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Task switching costs in preschool children and adults

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Abstract

Past research investigating cognitive flexibility has shown that preschool children make many perseverative errors in tasks that require switching between different sets of rules. However, this inflexibility may not necessary hold with easier tasks. The current study investigates the developmental differences in cognitive flexibility using a task-switching procedure that compares reaction times and accuracy in 4- to 6-year-olds to those of adults. The experiment involved simple target detection tasks, and was intentionally designed in a way that the stimulus and response conflicts were minimal, together with a long preparation window. Global mixing costs (performance costs when multiple tasks are relevant in a context), and local switch costs (performance costs due to switching to an alternative task) are typically thought to engage endogenous control processes. If this is the case, we should observe developmental differences with both these costs. Our results show, however, that when the accuracy was good, there were no age differences in cognitive flexibility between children and adults (i.e. the ability to manage multiple tasks and to switch between tasks). Even though preschool children had slower reaction times and were less accurate, the mixing and switch costs associated with task-switching were not reliably larger for preschool children. Preschool children did, however, show more commission errors and greater response repetition effects than adults, which may reflect differences in inhibitory control.

To negotiate our way adaptively in a dynamic environment, we need to be able to shift and focus our attention appropriately. This ability has been studied in both children and adults, revealing that both groups, depending on the context, can show task switching difficulties, albeit in different performance outcomes (c.f. Diamond & Kirkham, 2005; Kirkham, Cruess, & Diamond, 2003). In adult studies, participants show reaction time costs when switching between relatively simple cognitive tasks (e.g., identifying either a target form or a target color in a sequence of letters). Developmental studies have looked at similar costs in young children in terms of errors or perseverative performance. Indeed, numerous studies have shown that 3- and 4-year-old preschool children have great difficulty switching attention between tasks when instructed to do so, but that this ability improves greatly between 5 and 6 years of age (e.g. Carlson, 2005; Cepeda, Kramer, & Gonzalez de Sather, 2001; Chevalier, Sheffield, Nelson, & Clark, 2013; Zelazo, Frye, & Rapus, 1996; Zelazo, Müller, Frye, & Marcovitch, 2003). This line of work has underpinned research showing that the ability to attend selectively and to voluntarily shift one's attention is central to the development of executive control (Garon, Bryson, & Smith, 2008). However, a number of methodological and conceptual issues limit the conclusions that can be drawn from this work.

Firstly, it might seem reasonable to assume that both developmental and adult studies are investigating the same processes, and indeed both lines of research connect their findings to attention and cognitive control. There are, however, important differences in the experimental paradigms that can be used with young children and those used with adults, making direct comparisons difficult. Paradigms developed for young children, such as the Dimensional Change Card Sort (DCCS; Zelazo, Frye, & Rapus, 1996), the Day-Night Stroop task (Gerstadt, Hong, & Diamond, 1994), the Spatial conflict task (Davidson, Amso, Anderson, & Diamond, 2006), and the Shape School task (Blaye & Chevalier, 2011; Chevalier & Wiebe, 2011; Espy, 1997), are normally considered appropriate for preschool children because performance improves to ceiling level across childhood. These tasks traditionally measure perseveration errors and *accuracy*. However, due to the novel elements in the

tasks presented to the children (e.g., the lack of feedback, stimulus conflict, etc.), it is not clear that the results are comparable to those of the adult studies. Moreover, in adult studies, switching between two simple and often familiar and well-practiced cognitive tasks produces reliable *reaction time* (RT) costs, and to a lesser degree, accuracy costs. Thus, it remains unclear whether and how performance on these tasks relate to one another across development.

A second major challenge in this domain is the lack of consensus on what the appropriate measures and tasks are for a given age when measuring cognitive control in children (e.g. Best & Miller, 2010; Carlson, 2005). Large individual differences in performance exist, even within a specific age group. Thus, because chronological age is a crude proxy for the level of development, when the performance measure is also crude (e.g., pass/fail), it can be difficult to tease apart age-associated differences from individual differences in attentional control. We know, for instance, that some 3-year-olds can pass the DCCS task whereas some others show great difficulty in shifting attention to the other target dimension. In addition, when presented with a new set of stimuli, among the children who failed the standard DCCS task, some continued to perseverate on the first dimension in the new set whereas others successfully shifted to the new dimension (Hanania, 2010). Potential explanations for the disparate performances among the 3-year-olds are individual differences in either cognitive control and/or other experience-dependent knowledge acquisition, as well as other unspecified situational factors in the experimental context. While it is not clear what best differentiate the subgroups of the perseverators, what is clear is that variability in task-performance often goes beyond what chronological development could account for, and such an observation presents a great challenge to the developmental theory of cognitive flexibility.

Thirdly, error-based cognitive tasks are typically only applicable to a narrow range of ages, because of ceiling effect. This is at odds with the fact that cognitive development occurs on a protracted timescale (e.g. Fair et al., 2009; Giedd et al., 1999). In contrast, timed cognitive tasks can be used across a broad age range and are also sensitive to different experimental conditions. Indeed, many

developmental studies have reported continuous development on simple speeded cognitive tasks such as flanker's task and Go-NoGo task (Huizinga, Dolan, & van der Molen, 2006; Ridderinkhof & van der Molen, 1995); however, none of these involved task-switching in the preschool years.

