The development of strategy use in elementary school children: Working memory and individual differences

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Abstract

The current study tested the development of working memory involvement in children's arithmetic strategy selection and strategy efficiency. To this end, an experiment in which the dual-task method and the choice/no-choice method were combined was administered to 10- to 12-year-olds. Working memory was needed in retrieval, transformation, and counting strategies, but the ratio between available working memory resources and arithmetic task demands changed across development. More frequent retrieval use, more efficient memory retrieval, and more efficient counting processes reduced the working memory requirements. Strategy efficiency and strategy selection were also modified by individual differences such as processing speed, arithmetic skill, gender, and math anxiety. Short-term memory capacity, in contrast, was not related to children's strategy selection or strategy efficiency.

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Introduction

Learning to perform simple arithmetic tasks efficiently and with little effort is one of the most fundamental skills taught during the elementary school years. Several cognitive mechanisms may underpin the development of arithmetic skill in children. The current

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study was designed to investigate the role of one such cognitive mechanism, namely the executive component of working memory. Besides an online study of the role of working memory in the development of children's arithmetic strategy use, we tested the influence of individual difference variables such as processing speed, short-term memory, arithmetic skill, math anxiety, and gender.

The role of working memory in children's arithmetic strategy use

Working memory can be defined as a set of processing resources of limited capacity involved in information maintenance and processing (e.g., [Baddeley & Logie, 1999](#); [Engle, Tuholski, Laughlin, & Conway, 1999](#); [Miyake, 2001](#)). Most researchers agree that working memory resources play a role in children's simple arithmetic performance. This assertion is based mainly on studies showing a working memory deficit in mathematically disabled children (e.g., [Bull, Johnston, & Roy, 1999](#); [Geary, Hoard, & Hamson, 1999](#); [McLean & Hitch, 1999](#); [Passolunghi, Cornoldi, & De Liberto, 1999](#); [Passolunghi & Siegel, 2004](#); [Swanson & Beebe-Frankenberger, 2004](#); [Swanson & Sachse-Lee, 2001](#); [van der Sluis, de Jong, & van der Leij, 2004](#)). The goal of our study, however, was to investigate the role of working memory in arithmetic strategy use by normally developing children. To this end, we needed to overcome several shortcomings of the studies just mentioned.

First, the role of working memory has been studied predominantly by means of correlations between working memory measures (e.g., counting span, Trails task, Stroop task) and simple arithmetic performance (e.g., [Bull & Johnston, 1997](#); [Bull et al., 1999](#); [Bull & Scerif, 2001](#); [McLean & Hitch, 1999](#); [Passolunghi & Siegel, 2001](#)). Because correlation is not causation, it is still possible that working memory measures and mathematical ability rely on a common factor such as general intelligence or processing speed.

In the current study, we aimed at investigating the role of working memory in children's arithmetic performances online. To this end, we used the dual-task method, in which children needed to solve simple arithmetic problems (i.e., the primary task) while their working memories were loaded by means of the secondary task. The dual-task method has been used frequently in adult studies (for a review, see [DeStefano & LeFevre, 2004](#)), which clearly show that working memory is needed in adults' simple arithmetic performance. More specifically, adults' simple arithmetic performance always relies on executive working memory resources, as opposed to verbal and visuospatial working memory resources, of which the role in simple arithmetic is less clear.

Although the dual-task method has been used only rarely in child studies, [Hitch, Cundick, Haughey, Pugh, and Wright \(1987\)](#) conducted a dual-task study in which children needed to verify simple addition problems (e.g., $3 + 5 = 7$, true or false?) while their memories were phonologically loaded. Because errors and latencies rose under such a load, Hitch and colleagues concluded that children's counting processes involve inner speech. The dual-task method was further used by [Kaye, deWinstanley, Chen, and Bonnefil \(1989\)](#). In their study, second, fourth, and sixth graders verified simple addition problems while their working memories were loaded by means of a probe detection task. This secondary task affected addition speed most profoundly in second graders and much less so in fourth and sixth graders, indicating that computational efficiency increases with increasing grade level. Finally, [Adams and Hitch \(1997\)](#) did not use the dual-task method but rather manipulated the presentation format of addition problems (i.e., oral vs. visual presentation). The visual presentation provided an external record of the addends that reduced working memory

