context-specific congruency (CSCP) effect and the LWPC effect (Gonthier et al., 2021; Gonthier & Blaye, 2021; Li et al., 2019), the reasons for this pattern remain unclear. The hypothesis put forward by Kane and colleagues (Kane & Engle, 2003; Marcovitch et al., 2010; Meier & Kane, 2017) to account for unequal sensitivity to proportion of conflicts of low- vs. high-working-memory-capacity participants in both children and adults can be extended to the current findings. Undoubtedly, kindergartners can be considered as having overall lower working-memory capacity than fourth graders. Kane and colleagues proposed that conflictual trials (*i.e.,* incongruent trials in conflict tasks, or conflict cards in the version of the DCCS task used by Marcovitch et al., 2010) could serve as goal reminders; hence the difference of proportions of incongruent trials being all the more critical for participants who may neglect the goals, that is, those with lower working memory capacity. In the present study, it can similarly be hypothesized that frequent switch trials in the high-switch proportion condition contribute to maintaining a high level of activation of the two task goals and serve as reminders for the need to reconfigure, whereas long series of repeated trials in the low-switch proportion make it harder to reactivate the recently unused goal. This account provides an explanation for the fact that the bigger size of the LWSP effect in the younger age group in Experiment 1 is based on a higher switching cost in the younger group for the low-switch proportion. As younger children struggle more to actively maintain goals due to their lower working-memory capacity, they are specifically impeded in the condition offering a low proportion of goal reminders (Gonthier et al., 2019).

Adaptation of Flexibility in Situations Inducing Reactive vs. Proactive Control

Another important finding is that the induced dynamics of control processes engagement (Exp.1 vs. Exp. 2) modulated switch proportion effects, as shown by the partially different patterns of flexibility adaptation observed in the two experiments[2]. The present evidence of the LWSP effect in the reactive situation replicates in young children findings in adults revealing this effect when the cue-stimulus interval was short or null (Bonnin et al., 2011; Dreisbach & Haider, 2006; Eich et al., 2018; Kang & Chiu, 2021; Monsell & Mizon, 2006; Siqi-Liu & Egner, 2020). In the proactive situation, flexibility adaptation in children is in line with adults' when considering RTs. However, the fact that children still showed such an effect on error rates is at odds with adults' performance on this measure, which is insensitive to switch proportion due to floor effect. Unequal sensitivity of children's RTs and errors to the LWSP effect in the proactive situation can be accounted for when considering the processes targeted by the two measures respectively. RTs are computed on successful trials, and thereby provide an estimation of the duration of successful proactive processing of the cue and proactive reconfiguration of the task-set when necessary. Errors in the proactive situation (i.e., when an early task cue disappears at target onset) may be due to failures of one or more of the following processes: a) reactive reconfiguration of the task set when the target stimulus is displayed, or b) processing of the cue in advance of the target stimulus, and/or c)

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[2] Note that analyzing data of Experiment 1 and 2 together led to the same conclusions as those from previously reported separate analyses. The analysis on error rates revealed that the encouraged mode of control induced by the situation (Exp.1 vs Exp.2) did not interact with trial type and switch proportion (p = .44) neither with grade level (p = .48), in line with the significant LWSP effect observed in each experiment. Conversely, analysis on RTs revealed a significant interaction between situation, trial type, and switch proportion, $F(1,161) = 5.70$, p = .018; $\eta^2 p = .034$, in line with the finding of a significant LWSP effect in the reactive control situation, but not in the proactive control situation.

proactive reconfiguration of the task-set if necessary (i.e., on switch trials). Reactive reconfiguration seems highly implausible since the design made this process particularly difficult. Indeed, engaging in a reactive reconfiguration in a situation inducing proactive control (Exp. 2) should lead to longer RTs than in a situation eliciting reactive control (Exp. 1), which was not the case in the current study (mean RTs in Exp.2: 1579 ms vs. 2475 ms in Exp.1). Equally low error rates on nonswitch trials in the two switch proportion conditions suggest that children are able to proactively process the cue when no reconfiguration is required. Indeed, the LWSP effect appears to be due to a reduction of error rates on the switch trials in the high switch proportion condition. As a consequence, among the potential processes that may account for the LWSP effect on error rates, improved proactive reconfiguration of the task-set on switch trials in a context of frequent switches seems to be the most plausible.