Thus, the existing literature on cognitive control is limited by a number of methodological concerns. In response to this, the current study will investigate whether a protracted period of development of attentional control is observed when children perform a familiar task with an age-appropriate level of cognitive demand (as is the case in adult study and studies involving older children). In what follows, we first describe the general task-switching paradigm commonly used in adult studies, before turning to a discussion of existing developmental studies of task switching and their current shortcomings. We focus on task switching because it is a very well-studied paradigm in the adult literature that encapsulated the essential elements of cognitive control.

The Task-Switching Paradigm

The current study is inspired by the task-switching paradigm commonly employed in the adult studies. This paradigm is well-established and involves switching between two simple cognitive tasks, each of which requires attention to a different attribute of the stimuli presented, such as color or form of a letter sequence (Allport, Styles, & Hsieh, 1994; Gade & Koch, 2007; Meiran & Kessler, 2008; Rogers & Monsell, 1995; Rubin & Meiran, 2005). Despite the simplicity of this task, active cognitive control is still necessary for successful performance. Two types of processing costs are commonly reported—*global mixing cost* and *local switch cost*. Global mixing costs refer to the between-block differences in reaction times/accuracy when multiple tasks are involved in one block (e.g., mixed block; switching between responding to color and form in the sequence), compared to a block where only one task is involved (e.g., pure block; responding only to color or form). Importantly, these mixing costs are observed even when the participant is repeating the same task from the previous trial in a mixed block, when no attentional shift is required. Local switch costs refer to the within-condition

differences found by comparing task-switch trials with task-repetition trials in a mixed block, when attention has to be redirected to activate the new task rule and the associated stimulus-response mappings.

Task-switching costs across development

We focus here only on studies that have measured both RTs and accuracy within a task-switching context, and further limit our discussion to mixing costs and switch costs associated with task-switching studies.

Mixing Cost: Davidson et al. (2006) carried out a series of experiments with task-switching elements on children aged between 4 and 13 years, as well as on adults. Using a spatial incompatibility paradigm, participants had to switch between responding on either the same or opposite side of the screen from the target stimulus, based on the form of the stimuli. The authors reported greater global mixing costs in accuracy for children aged 10 years or younger, than for older participants. However, the accuracy mixing costs appeared as the result of a trade-off with RTs, with older participants showing greater RT mixing costs than younger children. This trade-off effect renders the overall effect of age on mixing costs difficult to interpret. It is also worth noting that accuracy in the mixed block did not reach above 80% until age 11. With such a low accuracy, it is not clear whether the mixing costs observed in young children reflect developmental differences in attention or other issues related to the task parameters.

To avoid the issues caused by low accuracy, Dibbets and Jolles (2006) carefully designed tasks suitable for preschool children (i.e. high accuracy). They also reported greater accuracy mixing costs among the youngest participants (aged from 4.8 years to 13 years), but no greater RT mixing costs. Thus, there was no change in cost criteria between age groups (i.e., no speed-accuracy trade-off). In contrast, other studies did find an age effect on RT and/or accuracy mixing costs (Cepeda et al., 2001, with participants aged 7 to 82 years; Kray, Eber, & Karbach, 2008, with participants aged 7 to 77;

Reimers & Maylor, 2005, with participants aged 10 to 66 years); however, these studies involved children older than the preschool years. Overall, past research generally support the presence of an age effect on mixing costs, although the types of costs are less consistent across studies. Finally, at least one experiment has failed to find any influence of age on mixing costs using a color/shape choice task, despite a large age gap in participants (7-year-olds vs. University students [Exp. 1], Ellefson, Shapiro, & Chater, 2006). Thus, it raises questions on whether the developmental effect on mixing costs is robust across different types of tasks.

At the mechanistic level, *mixing costs* were initially thought to reflect greater working memory demands with multiple task rules (Los, 1996; Rogers & Monsell, 1995). However, other studies have not supported the working memory account. It was found that increasing the number of task rules did not increase mixing costs, but increasing the stimulus ambiguity and the response conflicts did (Brass et al., 2003; Meiran, 2000; Rubin & Meiran, 2005). Steinhauser and Hübner (2005) proposed that mixing costs reflect the increasing difficulty in selective attention among the mixed task components— the selection between the conflicting task-relevant and irrelevant stimulus/response attributes.

Switch Costs: Strong effects of age on both RT and or accuracy switch costs have been reported in several studies (Cepeda et al., 2001, [7 to 82 years old]; Chevalier, Martis, Curran, & Munakata, 2015, [5 and 10 years old]; Crone, Bunge, Van Der Molen, & Ridderinkhof, 2006, [7 to 25 years old]; Davidson et al., 2006, [4 to 13 years old and adults]). However numerous others have found no age effect on either RT or accuracy switch costs (e.g. Dibbets & Jolles, 2006, [4.8 to 13 years old]; Ellefson et al., 2006, [7 years old and adults]; Reimers & Maylor, 2005 [10 to 66 years old]). Thus, at the moment it remains unclear whether switch costs are a meaningful correlate of cognitive development.

There are reasons to believe that switch costs should be sensitive to development as switching to an alternative task involves control processes in task-set reconfiguration (De Jong, 2000; Koch,

2003; Mayr & Kliegl, 2000; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001). In adult studies, support for the idea that cognitive factors play a role in task switching comes from studies on the preparation effect. It has been shown repeatedly that a longer preparation window reduces but does not eliminate switch costs. Other than this temporal effect, preparation can also be facilitated in both children and adults by increasing cue transparency (Blaye & Chevalier, 2011; Koch, 2003).