load. Because children's performance was better in the visual condition than in the oral condition, Adams and Hitch concluded that children's mental arithmetic performance is mediated by working memory resources. Unfortunately, none of these studies investigated the impact of an executive working memory load on children's arithmetic performance.

A second shortcoming in previous studies is the ignorance of the locus of effect of working memory support. Although it has been shown that working memory resources correlate with arithmetic performance, it is not clear whether working memory is needed in strategy selection processes (i.e., which strategies are chosen to solve the problem?) and/or strategy efficiency processes (i.e., is the problem solved fast and accurately by means of the chosen strategy?). This is a relevant question, however, because children do use several strategies to solve simple arithmetic problems (e.g., Barrouillet & Lépine, 2005; Davis & Carr, 2002; Geary, 1994; Geary & Brown, 1991; Geary, Brown, & Samaranayake, 1991; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Geary et al., 1999; Mabbott & Bisanz, 2003; Noël, Seron, & Trovarelli, 2004; Siegler, 1987, 1996; Steel & Funnell, 2001; Svenson & Sjöberg, 1983), including direct memory retrieval (e.g., "knowing" that $8 + 5 = 13$), transformation (e.g., $8 + 6 = 8 + 2 + 4 = 10 + 4 = 14$), and counting (e.g., $4 + 3 = 4 \dots 5 \dots 6 \dots 7$).

Unfortunately, all studies mentioned included a choice condition only, that is, a condition in which the children were free to choose any strategy they wanted. It has been shown convincingly that choice conditions provide reliable measures of strategy selection but not of strategy efficiency (Siegler & Lemaire, 1997). Indeed, strategy efficiency measures are biased by the strategy selection process. Because the current study aimed to investigate the role of working memory in both strategy selection and strategy efficiency, the choice/no-choice method (devised by Siegler & Lemaire, 1997) was used. This method includes a choice condition plus several no-choice conditions, in which participants are asked to use one single strategy for all problems. Data obtained in no-choice conditions provide reliable strategy efficiency measures. Some recent studies applied the choice/no-choice method successfully to investigate children's arithmetic performance (e.g., Carr & Davis, 2001; Lemaire & Lecacheur, 2002; Torbeyns, Verschaffel, & Ghesquière, 2002, 2004, 2005).

A third and final shortcoming is that very few studies have investigated the role of working memory in normally achieving children (but see Adams & Hitch, 1997; Ashcraft & Fierman, 1982; Bull & Scerif, 2001; Geary, Bow-Thomas, Liu, & Siegler, 1996; Hecht, Torgesen, Wagner, & Rashotte, 2001; Kaye et al., 1989). Because we believe that it is important to know how the interaction between working memory and arithmetic performance progresses in normal development, the current study tested children without mathematical disabilities. A similar research question was raised by Barrouillet and Lépine (2005), who tested normally developing elementary school children. They observed that children with high working memory capacities solved simple addition problems more efficiently than did children with low working memory capacities. Working memory capacity correlated with strategy selection as well; percentages of retrieval use were higher in high-capacity children than in low-capacity children.

To summarize, the current study addressed the development of working memory involvement in children's arithmetic strategy use. To this end, an experiment combining the dual-task method and the choice/no-choice method was administered to 10- to 12-year-olds. The dual-task method permits an online investigation of working memory involvement in arithmetic performance, and the choice/no-choice method permits collection of reliable strategy selection and strategy efficiency data. These methods have been combined successfully in adult studies (I. Imbo & A. Vandierendonck, unpublished results) but not

yet in child studies. However, results obtained in adult studies cannot simply be generalized to children. Therefore, the current study not only investigated the development of working memory involvement in children's strategies but also tested whether results obtained in adult studies apply to children.

