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# REPORT

# Switching between tasks and responses: a developmental study

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## Abstract

*Task switching requires the ability to flexibly switch between task rules and responses, and is sensitive to developmental change. We tested the hypothesis that developmental changes in task switch performance are associated with changes in the facilitating or interfering effect of the previously retrieved stimulus–response (S–R) association. Three age groups (7–8-year-olds, 10–12-year-olds and 20–25-year-olds) performed a two-choice reaction time (RT) task in which spatially compatible or incompatible responses were required. The RT costs associated with switching between tasks were larger when responses were repeated than when responses were alternated. Younger children showed a greater cost than adults when switching between tasks but repeating responses. This age difference decreased when the interval between the previous response and the upcoming stimulus increased. Switch costs were larger when switching to the compatible task than to the incompatible task, but this effect did not differ between age groups. These findings suggest that young children build up stronger transient associations between task sets and response sets, which interfere with their ability to switch to currently intended actions. A similar pattern has previously been observed for older adults (Mayr, 2001), suggesting a common contributor to task switching deficits across the life span.*

## Introduction

With age, children gain an increased capacity for behavioral inhibition and mental flexibility, as is evident from improvements in the ability to shift back and forth between multiple tasks (e.g. Diamond, 2002; Luciana & Nelson, 1998; Zelazo, Craik & Booth, 2004). This behavioral pattern is often associated with the maturation of the prefrontal region of the brain (e.g. Bunge, Dudukovic, Thomason, Vaidya & Gabrieli, 2002; Casey, Davidson, Hara, Thomas, Martinez, Galvan, Halperin, Rodriguez-Aranda & Tottenham, 2004), an area critical for the ability to control multiple task meanings (e.g. Brass, Ruge, Meiran, Rubin, Koch, Zysset, Prinz & von Cramon, 2003; Crone, Wendelken, Donohue & Bunge, 2005). The ability to flexibly switch between task demands has been extensively studied using the task switching paradigm, in which participants rapidly switch between two or more reaction-time (RT) tasks that are typically performed on the same set of stimuli (e.g. switching between color discriminations or shape discriminations). Activating the relevant 'task set', or the ability to select the appropriate rules for subsequent behavior, is a complex function that most likely requires multiple processes, including task rule retrieval (Mayr & Kliegl, 2000) and overriding the previously relevant stimulus–response (S–R) association (Meiran, 1996).

Switching between tasks is associated with a sizeable decrement in performance. Two types of switch-related performance decrements have been characterized: mixing costs and switch costs. Mixing costs refer to the increase in RT associated with performance of a mixed task block versus a single task block (e.g. Los, 1996). Switch costs refer to the difference in RTs when switching between tasks versus repeating tasks within a mixed task block (e.g. Meiran, 1996). Several developmental studies have reported that switch costs as well as mixing costs decrease as children grow older (e.g. Cepeda, Kramer & Gonzalez de Sather, 2001), but the processes underlying this trajectory remain unclear (Kray, Eber & Lindenberger, 2004).

Different task components of the switching paradigm can be investigated by manipulating the delay between consecutive trials, or between the task cue and the target trials. These manipulations can inform us as to whether performance deficits are associated with an inability to

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inhibit the previous task set (i.e. overriding the previously relevant S–R rule), or with difficulty activating the upcoming task set (i.e. rule retrieval). In a life-span study, Cepeda *et al.* (2001) manipulated the response–cue interval (RCI) and the cue–target interval (CTI) to examine whether age-related differences in task switch performance could be explained by age-related changes in 'passive' previous-task dissipation during the response–cue interval or 'active' upcoming-task preparation during the cue–target interval (Meiran, 2000; Monsell, 2003). Cepeda *et al.*'s results showed that the benefit of increasing the cue–target interval was similar for all age groups. In contrast, increasing the response–cue interval resulted in a decrease in switch costs for young adults, but not for children. These results were interpreted to suggest that younger children experience more interference from the previous S–R association, suggesting larger carry-over effects from the previous trial.

If children have difficulty overriding the previous S–R association, then the literature on 'sequential effects' may be particularly relevant for assessing switching ability in children (Kerr, Davidson, Nelson & Haley, 1982; Smulders, Notebaert, Meijer, Crone, van der Molen & Soetens, 2005). Sequential effects are changes in response speed due to the sequence of preceding tasks and responses. When a task is repeated, individuals benefit from response repetition if the response–stimulus interval (RSI) is short; this phenomenon is described as 'automatic facilitation' (Soetens, Boer & Hueting, 1985). The process of automatic facilitation reflects carry-over effects from the previous S–R association. Smulders *et al.* (2005) showed that automatic facilitation is larger in young children, providing evidence for the hypothesis that carry-over effects from the S–R association are larger in younger children.