Developmentally, the ability to switch between mental representations is associated with endogenous factors such as inhibitory control and the ability to reflect in anticipation of the stimulus (Cepeda et al., 2001; Chevalier et al., 2015; Diamond, Carlson, & Beck, 2005). Chevalier et al. (2015) found that the level of switch cost changed with the cueing methods used in 10-year-olds, but not in 5-year-olds. The cueing methods used in this experiment provided different opportunities to prepare for the upcoming task. They found that older children were more likely to employ proactive control in anticipation of the next trial than the younger children, although other physiological measurement with event-related potentials and pupillometric measures showed that 5-year-old also appeared to engage in endogenous preparation when there was a clear advantage in preparation.

Another plausible explanation for the switch cost is the presence of carry-over interference from the residual activation of the competing task-set and stimulus-response association (Allport et al., 1994; Grzyb & Hübner, 2013), which can be modulated by inhibitory processes associated with task-set management (Mayr & Keele, 2000). In contrast to the active task-reconfiguration account, switch cost in carry-over account include passive influence triggered by previous stimulus-task association, and does not strongly associate with cognitive control components. If so, developmental differences in switch effect may not be readily observable.

Current Study

The current experiment was designed not only to measure task-switching costs in preschool children, but also to create a paradigm that connects both child and adult performance. This was

achieved by adopting an age-appropriate procedure, with minimal cognitive conflicts, to ensure high accuracy among the youngest participants. The task also requires attentional control in order to select, maintain and switch between task sets. Despite the low level of task-difficulty and conflicts, the core principle of the task-switching procedure remains. It is hypothesized, therefore, that both mixing costs and switch costs will occur. In relation to developmental differences, it is posited that mixing costs will reflect the stimulus ambiguity and the demand on sequential selective attention. With an appropriate level of stimulus ambiguity, both children and adults should have little difficulty in selectively attending to the task-relevant attributes, and are therefore likely to exhibit similar mixing costs. An alternative to the stimulus ambiguity account is the working memory explanation of mixing costs which predicts an effect of development on mixing costs because working memory has a protracted developmental trajectory to adolescence (Gathercole, Pickering, Ambridge, & Wearing, 2004).

We also investigated the effect of development on switch costs. Here, we hypothesized that if the switch costs reflect cognitive control processes (e.g. task-reconfiguration and/or inhibitory control), then younger participants would experience greater switch costs than older participants.

In the current study, we focused on both preschool children aged 4 and 6 years, and adults. Given the significant changes in cognitive control in preschool years, it is particularly interesting to understand the processing costs associated with attentional shifts in this age group.

Methods

Participants

Eighty-two participants took part in the study: Thirty-four 4-year-olds (18 males, mean age=4.55 years, SD=.26 years), twenty-six 6-year-olds (15 males, mean age =6.28 years, SD=.25 years), and twenty-two adults (8 males, mean age =29.86 years, SD=9.17 years). Children with outlier performances were excluded from the final set of analyses (seven 4-year-olds did not meet this inclusion criterion, see Result for details). All children were recruited from local primary schools and

all testing was conducted in a quiet room at the participant's school. Children were given token rewards (i.e. stickers) at the end of each block to maintain their motivations. Each session lasted around 30 minutes. Adult participants were recruited from the University campus. No rewards were given to adults and they were tested in a quiet corner of the University campus. Informed parental consent was obtained for each child participant and informed consent from each adult participant in accordance with the University ethics committee guidelines. All participants had normal or corrected to normal vision and hearing.

Stimuli and Design

The current study employed an intermittent cued task-switching procedure with alternation-runs (i.e., the task switched every four trials). There were two detection tasks. Four categories were involved in the stimulus set (dog, cat, car and boat). Two of those (dog and car) formed the target set for the detection tasks while the remaining two formed the non-target set. The detection task involved 10 greyscale real-life photos in each category, totalling 40 photos. Participants were seated approximately 40cm in front of a 15.4" Macbook Pro. Each task was cued explicitly with a line drawing (measured approximately 5.5cm x 4.2cm), presented centrally on the screen against a grey background before the onset of stimulus presentation. Each stimulus consisted of paired photos (each measured approximately 4.5cm x 4cm) chosen randomly from the target and the non-target sets (e.g. a dog photo paired with a boat), but never from the same category (e.g. there were never two dog photos). The two photos were presented centrally in a white rectangular frame measuring 10.5cm x 5.3cm. There were four trials after each cue. A smaller version of the cue (approximately 3.5cm x 2.7cm) was shown throughout the run, and was placed above the rectangular frame. Participants were instructed to respond to the stimulus by pressing the spacebar whenever the stimulus contained a task-relevant target, and to withhold the response if no target was detected. The spacebar was marked with a green sticker for saliency. This procedure is similar to a Go/No-Go task as the non-target signalled

‘No-Go’ and the target signalled ‘Go’. There were two conditions in this experiment, a pure task condition (2 blocks, 40 trials each) and a mixed task condition (2 blocks, 40 trials each).

An auditory feedback with a cash register ‘kerching’ sound lasting 300ms at 32,000Hz, and at approximately 45dB was played through closed-back headphones when the participant made a correct positive or a correct nonresponse during the testing session. The feedback was immediate for correct positive response, and 3700ms after the stimulus onset for a correct nonresponse.

