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Asymmetrical switch costs in children

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Abstract

Switching between tasks produces decreases in performance as compared to repeating the same task. Asymmetrical switch costs occur when switching between two tasks of unequal difficulty. This asymmetry occurs because the cost is greater when switching to the less difficult task than when switching to the more difficult task. Various theories about the origins of these asymmetrical switch costs have emerged from numerous and detailed experiments with adults. There is no documented evidence of asymmetrical switch costs in children. We conducted a series of studies that examined age-related changes in asymmetrical switch costs, within the same paradigm. Similarities in the patterns of asymmetrical switch costs between children and adults suggested that theoretical explanations of the cognitive mechanisms driving asymmetrical switch costs in adults could be applied to children. Age-related differences indicate that these theoretical explanations need to incorporate the relative contributions and interactions of developmental processes and task mastery.

Keywords: Task switching; Children; Switch costs; Arithmetic

From infancy through to later adulthood, daily life requires us to switch continually between various tasks. Despite our vast experience, performance decrements, or switch costs, persist when we switch from one task to another, even if the onset of a switch is completely predictable (Rogers & Monsell, 1995). In recent years, the study of switch costs in adult participants has been explored in great detail (for a review, see Monsell, 2003). Numerous experiments have explored how children switch between tasks (e.g., Crone, Ridderinkhof, Worm, Somsen, & van der Molen, 2004; Deák, Ray, & Pick, 2004; Kirkham, Cruess, & Diamond, 2003; Zelazo, Müller, Frye, & Marcovitch, 2003), but very few have used this traditional task switching paradigm described by Monsell (2003) to study switch costs in children (Cepeda, Cepeda, & Kramer, 2000; Cepeda,

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Kramer, & Gonzalez de Sather, 2001; Kray, Eber, & Lindenberger, 2004; Reimers & Maylor, 2005).

Studies with adults have identified asymmetrical switch costs when two tasks differ in difficulty. In these cases, stronger tasks elicit greater switch costs compared to weaker tasks (Allport, Style, & Hsieh, 1994; Allport & Wylie, 2000; Monsell, Yeung, & Azuma, 2000; Rubenstein, Meyer, & Evans, 2001). Stronger tasks are those that participants find easier. Weaker tasks are those that participants find harder. Weaker tasks may be more difficult, less familiar, or less practiced. Asymmetrical switch costs appear to be a consistent finding in adults, but when do they emerge? Will children exhibit asymmetrical switch costs? By taking a developmental look at these switch costs, we are uniquely able to examine whether children exhibit similar switch cost patterns as adults. If these patterns are similar between children and adults, then their cognitive mechanisms responsible for switching also might be similar.

1. Task switching and switch costs

Switch costs have been defined as increased response time (RT) after switching between two tasks as compared to repeating the same task. More specifically:

$$\text{switch costs} = \text{switch RT} - \text{nonswitch RT}$$

To date, two key explanations of switch costs have emerged. These two theories are not necessarily incompatible. One class of theories, described as *online configuration* by Rogers and Monsell (1995), suggests that switch costs are due to the activation of a new set of procedures to solve the task after the switch. According to this view, switch costs arise from the active process of reconfiguring the cognitive system to the cognitive demands of the new task. Switch costs are viewed as a quantitative measure of this reconfiguration (e.g., De Jong, 2000; Mayr & Kliegl, 2000; Meiran, 1996; Meiran, Chorev, & Sapir, 2000).

The second class of theories suggests that switch costs are due the deactivation of the procedures involved in solving the task before the switch (e.g., Allport et al., 1994; Allport & Wylie, 2000; Ruthruff, Remington, & Johnston, 2001; Sohn & Carlson, 2000; Wylie & Allport, 2000). Allport et al. (1994) called this explanation *task set inertia*. Here, switch costs are an indirect measure of priming. According to this view, repetition increases priming to the repeated tasks (Waszak, Hommel, & Allport, 2003). This priming allows for quicker response times and/or greater accuracy when tasks are repeated. When tasks are switched, then priming is disrupted and slower response times and/or lower accuracies are produced. Rather than a disruption of priming, Mayr and Keele (2000) and Mayr (2002) have suggested that these switch costs are due to an inhibition of the previous task.

1.1. *General and specific switch costs*

Switch costs can be identified at two levels: general and specific. General switch costs quantify global performance differences between two kinds of blocks of trials: mixed blocks and pure blocks (Allport et al., 1994; Jersild, 1927). Mixed blocks contain predictable or, in some cases, random switches between two tasks. Pure blocks contain repetition of one single task. Specific switch costs identify local differences between switch trials and repeat trials (e.g., Gopher, Armony, & Greeshpan, 2000; Rogers & Monsell, 1995). For example, Rogers and Monsell (1995) used a predictable alternating runs pattern of AABBAABBAA to explore differences in performance for Task B during a switch trial (i.e., the previous trial comprised Task A) or during a repeat trial (i.e., the previous trial comprised Task B). One reason for assessing both general and specific switch costs is to explore the extent that each task influences performance of the other during the mixed blocks.

After controlling for age-related changes in RTs, previous studies have indicated differences in general and specific switch costs across the lifespan. Older adults typically exhibit greater general switch costs than younger adults (e.g., Kramer, Hahn, & Gopher, 1999; Kray & Lindenberger, 2000; Mayr, 2001; Mayr & Liebscher, 2001; Salthouse, Fristoe, McGuthry, & Hambrick, 1998). Switch costs have been identified in this task switching paradigm with children as young as 3-year-old (Cohen, Bixenman, Meiran, & Diamond, 2001). Younger children exhibit greater general and specific switch costs than older children and adults (Cepeda et al., 2000, 2001; Cohen et al., 2001; Kray et al., 2004). General and specific switch costs appear to have distinct developmental trajectories, with general switch costs decreasing from pre-adolescence to early adulthood, i.e., 10 years to 18 years of age, then increasing linearly until later adulthood (Kray et al., 2004; Reimers & Maylor, 2005). Specific switch costs remain stable throughout the lifespan (Kray et al., 2004; Reimers & Maylor, 2005).

There are numerous studies of children's abilities to switch between tasks outside of the task switching paradigm. These studies document children's relative abilities to switch between tasks, but emphasize performance before and after a critical switch (e.g., Crone et al., 2004; Deák et al., 2004; Kirkham et al., 2003; Zelazo et al., 2003). Typically, participants repeat a task for a number of trials, make a switch, and then repeat a second task for a number of trials. Some studies repeat this cycle of trials. These studies with children do not use the traditional task switching paradigm (e.g., Rogers & Monsell, 1995) used in our experiments and they tend to include one switch trial sandwiched between many repeat trials.