Our hypotheses are based on the assertion that many working memory resources are needed during the initial phase of learning and that fewer working memory resources are needed as procedural strategies (transformation and counting) are used less frequently and arithmetic facts become represented in long-term memory (see also Ackerman, 1988; Geary et al., 2004; Siegler, 1996). We suppose, however, that the decrease of working memory involvement in arithmetic tasks across development is not caused by strategy selection processes only but rather is also caused by strategy efficiency processes.

First, age-related differences in strategy selection might change the ratio between working memory involvement and the demands of the arithmetic task. Because direct memory retrieval needs fewer working memory resources than do nonretrieval strategies, more frequent retrieval use might reduce the requirements of the arithmetic task, leaving more working memory resources free for the secondary task. Stated differently, the impact of a working memory load on the arithmetic task will diminish when strategy selection becomes more efficient (i.e., when the outcome of the selection process leads to the least demanding strategy).

Second, the ratio between working memory involvement and simple arithmetic task demands might be changed further by more efficient retrieval use. Because direct memory retrieval relies on working memory resources (I. Imbo & A. Vandierendonck, unpublished results), it is hypothesized that faster retrieval would need fewer working memory resources than would slow and effortful retrieval. Indeed, as problem–answer associations become stronger across development, fewer working memory resources would be needed to retrieve the correct solution from long-term memory.

Third, we hypothesized that an age-related increase in nonretrieval strategy efficiency would also change working memory involvement. Because nonretrieval strategies (transformation and counting) rely heavily on working memory resources (I. Imbo & A. Vandierendonck, unpublished results), it is hypothesized that more efficient procedural use would need fewer working memory resources than would less efficient procedural use. The componential steps used in nonretrieval strategies would become more practiced and require less effort with age, resulting in lower working memory demands. The latter two hypotheses imply an age-related decrease in the impact of working memory load on strategy efficiency. More specifically, we anticipate that the execution time of retrieval, transformation, and counting strategies will suffer less from a working memory load as children become older.

Finally, we expected an age-related decrease in the working memory costs due to general (i.e., nonmathematical) processes such as encoding stimuli and pronouncing answers. To test this prediction, a “naming” condition was included in the current study. In this condition, children needed to name the correct answer to the problem presented on the screen. It was expected that the naming task would require fewer working memory resources with growing age. The naming condition also offers the opportunity to test whether direct memory retrieval relies on working memory. If the impact of working memory load on retrieval is larger than that on naming, one may conclude that the very specific fact retrieval processes (i.e., long-term memory access, activation of the correct answer, and inhibition of incorrect answers) need working memory resources.

Individual differences in children's arithmetic strategy use

To enhance understanding of children's arithmetic strategy use, the current study examined individual differences as well. Five individual difference variables that might influence children's arithmetic performance were selected: short-term memory, processing speed, arithmetic skill, math anxiety, and gender.

Short-term memory

Short-term memory is a system that passively stores information and can be distinguished from working memory (which entails both storage and processing) already by 7 years of age (Kail & Hall, 2001). Although the relation between short-term memory and arithmetic ability in mathematically disabled children is still questioned, short-term memory is not expected to play a great role in normally achieving children's arithmetic ability. Bull and Johnston (1997), for example, observed no correlations between short-term memory and retrieval frequency, retrieval efficiency, or counting efficiency. In the current study, digit span was used to collect data on children's short-term capacity.