Procedure

All testing was implemented using Matlab R2014b and Psychophysic Toolbox extensions (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). The experiment was divided into three parts—a demonstration session, a practice session and the testing session. The demonstration and the testing sessions were conducted with Microsoft PowerPoint. Neither the demonstration nor the training sessions were timed, in order to allow opportunities for explanation and correction. There were 8 trials each for the demonstration and practice sessions, with 4 consecutive trials of the dog game and 4 consecutive trials of the car game. The presentation sequence in the demonstration and practice trials was pre-determined and the stimuli came from the actual stimulus set. Children were told that they were going to play a game that involved looking for certain items—whenever they saw a drawing of a dog/or car (task cue), they would be playing the dog/or car detection game. On each trial, the child was instructed to press the button if they saw a target photo, and to withhold their response if no target was present. The experimenter was free to clarify the task rules as much as possible during the demonstration phase. At the end of the demonstration the experimenter queried the child about the rules. During the practice session, the experimenter gave additional verbal prompts at cue onsets (‘This is a dog/car game’) and on each trial (‘If you see a dog/car, press the button.’). During practice, the experimenter could also repeat the trial if the child made an error.

The experiment consisted of four blocks. The first two blocks were pure blocks, consisting of one task in each block (e.g. one block of the dog game and one block of the car game), counterbalanced across participants. The final two blocks were mixed blocks, which involved switching between the car and dog games every four trials (Figure 1).



Figure 1. Order of trial-type blocks

Simple auditory feedback was given for correct positive responses and correct nonresponses. A task cue was presented every four trials in both pure and mixed blocks. The test phase consisted of 160 trials equally spread across the blocks separated by a motivation screen to allow for a rest-break if needed. Targets appeared in 60% of the trials in both conditions. The task switched every four trials in the mixed block: the trials preceded by a task cue in the mixed block were *switch trials* (switching to a different task from the previous trial), and the trials not preceded by a task-cue were *repetition trial* (repeating the same task as the previous trial). Sixty percent of the switch trials in the mixed condition were target-positive. Children saw the cue for 3000ms, followed by a 1000ms cue-stimulus-interval (CSI) showing a fixation cross. A stimulus appeared in the centre of the screen and remained until a response was made or timed out after 4000ms. The inter-stimulus interval (ISI) and response-cue-interval (RCI) varied depending on the response—for a correct response, the interval was 1000ms; for an incorrect response, the interval was 2500ms to allow a recovery period. A fixation cross was shown during the ISI and RCI. A 300ms auditory feedback sound was given for a correct answer (immediately after a correct positive response, or 3700ms after the stimulus onset for a correct nonresponse). Figure 2 illustrates the experimental procedure.

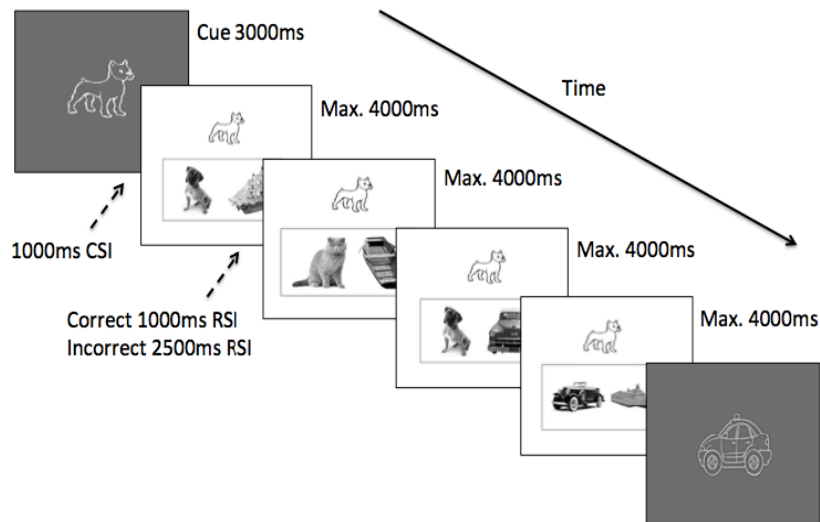


Figure 2. Experimental design in the mixed condition. CSI: Cue-stimulus interval, RST: Response-stimulus interval.

Results

Both reaction time and accuracy were measured in this study. A series of analyses of variance (ANOVAs) were carried out to determine the between-subject effect of Age and Gender, and the within-subject effects of Task Conditions (pure vs. mixed condition), and Trial Types (switch trial vs. repetition trials). The first four trials in each block were excluded from the final data since they do not correspond well to a specific task condition or trial types (i.e. the first trial in the mixed condition was not a switch trial; and the repetition trials in the mixed condition can be executed without conferring to multiple task rules). Only correct positive responses were included in the RT analyses. Trials with an RT of less than 300ms were considered as anticipatory errors and were therefore excluded, and the response window was capped at the onset of the auditory feedback (3700ms after the stimulus). The current study made no assumption about the distribution of the RT samples for each participant. Instead, the mean RTs of each participant were obtained by resampling the RT data for 5000 times to bypass the distribution problems (Bollen & Stinet, 1990). The case for adopting a bootstrap method is

particularly valid with the limited RT samples as in the current experiment (Mean number of RT samples ranged from 9.95 to 30.38 depending on the condition). The alpha level was set at .05 across all planned comparisons. Unless reported otherwise, all main effects of Age in the analyses reported below were significant at $p < .01$ level.

When testing such young children, there will always be participants who do not adhere to task instructions, for whatever reasons. Rather than choosing a pre-defined fixed level of performance as a cut off, we now adopt a cumulative probability method that allows the group to determine what the level of acceptable performance is by aiming to include ~95% of the participants. The level is set at 70% accuracy threshold in terms of a group-level performance. In our sample, 94% of participants reached this level of performance (Mean accuracy=90.09%, SD=12.88%). The cumulative probability method allows us to exclude participants with extreme performance while also letting the sample determine what the representative level of performance is. This resulted in the exclusion of seven 4-year-olds, leaving data from 27 four-year-olds (Male=15), 26 six-year-olds (Male=15), and 22 adults (Male=8) for the analyses.