Sequential analyses in the task-switching literature have revealed an interesting phenomenon related to carry-over effects of the previous trial. When switching between tasks, individuals show larger switch costs when repeating responses, a phenomenon that is referred to as the 'reversed repetition effect'. Although the precise mechanism underlying this reversed effect is still under debate (e.g. Kleinsorge & Heuer, 1999; Meiran & Gottler, 2001; Rogers & Monsell, 1995), researchers agree that this effect is most likely associated with the same mechanisms that underlie automatic facilitation, and hence with carry-over effects from the previous S–R association. Given that children show increased sensitivity to carry-over effects from the previous S–R association in a single task (Smulders *et al.*, 2005), we hypothesized that this increased sensitivity would also account for developmental changes in task switching.

The goal of the current study was therefore to test whether switch costs (related to switching between *tasks*) would be enlarged for children compared to adults when repeating responses versus switching responses. Previous studies have suggested that adult levels of performance are reached around the age of 12 (Cepeda *et al.*, 2001). However, task switching is complex, and most likely depends on several cognitive processes that may rely on different neural mechanisms (see Crone *et al.*, 2005). Therefore, different mechanisms may affect task-switch performance at different ages. To get a more precise index of the developmental trajectory of task switching, we included children of two age groups, 7–8 years and 10–12 years, and we compared these age groups with adults.

All participants performed a task in which they had to respond to two different task rules requiring a left- or right-hand response. This design allowed us to compare switch costs (decrement in RT due to switching between tasks) for trials on which responses were repeated against trials on which responses were switched. Specifically, reversed repetition costs were examined by comparing the time required to perform a task switch when the response differed from that on trial *N*-1 (task switch, response switch) with the time needed to complete a task switch when the response on trial *N* and trials *N*-1 were the same (task switch, response repetition). We expected based on prior studies (e.g. Rogers & Monsell, 1995) that all age groups would exhibit reversed repetition costs, but that these effects would be magnified in children (Kerr *et al.*, 1982; Smulders *et al.*, 2005; Soetens & Hueting, 1992).

Two further manipulations were added. First, response–stimulus interval (RSI) is known to affect switch costs (Rogers & Monsell, 1995) as well as response repetition benefits (Soetens *et al.*, 1985), and therefore can be expected to affect reversed repetition effects in children as well. Therefore RSI was manipulated at three levels (50 ms, 500 ms and 1250 ms). The target itself designated the new task, excluding the influence of advance preparation (see also Van Asselen & Ridderinkhof, 2000). If children are more influenced by carry-over effects from the previous stimulus–response association (Cepeda *et al.*, 2001), then children should show a larger reversed repetition effect especially for trials on which the RSI was short (Kerr *et al.*, 1982; Soetens & Hueting, 1992).

Second, we examined if developmental differences in task switching can be explained by children's difficulties inhibiting the previous task set. Switch costs are usually larger when individuals need to switch to the stronger (more dominant) task than to a weaker task. Allport, Styles and Hsieh (1994) argued that extra inhibition of the stronger task set is required to enable performance of the weaker task set, and therefore inhibition carries over to the next trial. To examine the influence of carried-over inhibition, we included tasks with different stimulus–response mapping strength (compatible and incompatible responses). Switch costs were expected to be larger for spatially compatible responses than for incompatible responses (cf. De Jong, 1995).

In the developmental literature, developmental changes in cognitive control are often interpreted in terms of changes in inhibitory control (e.g. Diamond, 2002; Kirkham, Cruess & Diamond, 2003). Thus, a possible interpretation of children's increased switch costs is that they are associated with a failure to inhibit the previously activated task set (or a failure to inhibit the previously activated rule). If developmental differences in switch costs are associated with a failure to inhibit the previous task rule, then there should be no developmental differences between switch costs for response repetitions and response switches. A second way of testing the task set inhibition hypothesis is by comparing age differences in switch costs to compatible and incompatible trials. If increased switch costs for young children result from age differences in the ability to inhibit a prior task set (cf. Diamond, 2002), then age differences in switch costs should be modulated by S–R compatibility (i.e. the carry-over effect of the previously relevant task rule).

Finally, we examined age differences in mixing costs by complementing the switching paradigm (Meiran, 1996) with the measurement of a non-switch baseline (Kray *et al.*, 2004). The goal was to assess control components that were specifically related to the switch situation and control components related to the dual-task situation in general. In single-task blocks, participants performed either the compatible S–R task or the incompatible S–R task. Costs of mixing were determined by computing the differences in reaction times between task repetitions in the mixed task and task repetitions in the single task and were termed mixing costs (Los, 1996). We predicted that mixing costs would be more pronounced for compatible than incompatible S–R relations (Los, 1996; Stoffels, 1996) and young children were expected to show more pronounced mixing costs than adults (Kray *et al.*, 2004, but see Span, 2002).

Taken together, the goals of this study were to use several task manipulations to explore the cognitive processes over childhood that enable flexible task-switching.

## Method

### Participants

Three age groups participated in the study: 22 children between 7 and 8 years of age (*M* = 8.0, SD = .50, 10 female), 23 children between 10 and 12 years of age (*M* = 11.2, SD = .49, 11 female), and 21 university students aged between 20 and 25 years (*M* = 22.8, SD = .47, 14 female).