Processing speed

The relation between processing speed and arithmetic ability was first examined by Bull and Johnston (1997). These authors observed that processing speed was the best predictor of mathematical ability among several other variables such as short-term memory, speech rate, and item identification. This result was further confirmed by Kail and Hall (1999), who observed that processing speed had the strongest and most consistent relation to arithmetic problem solving. Hitch, Towse, and Hutton (2001), however, maintained that working memory span is a better predictor of arithmetic ability than is processing speed. In a longitudinal study by Noël et al. (2004), processing speed did not predict children's later performance on addition tasks. However, the researchers observed a bizarre correlation between processing speed and retrieval frequency in that slower participants were those who used retrieval more frequently. Thus, the evidence is equivocal concerning the role of processing speed as a critical determinant of simple arithmetic performance. Because efficient strategy execution is generally defined as fast (and correct) strategy execution, we expected a positive correlation between processing speed and strategy efficiency. Because efficiently executed strategies strengthen the problem–answer association in long-term memory, we further expected that children with a higher processing speed would use retrieval more frequently. This expectation is in disagreement with the observation of Noël et al. (2004) but is more compelling than expecting a negative correlation between processing speed and retrieval efficiency.

Arithmetic skill

The relation between arithmetic skill, on the one hand, and strategy selection and strategy efficiency, on the other, is straightforward in that persons who use retrieval frequently and who are fast in executing strategies will perform better on arithmetic skill tests. This relation has been shown in adults (e.g., Ashcraft, Donley, Halas, & Vakali, 1992; Campbell & Xue, 2001; Hecht, 1999; Imbo, Vandierendonck, & Rosseel, in press; Kirk & Ashcraft, 2001; LeFevre et al., 1996; LeFevre, Sadesky, & Bisanz, 1996) as well as in children (e.g.,

Geary & Burlingham-Dubree, 1989). We expected more frequent retrieval use and more efficient strategy use in high-skill children than in low-skill children.

Math anxiety

In adults, math anxiety is an individual difference variable that affects online performance in math-related tasks (Ashcraft & Kirk, 2001). High- and low-anxious adults differ in complex arithmetic tasks (e.g., sums of two two-digit numbers) but not in simple arithmetic tasks (Ashcraft, 1995; Ashcraft & Faust, 1994; Faust, Ashcraft, & Fleck, 1996). More recently, however, effects of math anxiety have been observed on simple arithmetic strategy use in adults (I. Imbo & A. Vandierendonck, unpublished results). In general, high-anxious adults were slower in the execution of both retrieval and nonretrieval strategies. Effects of math anxiety on strategy selection were also found in that percentage retrieval use was lower in high-anxious adults than in low-anxious adults. In the current child sample, high-anxious children were expected to be less efficient than low-anxious children, and high-anxious children were expected to use retrieval less often than low-anxious children.

Gender

Several studies have indicated that gender differences exist in arithmetic strategy choices made by elementary school children. More specifically, direct memory retrieval is chosen more frequently by boys, whereas nonretrieval strategies are chosen more frequently by girls (Carr, 1996; Carr & Jessup, 1997; Davis & Carr, 2002). With respect to strategy efficiency, gender differences exist as well in that boys are faster than girls in executing computational processes (Carr & Jessup, 1997; Carr, Jessup, & Fuller, 1999; Fennema, Carpenter, Jacobs, Franke, & Levi, 1998; Geary, Bow-Thomas, Fan, & Siegler, 1993; Geary, Saults, Liu, & Hoard, 2000) and, more specifically, in direct memory retrieval (Royer, Tronsky, Chan, Jackson, & Marchant, 1999). Based on these previous results, we expected more frequent and more efficient retrieval use in boys than in girls.

Method

Participants

A total of 63 children participated. They all attended the same elementary school in the Flemish part of Belgium. Of the total participants, 21 were in the fourth grade of elementary school (mean age = 10 years 0 months, 9 girls and 12 boys), 21 were in the fifth grade (mean age = 11 years 1 month, 10 girls and 11 boys), and 21 were in the sixth grade (mean age = 12 years 2 months, 14 girls and 7 boys). Children were selected from the whole ability range, although those who were considered by their teachers to have specific learning or behavioral difficulties were excluded. The children had no documented brain injuries or behavioral problems. They participated only when they, as well as their teachers and parents, consented.