General Accuracy and RT on overall performance

Gender and Age were entered as between-subject factors for the analyses of variance on Accuracy and RT. The main effect of Age was significant for both Accuracy ($F(2,69)=82.86$ $p < .001$) and RT ($F(2,69)=9.07$, $p < .001$). All age groups achieved high accuracy, but older participants were both more accurate and faster than younger participants (4-year-olds: Mean(SE)=89.5(1.6)%, 1552(48)ms; 6-year-olds: Mean(SE)=93.3 (1.4)%, 1211(49)ms; adults: Mean(SE)=98.0(0.4)%, 734(33)ms). There was no main effect of Gender on RT ($p > .600$), or Accuracy ($p > .070$); nor was there an interaction between Age and Gender ($p > .400$).

Mixing Cost

The mixing cost was determined by comparing performance on the trials not preceded by the task cue in the pure condition, to the repetition trials in the mixed condition. As shown in Figure 3, RT was longer and error rates were higher in the mixed condition than in the pure condition across all age groups. Two separate repeated ANOVAs were carried out on RT and Accuracy, with Age (4-year-olds, 6-year-olds and adult) as the between-subject factor and Condition (pure vs. mixed) as the within-subject factor. This revealed a significant effect of Condition on both RT ($F_{RT}(1,72)=14.99$, $p<.001$, $\eta^2=.172$) and Accuracy ($F_{ACCU}(1,72)=14.98$, $p<.001$, $\eta^2=.172$), indicating global mixing costs on both RT ($M_{pure}(SE)=1127(44)$ ms; $M_{mixed}(SE)=1214(47)$ ms) and on Accuracy ($M_{pure}(SE)=94.94(.71)$ %; $M_{mixed}(SE)=91.62(1.11)$ %). There was a marginally significant Age by Condition interaction on Accuracy ($F_{ACCU}(2,72)=2.92$, $p=.060$, $\eta^2=.075$), but not on RT ($p>.300$). Further analyses revealed that the effect of Condition on Accuracy was significant for 4-year-olds ($F_{ACCU}(1,23)=7.54$, $p<.020$, $\eta^2=.247$), and 6-year-olds ($F_{ACCU}(1,25)=8.4$, $p<.010$, $\eta^2=.251$), but not adults, $p>.300$.

We also examined the types of errors contributing to the lower accuracy in the mixed condition. Due to the low number of error trials, non-parametric Wilcoxon Signed-Rank tests for each age group were conducted to examine the number of omission errors (missing targets) and commission errors (false alarm). Adults were excluded from the analyses as there was a large number of ties (>10). Four-year-olds and six-year-olds did not exhibit significant differences in omission error between pure and mixed conditions ($ps>.100$). In contrast, the commission errors were significantly greater in mixed condition than in pure condition for 4-year-olds ($Mdn_{pure}=1$, $Mdn_{mixed}=5$, $Z=-2.70$, $p<.007$), and 6-year-olds ($Mdn_{pure}=1.5$, $Mdn_{mixed}=2$, $Z=-2.703$, $p<.007$).

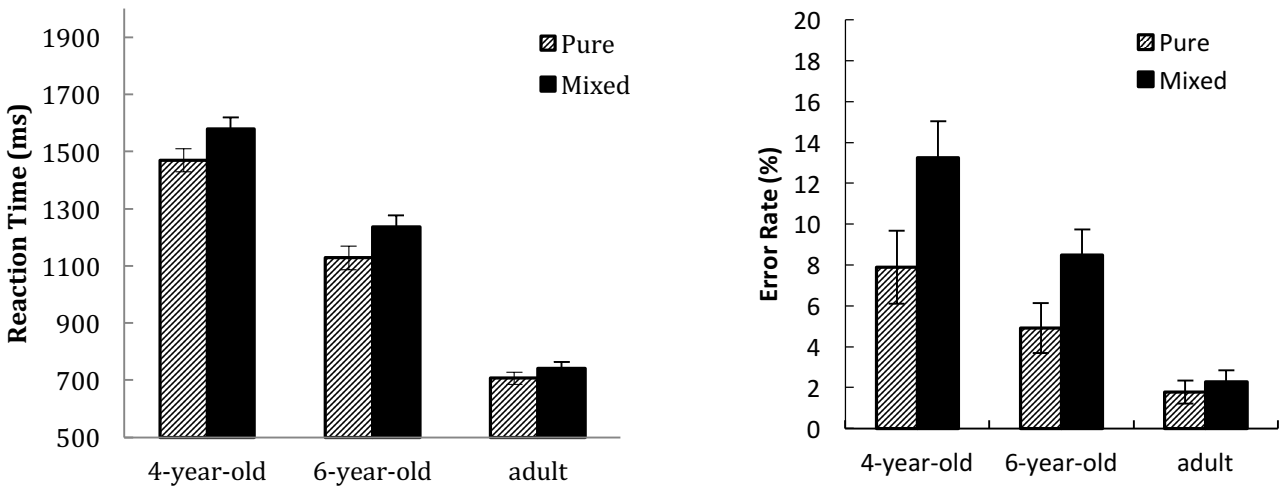


Figure 3. Mixing Cost: Left Panel—reaction time in the Pure condition and the Mixed condition in different age groups; Right Panel—error rates in the Pure and the Mixed conditions. All error bars denote within-subject 95% confidence intervals of means (Cousineau, 2005).