2. Asymmetrical switch costs

Asymmetrical switch costs occur when switching between two tasks with different relative strengths. Asymmetrical switch costs are evidenced in an interaction between switch/block type and task type (Wylie & Allport, 2000; Yeung & Monsell, 2003a). Basically, an asymmetrical switch cost occurs when there is a greater difference between repetition and switching for a stronger task than a weaker task (Allport et al., 1994; De Jong, 1995; Meuter & Allport, 1999; Yeung & Monsell, 2003b). Depending on the task, the interaction may be driven largely by the fact that there is little or no difference in performance between repetition and switching for the weaker task (Allport et al., 1994; Wylie & Allport, 2000). Early studies of asymmetrical switch costs utilized tasks where the stronger task was a prepotent response and the weaker task required an inhibition of that prepotent task (Allport et al., 1994; Meuter & Allport, 1999; Wylie & Allport, 2000). More recently, asymmetrical switch costs have been replicated using a weak task that does not require the inhibition of the prepotent response, but rather it is either more complex (Rubenstein et al., 2001), less familiar (Yeung & Monsell, 2003a), or less practiced (Yeung & Monsell, 2003b).

At first, this asymmetrical switch cost pattern may seem counter-intuitive. However, asymmetrical switch costs have been explained using the task switching components of task set inertia and online configuration. According to task set inertia (Allport et al., 1994), stronger tasks are primed more readily than weaker tasks, and more readily primed tasks are more susceptible to disruption. The disruption of priming caused by the switch may be responsible for the increased cost of switching to the stronger task. Weaker tasks, which may require more cognitive resources, may be less susceptible to priming and elicit smaller switch costs. In contrast, Yeung and Monsell (2003a) suggested that asymmetrical switch costs are due to the degree of interference between two tasks. According to this online configuration view, the weaker task interferes with the stronger task. By reducing this interference, Yeung and Monsell (2003a) greatly reduced asymmetrical switch costs.

3. The current project

We explore uniquely whether the asymmetrical switch cost patterns found in adults are found in children. Deák et al. (2004) were unable to find asymmetrical switch costs in young children using a switching paradigm unlike the traditional task switching paradigm used most recently to study asymmetrical switch costs in adults (e.g., Allport et al., 1994; Rubenstein et al., 2001; Yeung & Monsell, 2003a, 2003b). Because no study has yet documented the presence of asymmetrical switch costs in children, we include a variety of tasks to explore the robustness of asymmetrical switch cost patterns. If children and adults exhibit similar patterns in asymmetrical switch costs, then we might begin to consider the development of the mechanisms responsible for these switch costs. Such evidence should provide information regarding the relative contribution of the online-configuration and task set inertia theories. Regardless of the outcome, the strength of these theories depends on whether they can account for the performance of both adults and children. To achieve this goal, we measured young children's switch costs in two types of experiments: figure matching and arithmetic.

In the figure matching experiments, participants switched between matching figures by their shape or by their color. From previous studies with children, we know young children can do this with high accuracy (e.g., Espy, 1997; Kirkham et al., 2003; Zelazo et al., 2003). Some studies have found that children (e.g., Landau, Smith, & Jones, 1988; Prevor & Diamond, 2005; Siegel & Vance, 1970) and adults prefer to name objects by their function or shape rather than by their color (e.g., Colby & Robertson, 1942; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002). However, we used a perceptual similarity task. Both color and shape are perceived very quickly in adults (Viviani & Aymoz, 2001) and children (Pitchford & Mullen, 2001) and both are important in perceptual similarity tasks (e.g., Ling & Hurlbert, 2004). In some perceptual arrays, similarity judgments based on color are faster than those based on shape (Young & Ellefson, 2003). Hahn, Andersen, and Kramer (2003) found clear switch costs when participants switch between color and shape in a traditional task switching paradigm, but did not report whether there were differences in performance between color and shape. Rubenstein et al. (2001) found that asymmetrical switch costs using a more complex task containing color and shape. Here, we investigated whether these difference exist for children in this paradigm.

In the arithmetic experiments, participants switched between various arithmetical calculations. In one type of experiment, participants switched between addition and subtraction. In a second type of experiment, participants switched between addition and missing addends, e.g., $3 + \underline{\quad} = 5$ (e.g., Vergnaud, 1997). From toddler-hood to the preschool years, children learn solve a variety of tasks requiring simple mental computations (e.g., Bryant, Christie, & Rendu, 1999; Vilette, 2002). Upon school entry, their basic understanding of quantity, adding, and taking away objects is formalized into arithmetic knowledge as children learn to apply this understanding to written numerals (e.g., Nunes & Bryant, 1996). During the early primary school years, children acquire an understanding of addition and subtraction and learn to calculate addition and subtraction equations. Throughout childhood, the understanding of quantity and arithmetic problem-solving increases, with older children responding more accurately and more quickly to arithmetic equations than younger children (e.g., Ashcraft, 1982; Canobi, 2004).

Here, we include 7-year-old children who have nearly completed their third year of formal education in British schools. We chose this sample because by this age children have a good knowledge of addition and subtraction (e.g., Kamii, Lewis, & Kirkland, 2001; Levine, Jordan, & Huttenlocher, 1992) and would provide good levels of accuracy for both the figure matching and arithmetic experiments. Moreover, they will be competent, but not necessarily fluent, at the arithmetic experiments. In this way, we can explore asymmetrical switch costs in two sorts of tasks that differ in both content and in task fluency.

4. Experiment 1: Figure matching

During Experiment 1, participants switched between matching figures by color and shape. To make the task more suitable for young children, the design of our experiments involved several slight modifications to the standard task switching paradigm. The possibility remains, of course, that these procedural differences might have implications for the results with adults. Therefore, throughout this paper, we conducted our experiments with both early primary school children and university students. Thus, we could ensure that our design produced results consistent with the traditional task switching paradigm and ensure that our results might be attributed to developmental differences rather than design differences. We did expect, of course, that there would be absolute differences in speed and accuracy between the two age groups. However, we were most interested in determining whether these two age groups demonstrate similar patterns of results.

5. Method

5.1. Participants

A total of 72 Year 2 children from two primary schools in eastern England participated in this experiment. There were 38 females and 34 males, with an average age of 7.49 years (S.D. = .28, range = 6.84–7.84). Verbal IQ was assessed from the British Picture Vocabulary Scale (Dunn & Dunn, 1982). The mean standardized score for this sample was 94.24 (S.D. = 13.68, range = 59–127). In addition, 46 students from the University of Warwick, UK, participated in this experiment. There were 41 females and 5 males, with an average age of 19.31 years (S.D. = 2.27, range = 18.21–33.98). University participants were given course credit for their participation.

5.2. Materials

The stimuli for this experiment were two different shapes, a triangle or a circle, presented in two colors, blue or red. Two laptop computers with detachable keyboards were used to present the experiment.

5.3. Design and procedures

Children completed the experiment in a quiet room at their school and university students completed the experiments at our laboratory at the university. The E-Prime® program (Schneider, Eschman, & Zuccolotto, 2002) administered instructions and presented the stimuli. Children were seated in front of a laptop computer and university students were seated in front of a desktop computer. Participants were instructed to match the figures by color or shape, as accurately and as

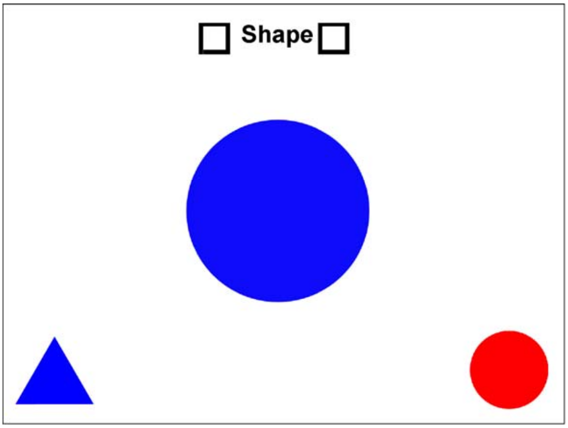

Fig. 1. An example of the stimulus presentation for Experiment 1 (the large circle and the small triangle presented in blue and the small circle presented in red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

quickly as possible. Ten practice trials were presented before the start of the experiment to ensure that the participants understood both tasks.