Children were recruited by contacting schools in the greater Amsterdam area, and were selected with the help of their teacher. Their primary caregiver signed a consent letter for participation. All children had average or above-average intelligence, based on teachers' report. An effort was made to match groups on IQ and gender as closely as possible. SES levels were not obtained, but children were recruited from middle-class background. Adults were recruited from the University of Amsterdam through flyers and received credit points for their participation. All participants reported to be in good health and having normal or corrected-to-normal vision.

### Stimuli and apparatus

Stimuli consisted of the characters 'O' or '▲', which were approximately 3 cm wide and 3 cm high, displayed in red or green on a white background, presented in random order and with equal probability, 3 cm to the left or right of a black vertical fixation line (6 cm in length) on a 15-inch computer monitor. Participants were instructed to respond to two types of stimuli. To facilitate discrimination, the two stimuli differed in both shape and color. Participants viewed the monitor from a distance of 60–75 cm, resulting in a between-stimulus horizontal visual angle of 1° to 1.15°. To one stimulus, the subject had to respond with a spatially compatible response (e.g. left to left). To the other stimulus, the subject responded with the spatially incompatible response (e.g. left to right). Thus, the color and shape redundantly cued the compatible or incompatible position-to-response mapping. The left key 'z' was operated with the left index finger in response to stimuli presented to the left of the fixation line and the right key '/' was operated with the right index finger for stimuli presented to the right of fixation. This mapping was reversed for stimuli in the incompatible conditions.

Across participants within a group, the four combinations of stimulus attribute and their assignment to compatible/incompatible were used with as near equal frequency as possible. Figure 1 shows a schematic of the task sequences.

### Procedure

First, a practice block of 50 trials was presented, in which the participants responded to compatible trials with 500-ms RSIs. The experimental task consisted of 20 blocks of 105 trials. The first five trials of each block were considered 'warm-up' trials and were excluded from analysis. The stimulus disappeared immediately following the response, and the response initiated the RSI. RSIs were fixed at 50, 500 or 1250 ms.

Participants completed four of each of the following five types of blocks: pure blocks of compatible trials

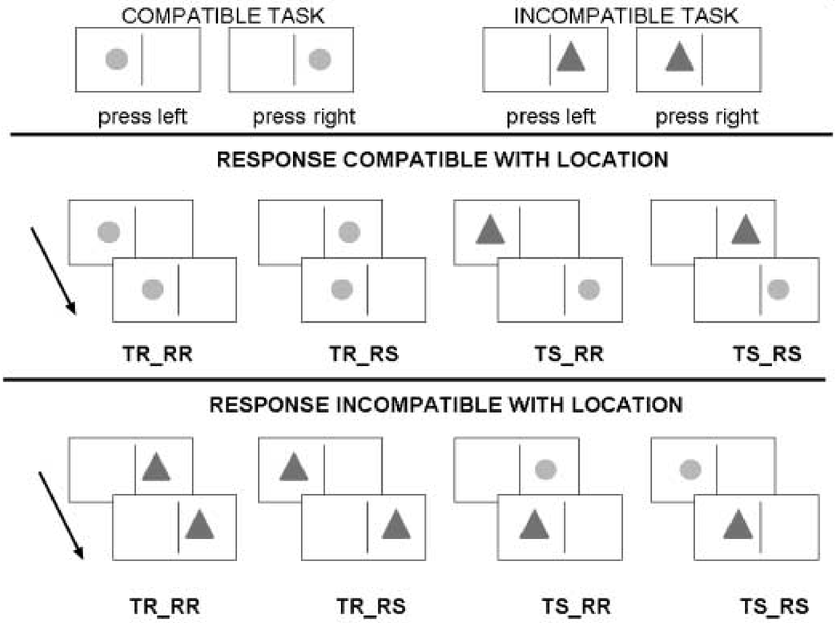

**Figure 1** *Schematic of task conditions and trial sequences. TR = Task Repetition, TS = Task Switch, RR= Response Repetition, RS = Response Switch.*

with RSIs of 500 ms, pure blocks of incompatible trials with RSIs of 500 ms, four switch blocks with RSIs of 50 ms, switch blocks with RSIs of 500 ms and switch blocks with RSIs of 1250 ms. The four blocks of each task were performed sequentially, and the order of task blocks varied across participants. All participants were tested individually in a quiet laboratory or classroom. Including instructions and breaks, participants spent approximately one hour in the laboratory or classroom.

## Results

### *Switch costs*

Trials with excessively short RTs (<100 ms), error trials and trials immediately following an error were excluded from RT analysis. All reported analyses were reiterated with RTs transformed to their natural logarithm to reduce the differences of baseline differences in performance between age groups (Meiran, 1996). All reported analyses remained significant when the data were reanalysed according to this procedure.