Switch Cost

Switch trials and Repetition trials in the mixed condition were entered into the analyses. RTs were longer on the switch trials across all age groups, but the accuracy rates were comparable across trial types (Figure 4). Two separate repeated ANOVAs were carried out on RT and Accuracy, with Age (4-year-olds, 6-year-olds and adult) as a between-subject factor and Trial Types (repetition vs. switch) as a within-subject factor. The participants were significantly slower on Switch Trials than on Repetition Trials ($F_{RT}(1, 72)=20.59, p<.001, \eta^2=.222$), indicating a local switch cost on RT ($M_{rep.}(SE)=1214(47)ms; M_{swi.}(SE)=1341(58)ms$). But no significant difference between Trial Types was found on Accuracy ($p>.500$). The Age X Trial Type interaction was not significant on either RT ($p=.089$) or Accuracy ($p>.500$).

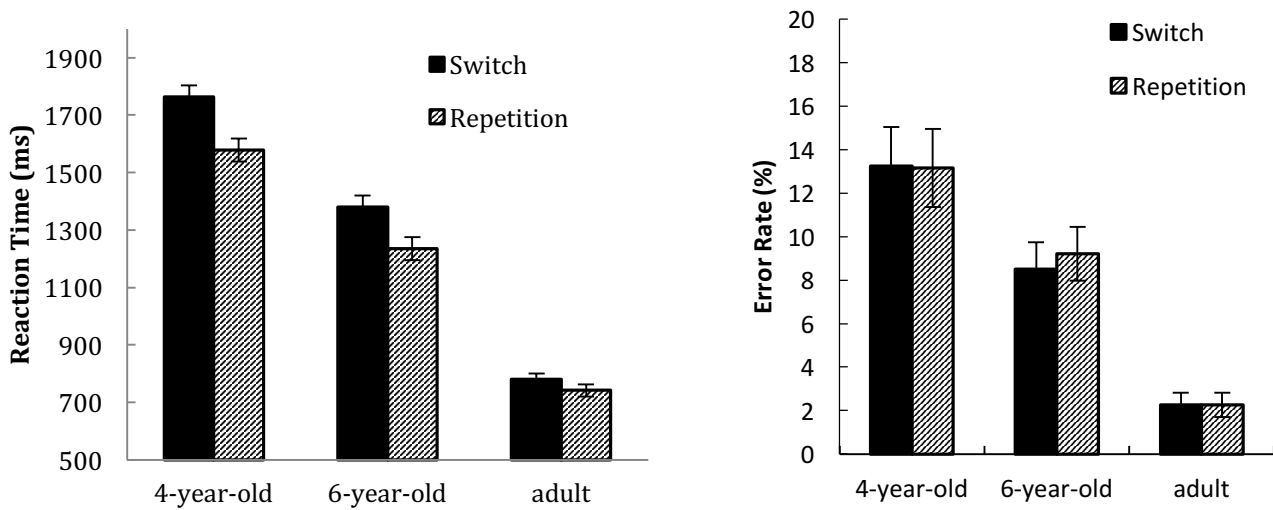


Figure 4. Switch Cost: Left Panel—reaction time in the Repetition Trials and the Switch Trials in different age groups; Right Panel—error rates in Repetition Trials and Switch Trials. All error bars denote within-subject 95% confidence intervals of means (Cousineau, 2005).

Response Repetition Effect

Only trials that were not preceded by a task-cue were included in the analyses of response repetition effect. The participants were quicker at making a response when it was preceded by a response than when preceded by a nonresponse (Figure 5). A repeated ANOVA was carried out with Age (4-year-olds, 6-year-olds and adult) as a between-subject factor, and Trial Type (single response vs. repeated response) and Condition (pure vs. mixed) as within-subject factors. The overall ANOVA revealed a significant main effect of Trial Type ($F(1,72)=42.32, p<.001, \eta^2=.370$) and Condition ($F(1,72)=10.53, p<.002, \eta^2=.128$). Younger children experienced a greater response repetition effect than adults (Trial Type X Age: $F(2,72)=4.26, p<.020, \eta^2=.106$). Follow-up analyses revealed that both 4-year-olds and 6-year-olds experienced a significant response repetition effect ($ps<.001, \eta^2 >.400$), but not adults ($p>.050$). There was an interaction of Trial Type X Condition ($F(2,72)=23.41, p<.001, \eta^2=.245$). No three-way interaction was found ($p>.100$).

The Trial Type X Condition interaction was further explored using one-way ANOVAs separated by Trial Type, with Condition as the within-subject factor. These analyses revealed that the

effect of Condition (pure vs. mixed) was only evident in the single response trials ($F(1, 74)=33.51$, $p<.001$, $\eta^2=.312$), but not in the repeated response trials ($p>.600$). This finding suggests that RT mixing costs might be largely attributable to RT increase in the single-response trials in the mixed condition, but not in the repeated-response trials, and the pattern was similar across all ages.