Each trial consisted of four simultaneous events (see Fig. 1). The target figure was presented in the center of the computer screen. This target figure could have been one of the two possible shapes (triangle or circle) in one of the two possible colors (blue or red). The cue to the matching task (i.e., shape or color) was presented at the top of the computer screen. Two to-be-selected figures were presented at the bottom of the computer screen, one on the left and one on the right. One of these to-be-selected figures was a triangle and the other was a circle. The color of each figure was either red or blue. The location and color of the to-be-selected figures was randomized across trials. The participants were instructed to select one of the two figures at the bottom of the screen that matched the target figure based on the matching task stated at the top of the screen. For example, suppose that the matching task concerned color, the target figure was a blue circle, and the selection figures were a red circle and a blue triangle. The participant would be expected to select the red circle to match the color of the target figure. Participants indicated their response by pressing one of two keys on a computer keyboard that corresponded to the to-be-selected figures. RTs and accuracy were collected for each trial.

The experiment comprised four blocks: pure color, pure shape, alternating, and alternating-runs. The pure color and pure shape blocks did not include switching between the two tasks, and comprised only color or shape matching tasks, respectively. The other two blocks, the mixed blocks, contained switches between the two tasks. The alternating block (Allport et al., 1994; Jersild, 1927) required switching on every trial, e.g., color, shape, color, shape, etc. The alternating-runs block (Rogers & Monsell, 1995) involved switching between color and shape matching tasks every other trial, e.g., color, color, shape, shape, color, color, etc. In sum, there were two pure blocks and two mixed blocks, i.e., alternating and alternating runs. Similar to many other task switching studies (e.g., Rogers & Monsell, 1995), the order of the presentation for the four blocks was fully counterbalanced across participants.

There were 25 trials in each block, for a total of 100 trials. The first trial in each block involved color or shape matching, counterbalanced across participants. There were two trial types: repeat and switch. Repeat trials occurred when participants repeated the same task as the previous trial. Repeat trials occurred in both of the pure blocks and in the alternating runs block. Switch trials occurred when participants changed to a different task from the previous trial. Switch trials occurred in the alternating and alternating runs blocks.

Here, we expected to find overall and asymmetrical costs of switching at the general and specific level. Overall, general switch costs would be evident in higher accuracy and faster RTs to pure than to mixed blocks. Specific switch costs would be evident in higher accuracy and faster RTs to repeat than to switch trials. This perceptual similarity task biases the participants to respond more quickly to color matching than to shape matching and we expected to find asymmetrical switch costs with larger switch costs for color matching than shape matching at the block and trial level.

6. Results and discussion

6.1. *Analyses*

The first item in each block was omitted from the analyses because the previous event was a break and hence the trial is neither a repeat nor a switch. To assess general switch costs on the effect of block (pure or mixed) and matching task (color or shape), a repeated measures 3 × 2 (Block × Task) ANOVA was conducted. To assess specific switch costs on the effect of trial (repeat or switch) and matching task (color or shape), a repeated measures 4 × 2 (Trial × Task) analysis of variance (ANOVA) was conducted. Here, trial type was compressed across blocks. These analyses were inspired by those conducted in previous studies of asymmetrical switch costs in a traditional task switching paradigm (e.g., Wylie & Allport, 2000; Yeung & Monsell, 2003a). One difference between the traditional analyses and ours is that we collapsed across blocks for repeat and switch trials to simplify our analyses for specific switch costs. Separate analyses were conducted using overall accuracy and RTs. To more accurately compare results between the two age groups, we analyzed RT data from correct trials only.[1] The portion of trials excluded from the RT analyses for all experiments are listed in Appendix A. Unless otherwise stated, identical procedures were used for the analyses for this and subsequent experiments. Effect sizes are reported as Cohen's *d* (1988).

6.2. *Early primary school student performance*

6.2.1. *Task effects*

Overall, the children more accurately responded to the color trials (89%) than to the shape trials (82%), $F\ (1, 71) = 6.92$, $p < .05$, mean squared error (M.S.E.) = .310, $d = .18$. Corroborating these results, the RT data indicated that children responded more quickly to the color trials (2429 ms) than to the shape trials (2766 ms), $F\ (1, 71) = 9.67$, $p < .01$, M.S.E. = 2512, $d = .12$.

6.2.2. *General switch costs*

The children more accurately responded to trials in the pure blocks (87%) than to trials in the mixed blocks (85%), $F\ (1, 71) = 5.05$, $p < .05$, M.S.E. = .308, $d = .06$. The left-hand side of

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[1] RTs collected from children, of course, are highly variable. We found that RTs to incorrect trials introduced more noise, resulting in similar patterns of results but reductions in the number of effects that were significant. Moreover, including RTs to correct trials only indicated that we included trials where the children had successfully repeated or switched tasks. Furthermore, we attempted to control for skewness and kurtosis of the RTs to correct trials, additional analyses were conducted after RTs were log transformed to control for skewness and kurtosis. These analyses confirmed the analyses conducted on raw RTs.

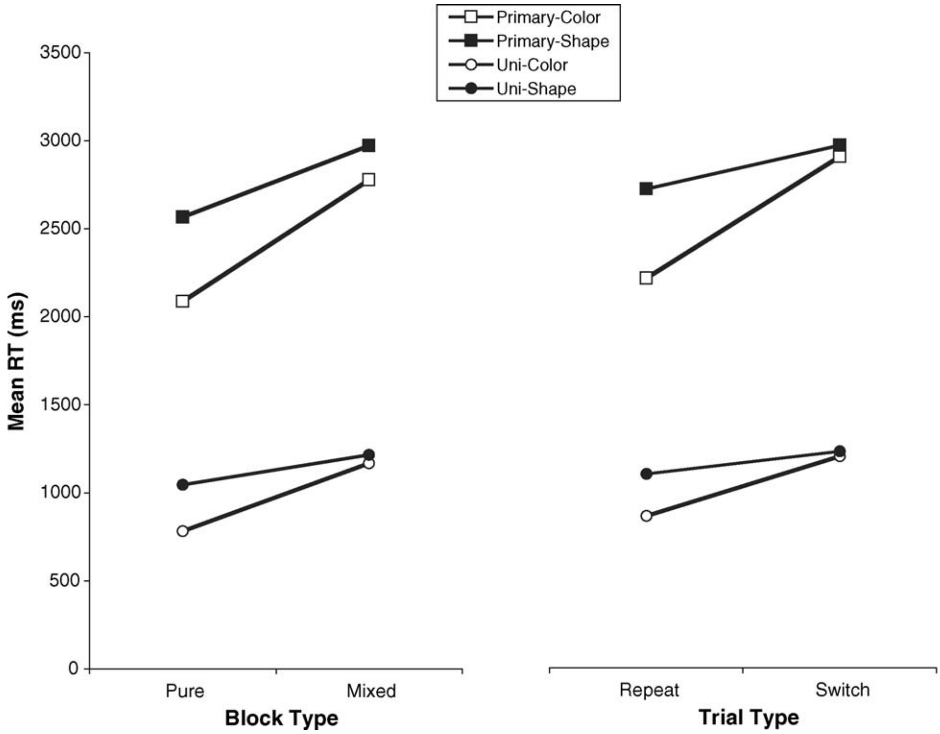

Fig. 2. Mean RT during Experiment 1 for early primary school and university students during pure and mixed blocks and during repeat and switch trials of colour and shape items.