Testing the development of children's modulation of their control processes in the context of task-switching instead of conflict processing might afford ruling out some alternative accounts of the effects of proportions on performance. As examined by Braem et al (2019), congruency proportion effects in conflict tasks might sometimes be accounted for by lower-level stimulus-response associations due to the very small number of distinct bi-dimensional stimuli usually used in these studies (for detailed considerations, see also Bugg & Crump, 2012). In the present study, the 64 stimuli used have made it highly unlikely for children to learn stimulus-response associations, thereby limiting the contribution of contingency learning processes. A further step in ruling out the contribution of item-specific learning processes in LWSP effects would be to dissociate inducer and diagnostic items, which has been already achieved in the literature on conflict processing adjustments (see Gonthier & Blaye, 2021). In the paradigm we used, individual items are all concurrently biased together with the overall list of trials. Flexibility adaptation considered here at the list level may then have been achieved by a series of local adaptations to the proportion of each item. Testing whether the LWSP effect transfers to diagnostic items presented as often as switch than non-switch trials within lists of mostly switch- vs. nonswitch items would allow testing this hypothesis. Recent findings in adults (Siqi-Liu & Egner, 2020) suggest that the effect does indeed transfer and cannot then not fully be accounted for by local adjustments.

To conclude, this study reports flexibility adaptation in children as a function of the probability of occurrences of task switches, suggesting that as young as 5-6 years, children can succeed in implicitly setting the equilibrium point between stability and flexibility in a way that is adjusted to the task demand. Implicit adaptation of control appears efficient earlier in children than intentional control.

References

Ambrosi, S., Lemaire, P., & Blaye, A. (2016). Do Young Children Modulate Their Cognitive Control? : Sequential Congruency Effects Across Three Conflict Tasks in 5-to-6 Year-Olds. *Experimental Psychology*, *63*(2), 117‑126. https://doi.org/10.1027/1618-3169/a000320

Blais, C., Harris, M. B., Guerrero, J. V., & Bunge, S. A. (2012). Rethinking the role of automaticity in cognitive control. *Quarterly Journal of Experimental Psychology*, *65*(2), 268‑276. https://doi.org/10.1080/17470211003775234

Bonnin, C. A., Gaonac'h, D., & Bouquet, C. A. (2011). Adjustments of task-set control processes : Effect of task switch frequency on task-mixing and task-switching costs. *Journal of Cognitive Psychology*, *23*(8), 985‑997. https://doi.org/10.1080/20445911.2011.594435

Braem, S., Bugg, J. M., Schmidt, J. R., Crump, M. J. C., Weissman, D. H., Notebaert, W., & Egner, T. (2019). Measuring Adaptive Control in Conflict Tasks. *Trends in Cognitive Sciences*, *23*(9), 769‑783. https://doi.org/10.1016/j.tics.2019.07.002

Braver, T. S. (2012). The variable nature of cognitive control : A dual mechanisms framework. *Trends in Cognitive Sciences*, *16*(2), 106‑113. https://doi.org/10.1016/j.tics.2011.12.010

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation : Dual mechanisms of cognitive control. In *Variation in working memory* (p. 76‑106). Oxford University Press.

Bugg, J., & Crump, M. (2012). In Support of a Distinction between Voluntary and Stimulus-

Driven Control : A Review of the Literature on Proportion Congruent Effects. *Frontiers in Psychology*, *3*, 367. https://doi.org/10.3389/fpsyg.2012.00367

Bugg, J. M., & Hutchison, K. A. (2013). Converging evidence for control of color-word Stroop interference at the item level. *Journal of Experimental Psychology. Human Perception and Performance*, *39*(2), 433‑449. https://doi.org/10.1037/a0029145

Buttelmann, F., & Karbach, J. (2017). Development and Plasticity of Cognitive Flexibility in Early and Middle Childhood. *Frontiers in Psychology*, *8*, 1040. https://doi.org/10.3389/fpsyg.2017.01040

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. C. M. (2001). Changes in executive control across the life span : Examination of task-switching performance. *Developmental Psychology*, *37*(5), 715‑730. https://doi.org/10.1037/0012-1649.37.5.715