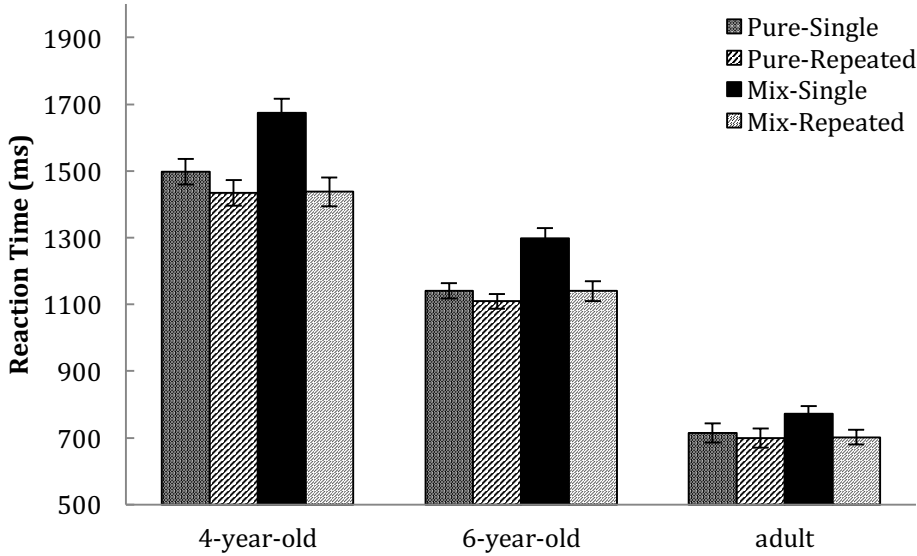


Figure 5. Response Repetition Effect in the Pure and Mixed condition: Single Response vs. Repeated Response. Error bars represent within-subject 95% confidence intervals of means in Pure and Mixed condition (Cousineau, 2005).

Discussion

The current study has investigated developmental differences in processing costs using a task-switching paradigm with a child-friendly novel design similar to a Go/No-Go detection task. The task yielded high accuracy rates— with 27 out of 34 in the youngest group achieving a mean accuracy score of 89.5% or above. The task was therefore suitable for measuring both RT and accuracy scores in children as young as 4 years of age, as well as adults. Having established the age-appropriateness of the experimental design, the current study investigated the impact of age on mixing cost, switch cost and response-repetition.

Both children and adults were slower in the mixed-task condition than in the pure-task condition. However, age did not interact with RT mixing costs, suggesting that RT mixing costs do not load heavily on cognitive control components known to develop across this age range (e.g. working memory). Instead, the current study provides support for the view that RT mixing costs reflect some elements of the *selection* processes involved in multitasking. In the current study, the task attributes are easily separable (i.e. the targets were not compound stimuli); consequently, there was a reduced demand on selective attention. In this context, we found that preschool children did not find it harder to manage two tasks than adults, at least in terms of RT costs related to switching between tasks. It thus appears that the efficiency in dealing with multiple tasks and the ability to attend selectively to simple task attributes are present in the preschool years, particularly when the tasks and stimuli are age-appropriate. This finding is comparable to Dibbets and Jolles's (2006) study, in which a child-friendly version of a task-switching experiment also found no age effect on RT mixing costs (from 4 to 13 years old). These findings raise some questions about the developmental effect on mixing costs reported in other studies (e.g. Cepeda, Kramer, & Gonzalez de Sather, 2001; Davidson, Amso, Anderson, & Diamond, 2006). In particular, it is unclear if the developmental effect on mixing costs reflect developmental differences in cognitive control, or instead, reflects experience-dependent

understanding of task structures and stimulus/response attributes, and/or the efficiency in translating stimulus into response execution (c.f. Ridderinkhof, van der Molen, Band, & Bashore, 1997).

Interestingly, the RT mixing cost was evident only when the response was not repeated in the previous trial. Thus, it appears that a primed stimulus-response mapping could be effective in overriding the need for selection processes to resolve the stimulus ambiguity. While the pattern of response repetition facilitation was evident across all ages, our analysis showed that preschool children experienced a greater response repetition effect than adults. One possible explanation for this may be that preschool children are more likely than adults to resort to the ‘fast selection strategy’ primed by the N-1 trial. In line with this interpretation, Mayr (2001) showed that age was an important mediator in the effect size of response repetition, with older adults exhibiting a larger response repetition facilitation than young adults. This result may simply be explained by two different types of selection—(a) a fast selection bypassing many inhibitory processes, and rely on processing primed or familiar information, and (b) a slower sequential selection where inhibitory processes act on each stage of selective attention (e.g. inhibition of return to the previously disengaged object and location, inhibition of the alternative task-set, and inhibition of N-1 response). Fast selection is less taxing on the attention system and can be applied reactively even when the task-representation is weak. Due to certain inhibition deficit, older adults may opt for the fast selection when the situation allows (e.g. on task repetition trials). A similar phenomenon may exist among preschool children as well, such that preschool children are more likely to resort to fast selection, whereas young adults are less likely to adopt the fast selection strategy when the stimulus is ambiguous.

Although there was no age interaction effect on RT mixing costs, a moderate age interaction effect was found for accuracy mixing costs. Specifically, 4- and 6-year-olds made more commission errors in the mixed condition than in the pure condition. If the poorer performance in the mixed condition was due to working memory demands, such that the children had difficulties in maintaining the relevant goal state, then we would expect an increase in both omission and commission errors.

Instead, the increase in commission errors alone indicates that the reason behind the errors is due to 4- and 6-year-olds' failure to endogenously inhibit responses to task-irrelevant attributes. The poorer inhibition is also consistent with the larger response repetition effect among preschool children than adults. Goschke (2000) argued that the level of response inhibition in proportion to the risk of perseverative responses (also see Grzyb & Hübner, 2013). While this strategic proportional inhibition-to-conflict task strategy might be well practiced by adults, it might not be robustly employed by children. Overall our results suggest that attentional selectivity and inhibition are dissociable components. Although preschool children may be equipped with the requisite attentional selectivity and perform well in multi-task condition, they experienced both greater facilitation and interference from the primed associations, as exhibited in the greater response repetition effect and commission errors.