Fig. 2 illustrates that the children responded more quickly to trials in the pure blocks (2319 ms) than to trials in the mixed blocks (2871 ms), F (1, 71) = 12.26, $p < .001$, M.S.E. = 2482, $d = .20$. The hypothesized asymmetrical switch costs were supported by a Block × Task interaction, F (1, 71) = 4.81, $p < .05$, M.S.E. = 2482, $d = .26$. Here, switch costs for the color task (690 ms) were larger than for the shape task (405 ms).

6.2.3. *Specific switch costs*

Overall, the children more accurately responded to the repeat trials (87%) than to the switch trials (84%), F (1, 71) = 6.92, $p < .05$, M.S.E. = .310, $d = .07$. The right-hand side of Fig. 2 illustrates that the children responded more quickly to the repeat trials (2418 ms) than to the switch trials (2888 ms), F (1, 71) = 12.56, $p < .001$, M.S.E. = 2512, $d = .11$. A significant Trial × Task interaction, F (1, 71) = 9.27, $p < .01$, indicated that the switch costs for color (690 ms) were greater than the switch costs for shape (405 ms), F (1, 71) = 40.09, $p < .0001$, $d = .25$. Additional analyses indicated that RTs to the repeat trials in the pure block for color (2087 ms) were faster than the RTs to the repeat trials in the alternating runs block (2540 ms), F (1, 7) = 7.80, $p < .01$, M.S.E. = 1906, $d = .19$, The same was true for shape, with the repeat trials in the pure block (2567 ms) faster than the repeat trials in the alternating runs block (3122 ms), F (1, 7) = 11.30, $p < .0001$, M.S.E. = 1906, $d = .18$. In addition, the shape switch trials in the alternating block (3040 ms) were slower than the switch trials in the alternating runs block (2677 ms), F (1, 7) = 4.71, $p < .05$, M.S.E. = 1906, $d = .14$. This is the only time we see differences in repeat or switch trials across blocks for either age group.

6.3. University student performance

6.3.1. Task effects

As expected, there were no significant effects or interactions involving accuracy. Responses to the color trials (973 ms) were faster than responses to the shape trials (1130 ms), $F\,(1, 45) = 36.85$, $p < .0001$, M.S.E. = 442, $d = .30$.

6.3.2. General switch costs

As expected, there were no significant effects or interactions involving accuracy. Similar to early primary school students, the university students responded more quickly to the trials in the pure blocks (913 ms) than to the trials in the mixed blocks (1191 ms), $F\,(1, 45) = 114.15$, $p < .0001$, M.S.E. = 433, $d = .55$. Finally, a Block × Task interaction, $F\,(1, 46) = 50.62$, $p < .0001$, M.S.E. = 443, $d = .80$, indicated that switch costs for color (385 ms) were greater than switch costs for shape (170 ms).

6.3.3. Specific switch costs

As expected, there were no significant effects or interactions involving accuracy. The university students responded more quickly to the repeat trials (966 ms) than to the switch trials (1195 ms), $F\,(1, 45) = 79.80$, $p < .0001$, M.S.E. = 443, $d = .44$. A significant Trial × Task interaction, $F\,(1, 45) = 56.46$, $p < .0001$, M.S.E. = 443, $d = .66$, indicated that the switch costs for color (333 ms) were greater than for shape (125 ms). Additional analyses indicated that there were no significant differences between the repeat trials in the pure versus alternating runs blocks or between the switch trials in the alternating and alternating runs blocks.

6.4. Age effects

As indicated by Table 1, the pattern of results was very similar between these two age groups. Differences between the groups occurred in their overall accuracy, $F\,(1, 116) = 37.19$, $p < .0001$, M.S.E. = .259, $d = .44$, and RT, $F\,(1, 116) = 70.44$, $p < .0001$, M.S.E. = 1943, $d = .76$. University students (97%, 1075 ms) were more accurate and responded more quickly throughout the experiment than the early primary school students (85%, 2549 ms). Age group did not interact with

Table 1
The significant effects in accuracy (Acc) and RT for early primary school and university students in Experiment 1

	Early primary school students	University students
Task effects		
Color vs. shape	Acc & RT	RT
Overall switch costs		
Pure vs. mixed blocks	RT	RT
Repeat vs. switch trials	Acc & RT	RT
Asymmetrical switch costs		
Task × Block	RT	RT
Task × Trial	RT*	RT

* Indicates non-significant trend with $p < .10$.

task type, block type, or trial type, indicating that, although the absolute values were different, the pattern of results remained the same across these two age groups.

6.5. Conclusions

In summary, the results indicated that this application of the task switching paradigm using two matching tasks elicited asymmetric switch costs in 7-year-old children. The results confirmed the expected cost of switching and switch cost asymmetries at both the general and specific levels. These results are consistent with our predictions. Moreover, the results suggested that this particular experimental task of switching between matching criteria is a useful method for assessing asymmetric switch costs in young children.

Table 1 summarizes the significant effects found for early primary school and university students. The pattern of results was very similar for adults and children. Both groups exhibited overall switch costs at the general and specific level. The presence of asymmetrical switch costs indicated that the cost of switching was greater for color than for shape matching. Despite similar patterns of performance, there were absolute differences with higher accuracy and faster RTs for university students than for early primary school students.

7. Experiment 2: Arithmetic I

As shown in Experiment 1, both children and adults do exhibit overall and asymmetrical switch costs when switching between two relatively simple tasks. Generally speaking, color and shape matching would be a task familiar to both age groups. The purpose of Experiment 2 was to determine whether asymmetrical switch costs persist in other tasks that may be slightly more complex than figure matching. As described earlier, by the time they reach the end of Year 2 in the British education system, most children can accurately solve addition and subtraction equations containing numbers less than 10, but their proficiency with subtraction is less than their proficiency with addition (e.g., Kamii et al., 2001). However, children of this age would not be very fast at this task (e.g., Canobi, 2004). In other words, although children might be accurate at these equations, they require time to ensure this accuracy. Furthermore, we have not yet explored whether there are costs for young children when switching between these two tasks. How might the pattern of switch costs differ when children switch between tasks that require more processing time?

Our aim was to identify asymmetrical switch costs at the general and specific level. Children of this age would find solving addition equations a stronger task than solving subtraction equations (Kamii et al., 2001). Moreover, it was expected that they would be more accurate and have faster RTs to the addition equations than to the subtraction equations. As with Experiment 1, general and specific switch costs were expected. For specific switch costs, we expected children to be more accurate and exhibit faster RTs to the repeat trials than to switch trials. For general switch costs, we expected children to be more accurate and exhibit faster RTs to the pure blocks than the mixed blocks. Finally, we expected asymmetrical switch costs, with greater general and specific switch costs for addition than for subtraction.