Chatham, C. H., Frank, M. J., & Munakata, Y. (2009). Pupillometric and behavioral markers of a developmental shift in the temporal dynamics of cognitive control. *Proceedings of the National Academy of Sciences*, *106*(14), 5529‑5533. https://doi.org/10.1073/pnas.0810002106

Chevalier, N., & Blaye, A. (2009). Setting Goals to Switch Between Tasks : Effect of Cue Transparency on Children’s Cognitive Flexibility. *Developmental psychology*, *45*, 782‑797. https://doi.org/10.1037/a0015409

Chevalier, N., & Blaye, A. (2016). Metacognitive Monitoring of Executive Control Engagement During Childhood. *Child Development*, *87*(4), 1264‑1276. https://doi.org/10.1111/cdev.12537

Chevalier, N., Blaye, A., Dufau, S., & Lucenet, J. (2010). What visual information do children and adults consider while switching between tasks? Eye-tracking investigation of cognitive flexibility development. *Developmental Psychology*, *46*(4), 955-972. https://doi.org/10.1037/a0019674

Chevalier, N., Dauvier, B., & Blaye, A. (2018). From prioritizing objects to prioritizing cues : A developmental shift for cognitive control. *Developmental Science*, *21*(2), e12534. https://doi.org/10.1111/desc.12534

Chevalier, N., Martis, S. B., Curran, T., & Munakata, Y. (2015). Meta-cognitive processes in executive control development : The case of reactive and proactive control. *Journal of cognitive neuroscience*, *27*(6), 1125-1136. https://doi.org/10.1162/jocn_a_00782

Cragg, L., & Chevalier, N. (2012). The processes underlying flexibility in childhood. *Quarterly Journal of Experimental Psychology (2006)*, *65*(2), 209-232. https://doi.org/10.1080/17470210903204618

Crump, M. J. C., Gong, Z., & Milliken, B. (2006). The context-specific proportion congruent Stroop effect : Location as a contextual cue. *Psychonomic Bulletin & Review*, *13*(2), 316-321. https://doi.org/10.3758/bf03193850

Crump, M. J. C., & Logan, G. D. (2010). Hierarchical control and skilled typing : Evidence for word-level control over the execution of individual keystrokes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(6), 1369-1380. https://doi.org/10.1037/a0020696

Davidson, M. C., Amso, D., Anderson, L. C., & 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*(11), 2037-2078. https://doi.org/10.1016/j.neuropsychologia.2006.02.006

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology*, *64*, 135-168. http://dx.doi.org/10.1146/annurev-psych-113011-143750

Dreisbach, G., & Haider, H. (2006). Preparatory adjustment of cognitive control in the task switching paradigm. *Psychonomic Bulletin & Review*, *13*(2), 334-338. https://doi.org/10.3758/BF03193853

Dreisbach, G., Haider, H., & Kluwe, R. H. (2002). Preparatory processes in the task-switching paradigm : Evidence from the use of probability cues. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(3), 468-483. https://doi.org/10.1037/0278-7393.28.3.468

Duthoo, W., De Baene, W., Wühr, P., & Notebaert, W. (2012). When Predictions Take Control : The Effect of Task Predictions on Task Switching Performance. *Frontiers in Psychology*, *3*, 282. https://doi.org/10.3389/fpsyg.2012.00282

Eich, T. S., MacKay-Brandt, A., Stern, Y., & Gopher, D. (2018). Age-Based Differences in Task Switching Are Moderated by Executive Control Demands. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *73*(6), 954-963. https://doi.org/10.1093/geronb/gbw117

Elke, S., & Wiebe, S. A. (2017). Proactive control in early and middle childhood : An ERP study. *Developmental Cognitive Neuroscience*, *26*, 28-38. https://doi.org/10.1016/j.dcn.2017.04.005

Erb, C. D., Moher, J., Song, J.-H., & Sobel, D. M. (2017). Cognitive control in action : Tracking the dynamics of rule switching in 5- to 8-year-olds and adults. *Cognition*, *164*, 163-173. https://doi.org/10.1016/j.cognition.2017.03.023

Gonthier, C., Ambrosi, S., & Blaye, A. (2021). Learning-based before intentional cognitive control : Developmental evidence for a dissociation between implicit and explicit control. *Journal of Experimental Psychology. Learning, Memory, and Cognition*. https://doi.org/10.1037/xlm0001005