Procedure

Several individual difference tests and one dual-task experiment were administered to each child. The whole procedure (individual difference tests and dual-task experiment)

took approximately 1 h per child but was divided into two parts of 30 min each. Each child was tested individually in a quiet room. Testing started with short questions about the child such as age, grade, and math anxiety (on a rating scale from 1 [*low*] to 5 [*high*]). Then the first part of the dual-task experiment was run, after which the digit span test was administered. Approximately 5 days later, the second part of the dual-task experiment was run, after which the processing speed test was administered. After all individual experiments were run, the arithmetic skill test was run classically. Each individual difference test and the dual-task experiment (consisting of a primary task and a secondary task) are described more extensively in the remainder of this section.

Primary task: Solving simple addition problems

Children needed to solve simple addition problems in five conditions: a choice condition, three no-choice conditions (the order of which was randomized), and a naming condition (in which correct answers were presented on the screen). The choice condition always was the first so as to exclude influence of no-choice conditions on the choice condition, and the naming condition always was last so as to exclude effects of naming on solving the problems. In the choice condition, 6 practice problems and 32 experimental problems were presented. The no-choice conditions started immediately with the 32 experimental problems. Each condition was further divided into two blocks: a control block without working memory load and a block in which the executive component of working memory was loaded. For half of the children, each condition started with the no-load block and was followed by the working memory load block. The order was reversed for the other half of the children.

The addition problems were composed of pairs of numbers between 2 and 9, of which the sum exceeded 10 (e.g., $6 + 7$). Problems involving 0 or 1 as an operand or answer (e.g., $5 + 0$) and tie problems (e.g., $8 + 8$) were excluded. Because commuted pairs (e.g., $9 + 4$ and $4 + 9$) were considered as two different problems, this resulted in 32 addition problems (ranging from $2 + 9$ to $9 + 8$). A trial started with a fixation point for 500 ms. Then the addition problem was presented horizontally in the center of the screen with the plus (+) sign at the fixation point. In the naming condition, the problem was presented with its correct answer (e.g., $9 + 8 = 17$). The problem remained on the screen until children responded. Timing began when the stimulus appeared and ended when the response triggered the sound-activated relay. To enable this sound-activated relay, children wore a microphone that was activated when they spoke their answer aloud. This microphone was connected to a software clock accurate to 1 ms. On each trial, feedback was presented to children—a happy face when their answer was correct and a sad face when it was not.

Immediately after solving each problem, children in the choice condition were presented with four strategies on the screen: Retrieval, Count, Transform, and Other (e.g., Campbell & Gunter, 2002; Campbell & Xue, 2001; Kirk & Ashcraft, 2001; LeFevre et al., 1996; Seyler, Kirk, & Ashcraft, 2003). These four choices had been explained extensively by the experimenter:

Retrieval: “You solve the problem by remembering or knowing the answer directly from memory.”

Count: “You solve the problem by counting a certain number of times to get the answer.”

Transform: “You solve the problem by referring to related operations or by deriving the answer from known facts.”

Other: “You solve the problem by a strategy unlisted here, or you do not know what strategy you used to solve the problem.”

Examples of each strategy were presented as well. Children needed to report verbally which of these strategies they had used.

In the no-choice conditions, children were forced to use one particular strategy to solve all problems. In no-choice/retrieval, they were asked to retrieve the answer; in no-choice/transform, they were asked to transform the problem by making an intermediate step to 10 (e.g., $9+6=9+1+5=10+5=15$); and in no-choice/count, they were asked to count (subvocally) until they reached the correct total (e.g., $7+4=7\dots8\dots9\dots10\dots11$). Children were free to choose whether they started to count from the larger addend on (cf. the “min” counting strategy (Groen & Parkman, 1972)). After solving the problem, children also answered with “yes” or “no” to indicate whether they had succeeded in using the forced strategy. In choice and no-choice conditions, the children’s answer, the strategy information, and the validity of the trial were recorded online by the experimenter. All invalid trials (e.g., failures of the voice-activated relay) were discarded and returned to at the end of the block, thereby minimizing data loss due to unwanted failures.