As with Experiment 1, we included both university and primary school students to identify whether the differences in the results were due to modifications in the task switching design or to developmental differences. Because previous studies indicated that these two age groups would have different levels of understanding of the inversion principle, we expected that the patterns of switch costs would be different between these two age groups.

8. Method

8.1. Participants

A total of 23 Year 2 children and 16 university students who completed Experiment 1 also participated in this experiment. The order of completing Experiments 1 and 2 was counterbalanced across participants. In the children's group, there were 13 females and 10 males, with an average age of 7.40 years (S.D. = .27, range = 6.90–7.83). In the university student group, there were 15 females and 1 male, with an average age of 18.98 years (S.D. = .53, range = 18.21–19.85).

8.2. Materials

The stimuli for this experiment were simple addition and subtraction equations (e.g., $3 + 1 = \_\_$, $7 - 2 = \_\_$), comprising only single digit numbers.

8.3. Design and procedures

The design and procedures were very similar to Experiment 1, with the following changes. The task in this experiment was to calculate the sum or difference for various addition or subtraction equations as accurately and as quickly as possible. Each trial consisted of three simultaneous events (see Fig. 3). The equation was presented in the center of the computer screen. At the bottom of the screen were two numbers. One of the numbers was the correct response. The other number was a foil. This foil was selected randomly as a number one or two digits higher or lower than the correct response. For example, given the equation $3 + 2 = \_\_$, the correct response would be 5; the foil could be one of 3, 4, 6, or 7. All possible foils and the target response for this example would be between 3 and 7. We randomized the location of the correct and foil responses between the lower left-hand side and the lower right-hand side of the computer screen. As with Experiment 1, participants indicated their response by pressing one of two keys on a keyboard that corresponded to the numbers on the left (a left key) and the right (a right key). RTs and accuracy were collected for each trial. Similar to Experiment 1, there were two pure blocks and two mixed blocks: pure addition, pure subtraction, alternating, and alternating runs. The order of

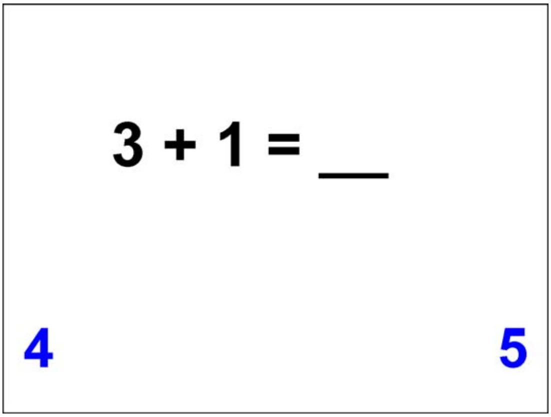

Fig. 3. An example of the stimulus presentation for Experiments 2 and 3.

the presentation of the blocks was counterbalanced across participants. The first trial within each mixed block could be either addition or subtraction, also counterbalanced across participants.

9. Results and discussion

9.1. Early primary school student performance

9.1.1. Task effects

Overall, the children were more accurate on the addition trials (90%) than to the subtraction trials (84%), $F(1, 22) = 9.31$, $p < .01$, M.S.E. = .230, $d = .19$. The children responded more quickly to the addition trials (4946 ms) than to the subtraction trails (5893 ms), but this difference was not significant, $F(1, 22) = 9.67$, $p < .10$.

9.1.2. General switch costs

At the block level, there were no significant main effects for accuracy. A Block × Task interaction, $F(2, 22) = 5.68$, $p < .05$, M.S.E. = .294, $d = .18$, indicated that there were larger accuracy switch costs for addition (5%) than for subtraction (1%). As seen on the left-hand side of Fig. 4, the same interaction was found with RT data $F(1, 22) = 6.55$, $p < .05$, M.S.E. = 6149, $d = .18$. Again, there were greater switch costs for addition (1281 ms) than for subtraction (28 ms).

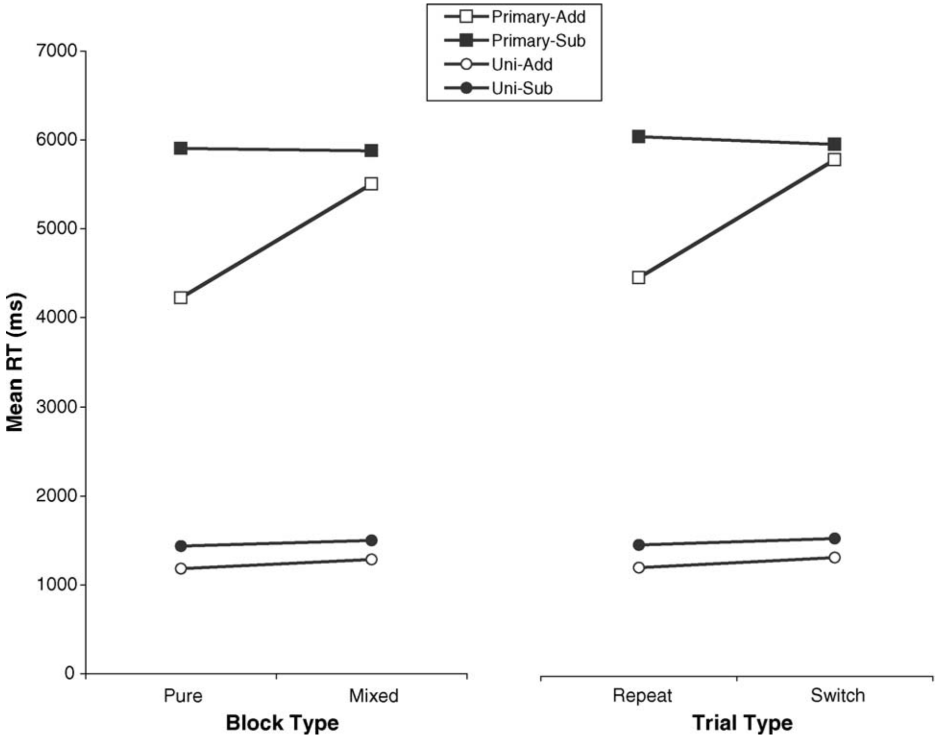

Fig. 4. Mean RT for Experiment 2 for early primary school and university students during pure and mixed blocks and during repeat and switch trials of addition (Add) and subtraction (Sub) items.

9.1.3. Specific switch costs

Overall, the children more accurately responded to the repeat trials (88%) than to the switch trials (85%), but this difference was not significant. As seen on the right-hand side of Fig. 4, there was a Block × Task interaction for RT, $F\,(1, 22) = 7.21$, $p < .05$, M.S.E. = 6167, $d = .16$, indicated that there were greater switch costs for addition (1295 ms) than for subtraction (84 ms). Additional analyses indicated that there were no significant differences between the repeat trials in the pure versus alternating runs blocks or between the switch trials in the alternating and alternating runs blocks.