### Response latencies

The first set of ANOVAs focused on switching in the separate switch blocks. The 'Task Switch' effect corresponded to the difference in RT on task switch trials in comparison to trials on which the same task was performed as on the previous trial. Similarly, 'Response Switch' corresponded to the difference in RT between trials on which the response alternated relative to the preceding trial compared to trials on which the same response was repeated. The difference in RT between spatially compatible and incompatible responses was examined by 'Stimulus–Response (S–R) Compatibility'. Finally, 'RSI' referred to the differences in RT when trials were presented within blocks of 50-ms RSI, 500-ms RSI and 1250-ms RSI. These factors were submitted to mixed model ANOVAs with Age Group (3) as a between-subjects variable, and Task Switch (2), Response Switch (2), S–R Compatibility (2), and RSI (3) as within-subjects variables.

The ANOVA on median RTs revealed main effects of Age Group, $F(2, 60) = 52.54$, $p < .001$, and Task Switch, $F(1, 60) = 225.42$, $p < .001$. A two-way interaction between Age Group and Task Switch, $F(2, 60) = 24.54$, $p < .001$, showed that switch costs decreased with age (237 ms for youngest children, 129 ms for older children, 72 ms for adults; differences between sequential age groups significant). A three-way interaction between RSI, Task Switch and Age, $F(4, 120) = 3.13$, $p < .05$, was followed up by post-hoc ANOVAs showing that Age × Task Switch interactions were significant for all RSIs (all $p$s $< .001$), but the increase in switch costs due to shorter RSIs was larger for young children than for older children and adults (see Figure 2, upper panel).

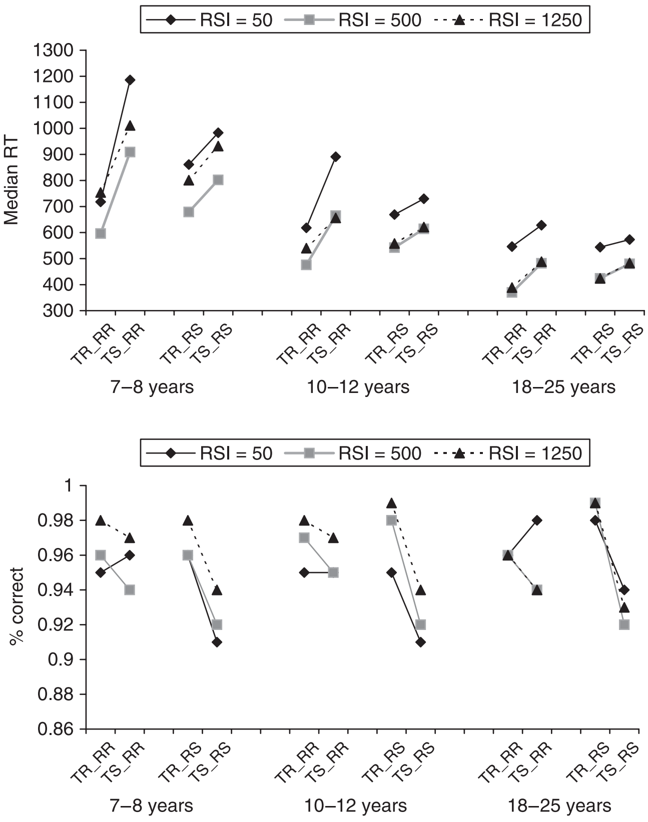

**Figure 2** *Switch costs: Response latencies (upper panel) and accuracy (lower panel) for response and task sequences for three age groups for three Response–Stimulus Intervals (RSI). TR = Task Repetition, TS = Task Switch, RR = Response Repetition, RS = Response Switch.*

As expected, there was a significant interaction between Task Switch and Response Switch, $F(1, 60) = 96.38$, $p < .001$, showing that switch costs were larger for response repetition trials (217 ms) than for response switch trials (79 ms). There were also interactions between Age, Task Switch and Response Switch, $F(2, 60) = 13.36$, $p < .001$, and Age, RSI, Task Switch and Response Switch, $F(4, 120) = 3.65$, $p < .05$ (see Figure 2, upper panel). Most importantly, the Task Switch × Response Switch effect was more pronounced for younger children (346 ms vs. 126 ms) than for older children (104 ms vs. 61 ms) and young adults (101 ms vs. 49 ms). Two types of post-hoc ANOVAs were performed. First, we examined task switch costs for response repetition and response switch trials separately (i.e. keeping response switching constant). These analyses both revealed significant Age × Task Switch interactions for both response repetition, $F(2, 60) = 21.87$, $p < .001$, and for response switch trials, $F(2, 60) = 14.83$, $p < .005$. However, for response repetition trials, the age-related decrease in switch costs was larger at short RSIs, as indicated by a significant RSI × Age × Task Switch interaction, $F(4, 120) = 3.95$, $p < .001$. The RSI × Age × Task Switch interaction was not significant for response switch trials, $F(4, 120) = .37$, $p = .80$. Second, we examined effects of response switching for task repetitions and task switches separately (i.e. keeping task switching constant). For task repetition trials, there was a significant main effect of Response Switch, $F(1, 52) = 19.06$, $p < .001$, showing that participants were faster on response repetition trials than on response switch trials. However, there was no significant interaction between Age and Response Switch, $F(2, 52) = 2.28$, $p = .12$, or between RSI, Age and Response Switch, $F(4, 104) = 1.92$, $p = .11$. In contrast, the ANOVA for task switch trials resulted in a significant main effect of Response Switch, $F(1, 52) = 73.37$, $p < .001$, showing that participants were slower on response repetition trials than on response switch trials. An interaction between Age and Response Switch revealed that this effect was larger for children than adults, $F(2, 52) = 14.55$, $p < .001$. Post-hoc analyses showed that both child groups differed from the adults group, but that the child groups did not differ from each other. An interaction between RSI and Response Switch showed that the RT slowing associated with repeating responses was larger for shorter RSIs, $F(2, 1042) = 16.93$, $p < .001$, but there was no interaction with Age, $F(4, 104) = 1.45$, $p = .22$.