Gonthier, C., & Blaye, A. (2021). Preschoolers are capable of fine-grained implicit cognitive control : Evidence from development of the context-specific proportion congruency effect. *Journal of Experimental Child Psychology*, *210*, 105211. doi:10.1016/j.jecp.2021.105211

Gonthier, C., Zira, M., Colé, P., & Blaye, A. (2019). Evidencing the developmental shift from reactive to proactive control in early childhood, and its relationship to working memory. *Journal of Experimental Child Psychology*, *177*, 1-16. doi:10.1016/j.jecp.2018.07.001

Jacoby, L. L., Lindsay, D. S., & Hessels, S. (2003). Item-specific control of automatic processes : Stroop process dissociations. *Psychonomic Bulletin & Review*, *10*(3), 638-644. https://doi.org/10.3758/BF03196526

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention : The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General*, *132*(1), 47-70. https://doi.org/10.1037/0096-3445.132.1.47

Kang, M. S., & Chiu, Y.-C. (2021). Proactive and reactive metacontrol in task switching. *Memory & Cognition*, *49*(8), 1617-1632. https://doi.org/10.3758/s13421-021-01189-8

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I.

(2010). Control and interference in task switching—A review. *Psychological Bulletin*, *136*(5), 849‑874. https://doi.org/10.1037/a0019842

Killikelly, C., & Szűcs, D. (2013). Delayed development of proactive response preparation in adolescents : ERP and EMG evidence. *Developmental Cognitive Neuroscience*, *3*(1), 33‑43. https://doi.org/10.1016/j.dcn.2012.08.002

Koch, I., Poljac, E., Müller, H., & Kiesel, A. (2018). Cognitive structure, flexibility, and plasticity in human multitasking-An integrative review of dual-task and task-switching research. *Psychological Bulletin*, *144*(6), 557‑583. https://doi.org/10.1037/bul0000144

Li, D., Liu, T., & Shi, J. (2019). Conflict adaptation in 5-year-old preschool children : Evidence from emotional contexts. *Frontiers in Human Neuroscience*, *13*. https://doi.org/10.3389/fnhum.2019.00014

Liu, X., Liu, T., Shangguan, F., Sørensen, T. A., Liu, Q., & Shi, J. (2018). Neurodevelopment of conflict adaptation : Evidence from event-related potentials. *Developmental Psychology*, *54*(7), 1347‑1362. https://doi.org/10.1037/dev0000524

Lorsbach, T. C., & Reimer, J. F. (2010). Developmental differences in cognitive control : Goal representation and maintenance during a continuous performance task. *Journal of Cognition and Development*, *11*(2), 185‑216. https://doi.org/10.1080/15248371003699936

Lucenet, J., & Blaye, A. (2014). Age-related changes in the temporal dynamics of executive control : A study in 5- and 6-year-old children. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00831

Lucenet, J., & Blaye, A. (2019). What do I do next? The influence of two self-cueing strategies on children's engagement of proactive control. *Cognitive Development*, *50*, 167‑176. https://doi.org/10.1016/j.cogdev.2019.05.001

Marcovitch, S., Boseovski, J. J., & Knapp, R. J. (2007). Use it or lose it : Examining preschoolers' difficulty in maintaining and executing a goal. *Developmental Science*, *10*(5), 559‑564. https://doi.org/10.1111/j.1467-7687.2007.00611.x

Marcovitch, S., Boseovski, J., Knapp, R., & Kane, M. (2010). Goal Neglect and Working Memory Capacity in 4- to 6-Year-Old Children. *Child development*, *81*, 1687‑1695. https://doi.org/10.1111/j.1467-8624.2010.01503.x

Mayr, U. (2006). What matters in the cued task-switching paradigm : Tasks or cues? *Psychonomic Bulletin & Review*, *13*(5), 794‑799. https://doi.org/10.3758/BF03193999

Meier, M. E., & Kane, M. J. (2017). Attentional control and working memory capacity. In *The Wiley handbook of cognitive control* (p. 50‑63). Wiley Blackwell. https://doi.org/10.1002/9781118920497.ch3

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component Processes in Task Switching. *Cognitive psychology*, *41*, 211‑253. https://doi.org/10.1006/cogp.2000.0736

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, *7*(3), 134‑140. https://doi.org/10.1016/S1364-6613(03)00028-7