9.2. University student performance

9.2.1. Task effects

Overall, the participants more accurately responded to the addition trials (98%) than to the subtraction trials (96%), $F\,(1, 15) = 5.37$, $p < .05$, M.S.E. = .179, $d = .11$. Corroborating the accuracy data, and as predicted, responses to the addition trials (1234 ms) were faster than responses to the subtraction trials (1468 ms), $F\,(1, 15) = 45.14$, $p < .0001$, M.S.E. = 433, $d = .48$. Here, the overall pattern of results for accuracy and RTs were remarkably similar to the accuracy and RT results with primary school children.

9.2.2. General switch costs

There were no significant effects or interactions for accuracy. As hypothesized, and very similar to the primary school student data, university students responded more quickly to trials in the pure blocks (1308 ms) than to trials in the mixed blocks (1393 ms), $F\,(1, 15) = 11.06$, $p < .01$, M.S.E. = 435, $d = .17$ (see the left-hand side of Fig. 4). There were no asymmetrical switch costs.

9.2.3. Specific switch costs

There were no effect or interactions for accuracy. As illustrated on the right-hand side of Fig. 4, the university students responded more quickly to the repeat trials (1316 ms) than to the switch trials (1407 ms), $F\,(1, 15) = 10.86$, $p < .01$, M.S.E. = 433, $d = .18$. There were no significant interactions. Again, there were no significant differences between the repeat trials in the pure versus alternating runs blocks or between the switch trials in the alternating and alternating runs blocks.

9.3. Age effects

Further analyses indicted that there was a main effect of age group for accuracy, $F\,(1, 37) = 6.42$, $p < .05$, M.S.E. = .253, $d = .36$, and RT, $F\,(1, 37) = 45.59$, $p < .0001$, M.S.E. = 4635, $d = .86$. University students (97%, 1350 ms) were more accurate and responded more quickly throughout the experiment than the early primary school students (87%, 5350 ms). An Age Group × Block × Task interaction indicated that the there were greater differences for early primary school students only between pure and mixed blocks for addition than for subtraction in accuracy (5% and 1% for addition and subtraction, respectively), $F\,(1, 37) = 4.84$, $p < .05$, M.S.E. = .253, $d = .18$, and RT (1281 ms and 28 ms for addition and subtraction, respectively), $F\,(1, 37) = 4.70$, $p < .05$, M.S.E. = 4621, $d = .18$. Similarly, an Age Group × Trial × Task interaction indicated that the there were greater differences for early primary school students only between repeat and switch trials for addition (1295 ms) than for subtraction (84 ms) in RT, $F\,(1, 37) = 5.28$, $p < .05$, M.S.E. = 4635, $d = .16$.

Table 2
The significant effects in accuracy (Acc) and RT for early primary school and university students in Experiment 2

	Early primary school students	University students
Task effects		
Addition vs. subtraction	Acc & RT*	Acc & RT
Overall switch costs		
Pure vs. mixed blocks		RT
Repeat vs. switch trials		RT
Asymmetrical switch costs		
Task × Block	Acc* & RT	
Task × Trial	Acc & RT*	

* Indicates non-significant trend with $p < .10$.

9.4. Conclusions

As in Experiment 1, we found asymmetrical switch costs at the general and specific level for children, with the cost of switching greater for addition than for subtraction, indicating that asymmetrical switch costs do scale up to arithmetic for children. Unlike Experiment 1, however, we did not find overall switch costs at the general and specific level. It is likely that these differences between pure and mixed blocks at the general level, and between repeat and switch trials at the specific level are due to the lack of switch costs for subtraction. It may seem relatively surprising that there are such small, and perhaps non-existent, switch costs for subtraction. This pattern of results is very similar to weaker tasks in other studies (e.g., Allport et al., 1994; Yeung & Monsell, 2003a). The general switch cost asymmetry result is that harder tasks show smaller switch costs and it follows that even harder tasks may show no discernable switch cost.

The university students in this task exhibited switch costs at the general and specific level. However, there were no asymmetrical switch costs. As seen in Table 2, the patterns of results for these two age groups were rather different. The university students exhibited overall general and specific switch costs, whereas the early primary school students exhibited asymmetrical switch costs at the general and specific level.

Given the consistency between these two age groups in Experiment 1, it is likely that the age group differences in Experiment 2 were due to developmental differences specific to the differences between these age groups in mastery of the task. Figure matching would have been a relatively simple task for both age groups, whereas arithmetic still would be a rather complex task for the younger students. It is likely that one reason for the increased asymmetrical switch costs for the early primary school students as compared to the university students may relate to differences in the computational understanding of these two age groups.

Initially, children's abilities to complete numerical equations reflect either memorization of arithmetic facts or competent counting on and counting back skills (e.g., Lucangeli, Tressoldi, Bendotti, Bonanomi, & Siegel, 2003). Using counting strategies, $4+2$ could be solved by counting on two numerals from 4; *4*, *5*, *6*, or $7-3$ could be solved by counting back three numerals from 7; *7*, *6*, *5*, *4*. Later children demonstrate a more sophisticated understanding of these computations when they grasp the inverse relation between addition and subtraction, i.e., $7-3=4$ is the inverse of $3+4=7$. Understanding this inverse relationship allows children to solve $3 + \_\_\_ = 7$ by asking $7-3=\_\_\_$. Children seem to grasp the inverse problem with simple mathematical events presented orally by about 5 years of age (e.g., Bryant et al., 1999; Vilette, 2002). However, it is not until later, at least 8 years of age, when children seem to be able to apply this principle to actual equations rather than simple mathematical events (Baroody, 1999; Bryant et al., 1999)

Complete understanding of addition and subtraction seems to be dependent on the acquisition of the inversion principle, i.e., subtraction is the inverse of addition. University students may exhibit general and specific switch costs, but because they have acquired the inversion principle, and neither addition nor subtraction is a stronger task. On the other hand, the early primary school children may exhibit asymmetrical general and specific switch costs because their lack of the inversion principle with written equations results in addition being a stronger task than subtraction because they rely on more elementary strategies like counting on and counting backwards (e.g., Lucangeli et al., 2003).

It may be the case that for the university students, this task required the loading up of an arithmetic module that includes different applications, i.e., addition and subtraction. Younger children, who have not yet acquired the inversion principle, may be loading up separate and distinctive rule sets for addition and subtraction. The final set of experiments attempted to explore further the role of task mastery in switch costs and how one measure of task mastery in arithmetic, the inversion principle, might impact on asymmetrical switch costs.

10. Experiment 3: Arithmetic II

In Experiment 3, participants switched between addition and missing addend equations, e.g., $3 + \_\_ = 5$. Here, the goal was to identify whether switch costs persist when switching includes the more complex task of missing addends. The use of missing addends allows for a further investigation of the role of task mastery and understanding of the inversion principle. If participants have acquired the inversion principle, then switching between addition and missing addends would produce general and specific switch costs, but not asymmetrical switch costs. Baroody's (1999) and Bryant et al.'s (1999) studies indicated that early primary school children would not have acquired the inverse principle for written equations. Without the inverse principle, addition would be a stronger task than missing addends. Similar to Experiment 2, we expected to find asymmetrical switch costs at the general and specific levels for children, indicating that addition is the stronger task than subtraction for younger participants.