Finally, there were no interactions between S–R Compatibility and Age (all $F$s < 1). S–R Compatibility interacted with Task Switch, $F(1, 60) = 16.90$, $p < .001$, and with Response Switch, $F(1, 60) = 29.59$, $p < .001$, and there was a four-way interaction between S–R Compatibility, Task Switch, Response Switch and RSI, $F(2, 120) = 10.60$, $p < .001$, presented in Figure 3. Post-hoc ANOVAs for response repetition and response switch trials separately revealed that in both cases switch costs were larger for compatible trials than for incompatible trials. This difference was somewhat larger for compatible trials (231 ms vs. 92 ms) than for incompatible trials (193 ms vs. 76 ms), and these interactions were significant for all RSIs (all $p$s < .01).

### Errors

Square roots of error percentages were submitted to a 3 (Age Group) × 2 (S–R Compatibility) × 2 (Task Switch) × 2 (Response Switch) × 3 (RSI) ANOVA. In general, the mean number of errors was low (8%) (see Figure 2, lower panel). Most importantly, age groups did not differ in accuracy, $F(2, 64) = .24$, $p = .79$, and there were no interactions including the Age Group effect.

As expected, there was a main effect of Task Switch, $F(1, 63) = 164.19$, $p < .001$, showing that participants made more errors when switching between tasks (10.0%) compared to repeating tasks (4.3%), and there were

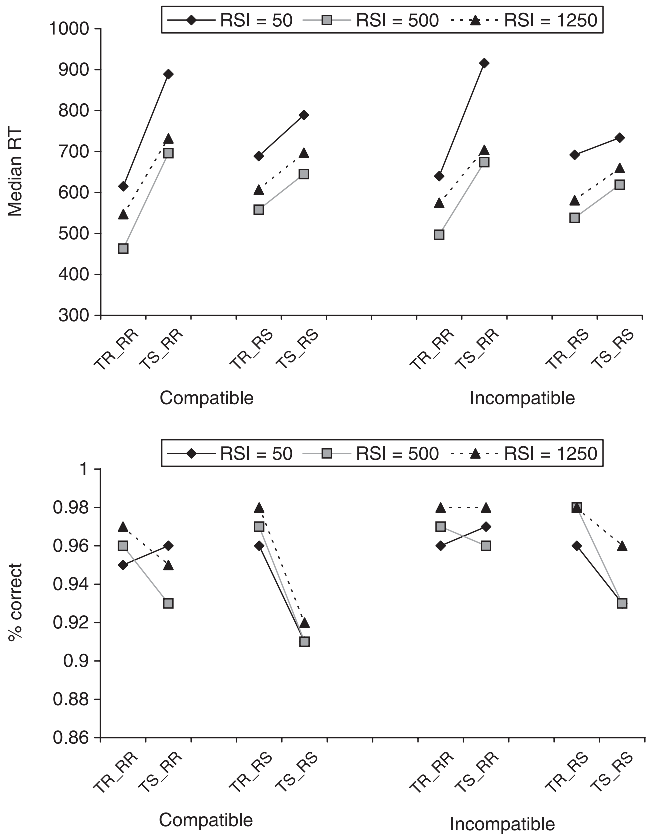

**Figure 3** *Switch costs: Response latencies (upper panel) and accuracy (lower panel) for response and task sequences for compatible and incompatible tasks for three Response–Stimulus Intervals (RSI). TR = Task Repetition, TS = Task Switch, RR = Response Repetition, RS = Response Switch.*

interactions between Task Switch and Response Switch, *F*(1, 63) = 157.49, *p* < .001, Task Switch and S–R Compatibility, *F*(1, 63) = 47.05, *p* < .001, Task Switch and RSI, *F*(2, 126) = 15.87, *p* < .001, Task Switch, Response Switch and S–R Compatibility, *F*(1, 63) = 19.89, *p* < .001, and Task Switch, S–R Compatibility and RSI, *F*(2, 126) = 4.74, *p* < .01. The latter interactions are plotted in Figure 3 (lower panel) and show that the task switch costs for accuracy were larger when responses alternated compared to when responses were repeated, and that these differences were larger for compatible than for incompatible trials. Furthermore, accuracy on task switch trials compared to task repetition trials showed a greater decrement for compatible than for incompatible trials, and this difference was more pronounced for longer RSIs.