Monsell, S., & Mizon, G. A. (2006). Can the task-cuing paradigm measure an endogenous task-set reconfiguration process? *Journal of Experimental Psychology: Human Perception and Performance*, *32*(3), 493‑516. https://doi.org/10.1037/0096-

1523.32.3.493

Munakata, Y., Snyder, H. R., & Chatham, C. H. (2012). Developing Cognitive Control : Three Key Transitions. *Current Directions in Psychological Science*, *21*(2), 71‑77. https://doi.org/10.1177/0963721412436807

Niebaum, J. C., Chevalier, N., Guild, R. M., & Munakata, Y. (2021). Developing adaptive control : Age-related differences in task choices and awareness of proactive and reactive control demands. *Cognitive, Affective & Behavioral Neuroscience*, *21*(3), 561‑572. https://doi.org/10.3758/s13415-020-00832-2

Reimers, S., & Maylor, E. A. (2005). Task Switching Across the Life Span : Effects of Age on General and Specific Switch Costs. *Developmental Psychology*, *41*(4), 661‑671. https://doi.org/10.1037/0012-1649.41.4.661

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia*, *42*(8), 1029‑1040. https://doi.org/10.1016/j.neuropsychologia.2003.12.012

Siqi-Liu, A., & Egner, T. (2020). Contextual adaptation of cognitive flexibility is driven by task- and item-level learning. *Cognitive, Affective & Behavioral Neuroscience*, *20*(4), 757‑782. https://doi.org/10.3758/s13415-020-00801-9

Smulders, S. F. A., Soetens, E. L. L., & van der Molen, M. W. (2018). How Do Children Deal With Conflict? A Developmental Study of Sequential Conflict Modulation. *Frontiers in Psychology*, *9*, 766. https://doi.org/10.3389/fpsyg.2018.00766

Vandierendonck, A., Liefooghe, B., & Verbruggen, F. (2010). Task Switching : Interplay of

Reconfiguration and Interference Control. *Psychological bulletin*, *136*, 601-626. https://doi.org/10.1037/a0019791

Wilk, H. A., & Morton, J. B. (2012). Developmental changes in patterns of brain activity associated with moment-to-moment adjustments in control. *NeuroImage*, *63*(1), 475-484. https://doi.org/10.1016/j.neuroimage.2012.06.069

Zelazo P. D. (2006). The Dimensional Change Card Sort (DCCS): a method of assessing executive function in children. *Nature protocols*, *1*(1), 297–301. https://doi.org/10.1038/nprot.2006.46

Appendix

Table 1. Mean scores on error rates and response times (RTs) transformed to their natural logarithm (ln ms) as a function of Switch Proportion, Situation, Grade level, and Trial type (with standard deviations in parentheses).

	Low Switch	High Switch
Trial Type	*M (SD)* Error rates *M (SD)* Response Times *M (SD) Log-transformed RTs*	*M (SD)* Error rates *M (SD)* Response Times *M (SD) Log-transformed RTs*
Reactive situation		
	Kindergartners	
Nonswitch	5.70 (0.70) 3085 (115) 7.88 (0.03)	8.83 (1.09) 3290 (110) 7.97 (0.03)
Switch	14.13 (1.35) 3562 (151) 8.03 (0.04)	9.60 (1.02) 3461 (118) 8.02 (0.03)
	Fourth graders	
Nonswitch	3.65 (0.75) 1518 (122) 7.24 (0.03)	2.89 (1.15) 1626 (116) 7.32 (0.03)
Switch	7.92 (1.43) 1608 (160) 7.32 (0.04)	4.47 (1.08) 1653 (125) 7.34 (0.03)
Proactive situation		
	Kindergartners	
Nonswitch	10.16 (0.76) 1931 (74) 7.45 (0.04)	8.99 (1.05) 2159 (86) 7.56 (0.04)
Switch	23.17 (1.88) 2049 (73)	14.22 (1.04) 2179 (87)

	7.53 (0.04)	7.59 (0.04)
	Fourth graders	
Nonswitch	5.10 (0.80) 1029 (77) 6.85 (0.04)	5.23 (1.11) 1108 (90) 6.92 (0.04)
Switch	13.73 (1.98) 1110 (77) 6.93 (0.04)	8.50 (1.09) 1217 (91) 7.00 (0.04)