Age group differences in Experiment 2 might have been driven by mastery of the task. More specifically, the children may have a different understanding of addition and subtraction than adults, and differences in this understanding are responsible at least partially for the differences in switch costs between these two age groups. University students have acquired the inversion principle and addition is no longer a stronger task than subtraction. Further evidence of the use of the inversion principle would be that university students continue to exhibit only general and specific switch costs when switching between addition and missing addends. If university students have acquired the inversion principle, then the patterns of results for adults in Experiment 3 would be similar to Experiment 2, with adults exhibiting general and specific switch costs, but not asymmetrical switch costs.

11. Method

11.1. Participants

A total of 21 Year 2 children and 15 university students who completed Experiment 1 participated in this experiment. The order of completing Experiments 1 and 3 was counterbalanced across participants. In the children's age group, there were 11 females and 10 males, with an average age of 7.38 years (S.D. = .25, range = 6.89–7.84). In the university age group, there were 13 females and 2 males, with an average age of 19.04 years (S.D. = .51, range = 18.46–20.18).

11.2. Materials

The stimuli for this experiment were simple addition equations in three different formats. Format 1 was the standard addition format (e.g., $3 + 2 = \_\_$) and Formats 2 and 3 were missing addend equations. In Format 2, the middle number was missing (e.g., $3 + \_\_ = 5$). In Format 3, the first number was missing (e.g., $\_\_ + 2 = 5$). Again, only single digit numbers were included in the equations.

11.3. Design and procedures

The design and procedures were identical to Experiment 2 with the following changes. There were six blocks presented in a counterbalanced order across participants. Three of the blocks were pure blocks, one each of Formats 1–3. Three of the blocks were mixed blocks using the alternating runs pattern. There was one block each of Formats 1 and 2 mixed, Formats 1 and 3 mixed, and Formats 2 and 3 mixed. To prevent fatigue in the children, the number of trials per block was reduced to 21, for a total of 126 trials.

12. Results and discussion

12.1. Analyses

Initial analyses indicated that there were no significant differences between Formats 2 and 3. To simplify the analyses, these two format types were combined into one group. As a result, the blocks containing switches between the two missing addend formats were dropped from further analyses.

12.2. Early primary school student performance

12.2.1. Task effects

There were no significant effects or interactions for accuracy. The children responded more quickly to addition (4578 ms) than to missing addends (8594 ms), F (1, 20) = 14.95, $p < .001$, M.S.E. = 8096, $d = .55$.

12.2.2. General switch costs

There were no significant effects or interactions for accuracy. As indicated by the left-hand side of Fig. 5, there was a significant Block × Task interaction for RT, F (1, 20) = 6.22, $p < .05$, M.S.E. = 8093, $d = .24$. The switch costs for addition (1054 ms) were greater than for missing addends (−430 ms). This interaction was driven largely by the unexpected finding that the RTs for the missing addend items were faster during the switch than the repeat trials.

12.2.3. Specific switch costs

There were no significant effects or interactions for accuracy. As indicated by right-hand side Fig. 5, there was a non-significant Trial × Task interaction for RT, F (1, 20) = 2.86, $p = .10$,

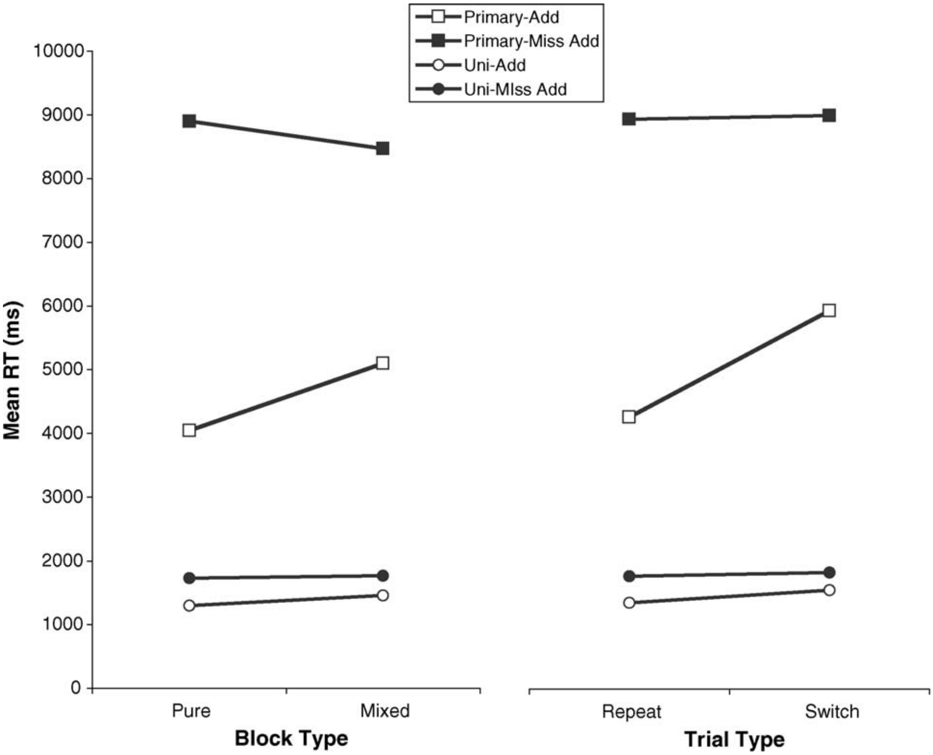

Fig. 5. Mean RT for the Experiment 3 for early primary school and university students during pure and mixed blocks and during repeat and switch trials of addition (Add) and missing addends (Miss Add) items.

M.S.E. = 8096, $d = .35$. The switch costs was larger for addition (1631 ms) than for missing addends (56 ms). Additional analyses indicated that there were no significant differences between the repeat trials in the pure versus alternating runs blocks or between the switch trials in the alternating and alternating runs blocks.

12.3. University student performance

12.3.1. Task effects

There were no significant effects or interactions for accuracy. RTs were faster to addition (1419 ms) than for missing addends (1759 ms) items, F (1, 14) = 49.67, $p < .0001$, M.S.E. = 766, $d = .45$.

12.3.2. General switch costs

There were no significant effects or interactions for accuracy. As on the left-hand side of Fig. 5, participants responded faster to the repeat blocks (1584 ms) than to the mixed blocks (1612 ms), F (1, 14) = 12.04, $p < .01$, M.S.E. = 767, $d = .03$. Furthermore, a non-significant Block × Task interaction, F (1, 14) = 4.19, $p = .06$, M.S.E. = 767, indicated that there were larger switch costs for addition (159 ms) than for missing addends (38 ms).

12.3.3. Specific switch costs

There were no significant effects or interactions for accuracy. As shown on the right-hand side of Fig. 5, there was a main effect of Trial Type, F (1, 14) = 10.48, $p < .01$, M.S.E. = 766, $d = .09$. Participants responded more quickly to repeat (1578 ms) than to switch trials (1657 ms). There were no asymmetrical switch costs. Again, there were no significant differences between the repeat trials in the pure versus alternating runs blocks or between the switch trials in the alternating and alternating runs blocks.