### Speed–accuracy trade-offs

The finding that responses to alternating switch trials were slower but more accurate apparently suggests that the general interaction between Task Switch and Response Switch may have been influenced by speed–accuracy trade-off. However, closer inspection reveals that increases in RT for task switches relative to task repetitions were consistently accompanied by corresponding decreases in accuracy, thus rendering interpretations in terms of speed/accuracy trade-off unlikely. To corroborate this conclusion, an additional analysis was performed in which participants of each age group were split into low accuracy and high accuracy groups. Given that accuracy did not differ between age groups, this resulted in a similar distribution of age groups in the high accuracy group: 11 7–8-year-olds, 12 10–11-year-olds and 10 adults. A 2 (Accuracy Level) × 2 (Task Switch) × 2 (Response Switch) × 3 (RSI) ANOVA resulted in the expected Task Switch × Response Switch interaction, *F*(1, 64) = 62.62, *p* < .001, and this effect was modulated by Accuracy Level, *F*(1, 64) = 4.67, *p* = .04. This effect showed a pattern opposite to what would be expected if the data were influenced by a speed–accuracy trade-off. That is, High Accuracy performers showed smaller RT costs when switching tasks but repeating responses (TR_RR: 559, TR_RS: 594, TS_RR: 720, TS_RS: 654) than Low Accuracy performers (TR_RR: 563, TR_RS: 640, TS_RR: 839, TS_RS: 738). To further examine whether age differences could be influenced by speed–accuracy trade-off, the 2 (Task Switch) × 2 (Response Switch) × 3 (RSI) × 3 (Age Group) ANOVA was performed with general accuracy as a covariate factor. This analysis should reveal whether differences between age groups could be explained by differences in accuracy. Again here, interactions were observed between Task Switch, Response Switch and Age Group, *F*(2, 59) = 12.79, *p* < .001, and between Task Switch, Response Switch, RSI and Age Group *F*(4, 118) = 3.39, *p* < .05.

Taken together, the results of these follow-up analyses render it unlikely that a speed–accuracy trade-off influenced the current results because (1) there were no differences between age groups in accuracy, whereas these were prominent in RTs, (2) High Accuracy performers were faster when switching tasks and repeating responses, not slower as would be expected following a speed–accuracy explanation and (3) after partialing out the co-variance with accuracy, the remaining interactions between Age Group, Task Switch and Response Switch could not be accounted for by variation in accuracy.

## *Mixing costs*

### Response latencies

The next set of ANOVAs focused on age-specific effects on general mixing costs (task repetitions in pure blocks versus task repetitions in switch blocks). Task repetitions in the pure blocks and in the switch blocks with 500-ms RSI were examined with the factor 'Block Type'. Task repetitions could occur for compatible S–R trials and for incompatible S–R trials, referred to as 'S–R Compatibility'. Task repetitions could occur for response repetition and response alternations, referred to as 'Response Switch'. The 3 (Age Group) × 2 (Block Type) × 2 (S–R Compatibility) × 2 (Response Switch) ANOVA revealed a main effect of Age Group, $F(2, 63) = 76.91$, $p < .001$, showing that RTs from young adults ($M = 336$, SD = 13.5) were faster than those of older children ($M = 440$, SD = 14.3), and older children responded faster than younger children ($M = 561$, SD = 14.7). There were also main effects of Block Type, $F(1, 63) = 283.37$, $p < .001$, S–R Compatibility, $F(1, 63) = 102.14$, $p < .001$, and Response Switch, $F(1, 63) = 46.82$, $p < .001$. There were two-way interactions between Block Type and S–R Compatibility, $F(1, 63) = 51.76$, $p < .001$, and between Block Type and Response Switch, $F(1, 63) = 29.06$, $p < .001$. Finally, there was a three-way interaction between Block Type, S–R Compatibility and Response Switch, $F(1, 63) = 119.11$, $p < .001$. This last interaction is plotted in Figure 4. As can be seen in the figure, responses were slower for mixed blocks than for pure blocks and for incompatible than for compatible responses. However, the difference in response time to incompatible and compatible trials disappeared in mixed blocks when responses were alternated, whereas this was not observed when responses were repeated. Most importantly, there were no interactions including the factor Age Group (all *p*s > .10).

### Errors

Square roots of choice error percentages were submitted to a 3 (Age Group) × 2 (Block Type) × 2 (S–R Compatibility) × 2 (Response Switch) ANOVA. This analysis resulted in only an effect of Block Type, showing that subjects made more errors in the mixed blocks (9.6%) than in the pure blocks (6.5%), $F(1, 63) = 11.55$, $p < .001$. No other main or interaction effects approached statistical significance.