The RT switch costs were also evident across all age groups, replicating previous findings that switching to another task-set produces reliable RT costs even when allowing a generous preparation time for the upcoming task. Switch costs have generally been taken to reflect additional cognitive processes in task-set reconfiguration (Meiran, 2000; Rogers & Monsell, 1995; Rubinstein et al., 2001), and in development, to other general endogenous factors such as the ability to reflect on changing situations and to inhibit prepotent representations (Cepeda et al., 2001; Diamond et al., 2005). We therefore predicted that preschool children would experience greater switch costs than adults. Contrary to our prediction, we found no age interaction with the RT and accuracy switch costs, indicating that switch costs are not a sensitive measurement of the development of cognitive control. Children as young as 4 years old were effective at preparing for the alternative task prior to the stimulus onset, incurring no cost in accuracy on switch trials as compared to the repetition trials.

Perhaps the combination of a long preparation window, high target discriminability and the overall task simplicity allowed any potential developmental effects to be minimised. However, other studies using more 'traditional' task design and stimuli have also failed to find an age interaction with

switch costs (e.g. color/shape task with participants aged 7 to adults [Exp. 1], Ellefson, Shapiro, & Chater, 2006). It seems likely that switch costs are more sensitive to other factors such as the carry-over effect from pre-switch trials, in which the inhibition of the task-set (e.g Mayr & Keele, 2000) and/or the activation of the N-1 task/stimulus has lingered into the switch trial (Allport et al., 1994). That said, our study demonstrates that young children can clearly switch between different goal states given an age appropriate task and context. The developmental differences in switch costs observed in other studies may reflect differences in carry-over effects rather than the ability to shift between mindsets.

Overall, the current study has found that 4- to 6-year-olds exhibit mixing costs and switch costs in very similar ways to adults. The lack of an age interaction effect on switch costs indicates that children as young as 4 were able to prepare for the task set prior to stimulus onset; while the absence of an age interaction effect on RT mixing costs suggests that, given the current design, children experienced a similar amount of stimulus ambiguity as adults. In sum, the attentional control necessary to perform at least two tasks and to switch between tasks is present in preschool children. Although the attention flexibility in switching between tasks is largely present at the age of 4, there are still developmental differences uncovered in the current study. Younger children appeared to have greater difficulty in inhibiting a prepotent response that resulted in an increase in commission errors in the mixed condition; relatedly, they also experienced greater response repetition facilitation, possibly due to the lack of inhibitory processes on the response repetition trials.

The primary aim of the current study was to investigate the extent to which preschool children exhibit cognitive and attentional flexibility in a multitask context, and whether this flexibility, if present, reflects global mechanisms associated with task-switching and task maintenance, or rather, reflects other task-specific factors such as the types of stimulus attributes and the ease of translating perceptual information into response selection, as well as general novelty. Since the current study found no age interaction effects on either mixing costs or switch costs, it is likely that previous reports

of age interaction effects reflect other processes specific to each task context. The range of attentional and cognitive processes in different task-switching studies is greatly variable, and therefore the cognitive demand to switch task and to multitask can differ greatly between experiments and between age groups. However, by focusing on the most demanding type of task for preschool children (e.g. those that involve novel situation, high working memory and inhibitory demand, and complex stimulus-response translations), preschool children's attentional control may be underappreciated. In all, our study suggests that a task-switching paradigm itself is insufficient to uncover developmental differences in attentional control, and more detailed specifications of processing cost beyond a general measurement of mixing costs and switch costs are needed to understand developmental differences in cognitive control using task-switching procedures.

While the current study was inspired by task-switching studies in the adult literature, it made some major modifications to the experimental design. Most notably, the task took the form of Go/No-Go with a single response, rather than the typical two-button choice task. One may argue that changing the nature of stimulus-response mappings could have a dramatic effect on task conflicts, and therefore masking the developmental differences in cognitive controls in dealing with these task conflicts. It is well known that younger children are poorer at overcoming prepotent responses (e.g. Ridderinkhof, van der Molen, Band, & Bashore, 1997; Simpson et al., 2012; Wright & Diamond, 2014). Stimulus-response conflicts are often inherent in the task-switching paradigm as most studies employed choice tasks with bivalent response sets. At least one adult task-switching study employed Go-NoGo similar to the current study and found sizeable switch costs (Schuch & Koch, 2003). It was also found that switch costs were dependent on the response execution of the N-1 trial, where a response was necessary to elicit switch costs. Nonetheless, both choice and Go-NoGo designs show a consistent pattern of processing costs. When the level of task difficulty and conflicts are aligned across age groups, there is no strong reason to believe that an age effect on mixing costs and switch costs, if present, would be affected by the decision to adopt Go-NoGo or choice tasks.

In summary, the current study found that preschool children were no worse than adults at attentional flexibility when switching between two task goals. When focusing on RT measures, we found that preschool children did not exhibit greater difficulty at multitasking, nor at moment-to-moment shifts between two different task goals, when the tasks and stimuli were age-appropriate. Our findings suggest that the age effects reported in cognitive flexibility may derive from resolving task conflicts and/or differences in age-related familiarity with the stimuli and the testing context, rather than difficulties in task switching per se.

Declaration of Interest

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

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