12.4. Age effects

There was a trend for university students (99%) to be more accurate than early primary school students (92%), but this was not significant, F (1, 34) = 3.58, $p = .07$, M.S.E. = .200, $d = .92$. Overall, university students (1595 ms) responded more quickly than early primary school students (7072 ms), F (1, 34) = 48.40, $p < .0001$, M.S.E. = 4629, $d = .32$. There was a significant Age Group × Task Interaction, F (1, 34) = 14.07, $p = .001$, with larger differences between addition and missing addends for early primary school students (4183 ms) than for university students (867 ms). A significant Age Group × Block × Task interaction, F (1, 34) = 5.37, $p < .05$, M.S.E. = 4629, $d = .24$, indicated that larger general switch costs for addition (1054 ms) than for missing addends (−430 ms) were found in early primary school students only. Finally, a significant Age Group × Trial × Task interaction, F (1, 34) = 5.58, $p < .05$, M.S.E. = 4629, $d = .35$, indicated that larger specific switch costs for addition (1631 ms) than for missing addends (56 ms) were found in early primary school students only.

12.5. Conclusions

The results for the children are fairly similar to Experiment 2 (see Tables 2 and 3), except that here we found asymmetrical switch costs in young children at the general level only. As reflected by the larger RTs, this task was much more difficult than Experiment 2. There were significant age group differences. Similar to Experiment 2, university students exhibited significant switch costs at the general and specific level, and did not exhibit switch cost asymmetries between addition and missing addends. These results support the idea that acquisition

Table 3
The significant effects in accuracy (Acc) and reaction time (RT) for early primary school and university students in Experiment 3

	Early primary school students	University students
Task effects		
Addition vs. missing addends	RT	RT
Overall switch costs		
Pure vs. mixed blocks		RT
Repeat vs. switch trials		RT
Asymmetrical switch costs		
Task × Block	RT	RT*
Task × Trial	RT*	

* Indicates non-significant trend with $p < .10$

of the inversion principle might result in addition no longer being a stronger task than subtraction. Thus, apparent developmental differences between early primary school and university students might reflect an interaction between the development of cognitive structures and task mastery.

13. General discussion

This is the first project to identify asymmetries in general and specific switch costs for primary school children across switching tasks. The evidence here suggests that children are in fact sensitive to switch costs at both the block and the trial level and that these switch costs are different for the stronger versus the weaker task. Following other studies of asymmetrical switch costs with adults (e.g., Allport et al., 1994; Yeung & Monsell, 2003a), we found that switch cost asymmetries were larger for the stronger tasks of color matching and addition than for the weaker tasks of shape matching and subtraction.

Replicating our experiments with university students indicated that the modifications in our experimental design that were necessary to enable young children to complete the tasks continued to elicit traditional task switching results. In addition, the results with university students suggested that our results with children might be driven by developmental differences between adults and children and not by the design modifications. Similar to previous task switching studies comparing adults with children (Cepeda et al., 2001; Cohen et al., 2001) and adolescents (Reimers & Maylor, 2005), we found that adults were faster and more accurate on the tasks than children. However, despite these absolute differences, the overall patterns of switch performance were the same between adults and children in the figure matching switching experiments. In the arithmetic experiments, children exhibited greater asymmetrical switch costs than adults.

There are a few possible explanations for the differences between the results for children and adults. Firstly, these tasks differ in difficulty. The figure matching experiment might have been relatively simple for both age groups, whereas the arithmetic experiments might have been more difficult for the children. Increased asymmetrical switch costs in children may reflect the fact that the difference in difficulty between addition and subtraction is greater for children than adults. It might be possible that the large asymmetrical switch costs here were driven by a general slowing for children during the addition trials in the presence of the subtraction or missing addend trials. In other words, subtraction and missing addends are so difficult for children that they slow down for the entirety of the mixed blocks. However, because we do not see significant differences in response time for the addition repeat trials during the pure versus the mixed blocks, this interpretation does not account for our data. A second possibility here would be that participants slow down on a trial after making an error. It is true that the children in our study show significant differences in accuracy for addition over subtraction and it is possible that they slowed down their responses to the addition trials after making a mistake on the subtraction trials. However, this does not explain the differences between the adults and the children for asymmetrical switch costs, because the adults show significant differences in accuracy for addition versus subtraction equations and because neither group shows significant differences in accuracy for addition versus missing addend equations.

Secondly, previous task switching studies have indicated that task familiarity (Meuter & Allport, 1999; Yeung & Monsell, 2003a) and task complexity (Rubenstein et al., 2001) influence switch costs. Given the fact that university students have more years experience with arithmetic, more generally, and addition and subtraction, more specifically, it is possible that their familiarity with these tasks results in differences between the two groups. And, because adults have more practice, more experience, and more familiarity with these tasks, and because adults generally are more competent in arithmetic, it is likely that these abilities result in decreased task complexity for the adults compared to the children.

Secondly, children may exhibit greater differences than adults because they do not fully understand the inverse relationship between addition and subtraction (e.g., Baroody, 1999). It may be the case that asymmetrical switch costs will decrease as children begin to understand this inverse relationship. Understanding the inverse relationship between addition and subtraction may allow for the two tasks to become more similar and less like two different computational tasks. Assuming that children's early computational skills rely on counting on for addition and counting backwards for subtraction then switch costs may reflect the cognitive mechanisms required to switch from counting forwards to counting backwards. Once the inverse relation between addition and subtraction is acquired, then addition is no longer a stronger task than subtraction and the asymmetrical switch costs diminish. While at the same time, general and specific switch costs persist because participants still must switch between the tasks. This fits with Shafiulla and Monsell (1999)'s observation of specific switch costs in native speakers of Japanese. Switching between two Japanese scripts that share similar familiarity and task strength produce switch costs.

These results lend support to the online configuration explanation of asymmetrical switch costs. The weaker task may interfere with performance of the stronger task. This is evidenced by the fact that the asymmetry gets stronger for the children as the weaker task gets more difficult and by the fact that the asymmetry goes away for the adults in the arithmetic experiments. On the other hand, these same results could be used to support the task set inertia explanation. It might be the case that the asymmetrical switch costs seen here are a result of the weaker task disrupting the priming of the stronger task. Further studies that manipulate the wide variety of factors that have been used to support the theoretical interpretations in task switching will be necessary before firm conclusions regarding the strength of either of these explanations of task switching as they relate to cognitive development.

Although differences between adults and children seem to indicate differences in development, task mastery, and/or an interaction between the two, the general patterns of asymmetrical switch costs are remarkably similar between these two age groups for the figure matching task. These similarities indicate that there is consistency between children's and adult's asymmetrical switch costs and that the theoretical explanations of the cognitive mechanisms responsible for switch costs in adults can be applied to children. However, the differences between the age groups indicate that levels of task mastery must be considered when applying these theoretical explanations. An accurate understanding of the development of these mechanisms requires additional studies that account for the relative contributions of development and task mastery.

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Appendix A. The proportion of error trials that were errors and excluded from the RT analyses by age group and block type for Experiments 1–3

	Pure color (%)	Pure shape (%)	Pure add (%)	Pure subtract (%)	Pure missing addends (%)	Switch (%)	Alternating runs (%)
Experiment 1							
Primary	10	16				16	15
University	2	3				2	3
Experiment 2							
Primary			7	17		15	13
University			2	4		3	4
Experiment 3							
Primary			8		8		8
University			1		2		1

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