## Discussion

The switch pattern of adults was consistent with the observation that switch costs differ as a function of response repetition/switching. That is, adults benefited from repeating the same response in task repetition trials (repetition benefit), but were hindered by repeating the same response in task switch trials (reversed repetition effect). This interaction is consistent with previous reports (e.g. Meiran, 2000; Kleinsorge & Heuer, 1999; Rogers & Monsell, 1995), and has been interpreted in terms of carry-over effects of the previous S–R association. Most importantly, these reversed repetition costs were larger for younger children, and age differences were reduced as a function of increased RSI. Post-hoc comparisons revealed that this effect was mostly driven by task switch response repetition trials, on which 7–8-year-olds and 10–12-year-olds showed a pronounced RT slowing in comparison to young adults. Below we discuss possible accounts for this developmental trajectory.

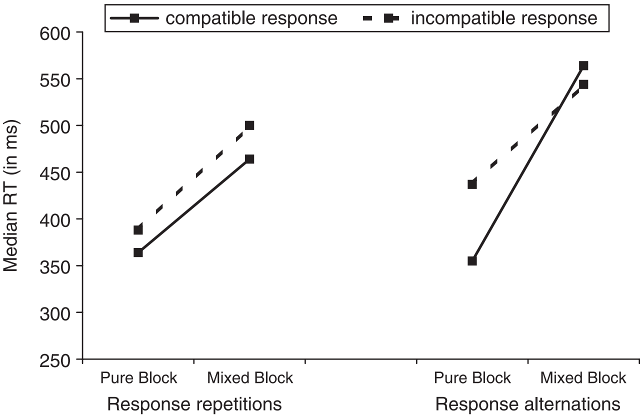

**Figure 4** *Mixing costs: Response latencies for response repetitions and response alternations in compatible and incompatible tasks for task repetitions in pure and mixed blocks.*

One possibility is that children experienced greater carry-over effects from the previously activated S–R association because the binding between stimuli and responses is stronger in children. For example, when performing task *A* with a left-hand response, the association between *A* and the left-hand response makes subsequent performance of task *B* with the left-hand response more difficult. This interpretation parallels results of developmental studies by Kerr *et al.* (1982) and Soetens and Hueting (1992). These authors showed that when trials occur in rapid succession, stimuli are processed rather automatically, which benefits children more than adults in single task conditions. Greater automatic facilitation during short RSIs when tasks repeat presumably results from a temporary shortcut in central processing stages (Soetens *et al.*, 1985). Following this interpretation, children may adjust associations between responses and tasks more strongly, resulting in benefits when the tasks repeat but costs when the tasks switch (Meiran, 2000). It should be noted that we did not observe greater response repetition benefits for children compared to adults on task repetition trials, although this was observed in a prior study in single task conditions (Smulders *et al.*, 2005).

Our results show a pattern similar to Mayr's (2001) study comparing young and older adults. Mayr (2001) reported greater reversed repetition costs in older adults, and provided a specific interpretation of this effect. He suggested that the appearance of a stimulus elicits a set-updating operation, especially in older adults, allowing binding of the item-specific S–R configuration to the simultaneously activated task set. Reactivating this memory trace on the following trial would then lead to large priming effects. In this context, priming refers to the carry-over effect of S–R binding on the previous trial.

The priming hypothesis resembles the interpretation of stronger response adjustments in a model proposed by Meiran (2000). Following this model, children may be more sensitive to memory traces of the previously active S–R association. Let us denote *S[A,L]* for the strength of the association between task *A* and the left-hand response; *S[A,R]* for the strength of the association between task *A* and the right-hand response; *S[B,L]* for the strength of the association between task *B* and the left-hand response; and *S[B,R]* for the strength of the association between task *B* and the right-hand response. Assuming (arbitrarily) that *S[A,L]*, *S[A,R]*, *S[B,L]* and *S[B,R]* add up to 1.0, and that each has a starting value of 0.25, pressing the left key on task *A* on trial *N*-1 results in strengthening of *S[A,L]* to, say, 0.4, and in reducing *S[B,L]* to, say, 0.1. Since the right-hand key was not pressed on trial *N*-1, *S[A,R]* and *S[B,R]* remain unaltered at 0.25. Switching to task *B* on trial *N* would result in relatively difficult selection of the left-hand compared to the right-hand response, because *S[B,L]* is weaker (0.1) than *S[B,R]* (0.25). A *repetition* of task *A* on trial *N* would, by contrast, facilitate selection of the left-hand compared to the right-hand response, because *S[A,L]* is already stronger (0.4) than *S[A,R]* (0.25) (see Meiran, 2000; Meiran & Gottler, 2001).[1] If the strength of associations is stronger in early development, then this leads to increased strengthening of *S[A,L]* (e.g. 0.45) and reduced strengthening of *S[B,L]* (e.g. 0.05), resulting in increased switch costs when responses are repeated. This model is a possible way to explain the current results but should be tested in future research.

An alternative hypothesis is that children have larger switch costs because they find it harder to inhibit their responses to the previously activated task (e.g. Diamond, 2002; Kirkham *et al.*, 2003; van den Wildenberg & van der Molen, 2003). Following this interpretation, increased switch costs are associated with difficulty suppressing the previously relevant task set, thus referring to inhibition of the set of rules. Kirkham *et al.* (2003) and others have suggested that children experience attentional inertia when they have to switch from one rule to another. Attentional inertia refers to children's failure to inhibit to respond to the first-learned rule, resulting in perseveration. However, if the inhibition hypothesis should be interpreted as a failure to inhibit task sets, then developmental differences in switch costs should be similar for response repetitions and response switches. In contrast, we found that the developmental differences in switch costs were driven by the reversed repetition effect, on those trials where participants switch task rules but repeat responses.

We included compatible and incompatible S–R mappings to further test the hypothesis that children would have difficulty switching to the currently attended task set because of greater difficulty inhibiting the prior task set. To explore whether the present data offer support for inhibitory deficits, we examined 'asymmetric switch costs', referring to the effect that there are typically larger switch costs for the compatible task than for the incompatible task (De Jong, 1995). Although we observed robust asymmetric switch costs, this effect did not differ between children and adults. Asymmetric switch costs have previously been interpreted as suggesting that suppression of a strongly competing task set can carry over to a later trial, making it more difficult to activate the previously competing task set on a switch trial (Allport *et al.*, 1994). If children are less proficient at inhibiting the previous task set less, then the interference from the previous weaker task should be less pronounced for young children. However, the effects of switching to compatible and incompatible tasks were similar for all age groups, thus failing to support an interpretation of age changes in terms of task set inhibition.[2]

In favour of the S–R binding hypothesis, the developmental differences in reversed repetition effects decreased when the RSI increased. This result is consistent with Soetens *et al.* (1985), who argued that automatic processing

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[1] Kleinsorge and Heuer (1999) suggest a similar model but argue that switching between stimulus–response assignments within the same task is structured hierarchically, where control processes first operate on representation of the first type of judgement (i.e. task A or task B), followed by the mapping of judgements on their responses (i.e. response L or R), followed by the response itself. Although the nature of the basic processes is different, for the current study the output of results is the same.

[2] It should be noted that Yeung and Monsell (2003) have a somewhat different explanation of carry-over effects of previous task sets. They argue that the asymmetry in switch costs to strong and weak tasks is best described by the combination of transient persistence of the task set activation, with the assumption that executive processes apply the minimum endogenous control input that enables the appropriate task. In either case, we show in this study that different developmental trends are observed for reverse repetition effects and asymmetry to switch costs due to task difficulty.

mainly takes place when the RSI is very short. However, the reversed repetition effect remained reliable even at longer RSIs. This latter effect is consistent with Waszak, Hommel and Allport (2003; see also Stoet & Hommel, 1999 for a similar interpretation), who showed that there may also be long-term traces of S–R associations. It remains to be investigated whether S–R bindings simply decay over time, or whether participants actively disengage the previous task set. The difference between short-term stimulus–response retrieval versus long-term binding and their underlying mechanisms should be examined in greater detail in future experiments.

A final aim of this study was to examine the performance decrement associated with the fact that trials of two tasks were intermixed. Consistent with prior studies, we found that participants responded slower in the mixed situation compared to the pure blocks (e.g. Cepeda *et al.*, 2001; Los, 1996). When responses were repeated, this decrement was similar for compatible and incompatible S–R trials. When responses were alternated, this decrement was larger for compatible S–R trials than for incompatible S–R trials. The latter finding is consistent with prior studies (Allport *et al.*, 1994; Los, 1996; Stoffels, 1996) and reflects that mixing costs are larger for the fast and possibly automatic level of processing than for the slow, control-demanding level. The absence of this effect when responses are repeated is intriguing, and there is currently no theory that can account for this finding. This phenomenon should be examined in a separate study. Most important, mixing costs did not differentiate between age groups, suggesting that age-related differences in specific task switch performance cannot be attributed solely to age-related differences in the ability to perform two tasks intermixed. This finding is consistent with findings reported by Span (2002), who found that children show greater switch costs but do not differ in mixing costs. Cepeda *et al.* (2001) and Kray *et al.* (2004) observed that not only switch costs but also mixing costs were larger in children, but they referred to mixing costs as the difference in RT between repetitions in pure blocks and the average of repetition and switch trials in switch blocks, so the difference in selected trial types might account for the differences in findings.

The present findings show that developmental differences in task switch costs can be largely explained by the younger children experiencing greater carry-over effects or previous S–R associations, which interferes with their ability to switch to currently intended actions, and is more likely an automatic rather than an endogenous process (see also Kerr *et al.*, 1982; Smulders *et al.*, 2005; Soetens & Hueting, 1992). The notion that involuntary retrieval of task–response associations was a critical factor for age-related changes in switch costs might also account for the finding that age differences in task switching are not observed under some conditions (Kray *et al.*, 2004). This is one of the few studies reporting developmental trends in switch costs in task switching across school-age childhood, and the results are consistent with other studies examining children's ability to flexibly switch between tasks, following for example performance feedback (for a review, see Diamond, 2002; see also Crone, Ridderinkhof, Worm, Somsen & van der Molen, 2004).

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