Secondary task: Executive working memory load

An adapted version of the Continuous Choice Reaction Time Task-Random (CRT-R task) (Szmalec, Vandierendonck, & Kemps, 2005) was used to load the executive working memory component. Compared with the original version of the CRT-R, the difference between low and high tones was larger (262 and 1048 Hz vs. 262 and 524 Hz), the interval between both tones was longer (2000 and 2500 ms vs. 900 and 1500 ms), and the duration of each tone was longer (300 ms vs. 200 ms). Children needed to press the 4 on the numerical keyboard when they heard a high tone and needed to press the 1 when they heard a low tone. This task was also performed alone (i.e., without the concurrent solving of addition problems) at the beginning of the working memory load block.

Digit span

Digit span was tested using the Wechsler Intelligence Scale for Children-Revised (WISC-R) digit span subtest (Wechsler, 1986). In this task, digits are read aloud by the experimenter, and children need to repeat them in the correct order. There were two trials for each span length. The experimenter started from a span length of two digits and continued until the children made a mistake in both trials of the same span length. The highest span length reached by the children was set as “digit span.”

Processing speed

Processing speed was tested by a visual number matching task (also used by Bull & Johnston, 1997),¹ which consisted of 30 rows of six digits, with two digits in each row being

¹ We are grateful to these authors for providing us with the stimuli used in their visual number matching task.

identical (e.g., 5 3 1 8 9 3). Children were instructed to cross out the identical digits in each row and to work both as quickly and as accurately as possible. The performance measure was the time taken to complete all 30 rows of digits. Note that a higher measure indicates slower performance.

Arithmetic skill

A standardized skill test (Arithmetic Tempo Test (DeVos, 1992)) was administered classically after all individual experiments were run. This pen-and-paper test consists of several subtests that require elementary computations. Each subtest concerns only one arithmetic operation. In the current experiment, we administered the addition subtest (e.g., $2 + 3 = ?$, $76 + 18 = ?$) and the subtraction subtest ($7 - 5 = ?$, $54 - 37 = ?$), each consisting of 40 items of increasing difficulty. For each subtest, children were given 1 min to solve as many problems as possible. Performance was the sum of the addition and subtraction subtests.

Results

Of all trials, 5.2% were spoiled due to failures of the sound-activated relay. Because these invalid trials were readministered at the end of the block, most of them were recovered, thereby reducing to 0.8% the trials spoiled due to failures of the sound-activated relay. Furthermore, all incorrect trials (3.5%), all choice trials on which children reported having used an Other strategy (0.3%), and all no-choice trials on which children failed to use the forced strategy (8.8%) were deleted. All data were analyzed on the basis of the multivariate general linear model, and all reported results are considered to be significant at $p < .05$ unless mentioned otherwise.

This section is divided into four parts. We start with the results of the secondary task. Thereafter, the results concerning strategy efficiency and strategy selection are reported. Finally, the importance of individual differences is discussed. Due to voice key problems, 2 children (1 fourth grader and 1 sixth grader) were excluded from analyses, leaving scores for 20 fourth graders, 21 fifth graders, and 20 sixth graders.

Secondary task performance

A 3×6 analysis of variance (ANOVA) was conducted on accuracy on the CRT-R task, with grade (fourth, fifth, or sixth) as a between-subjects factor and primary task (no primary task, naming, no-choice/retrieval, no-choice/transform, no-choice/count, or choice) as a within-subjects factor (Table 1). The main effect of grade was significant, $F(2, 58) = 5.77$, $MSe = 3770$; fourth graders were less accurate than fifth graders, $F(1, 58) = 8.95$, but there was no difference between fifth graders and sixth graders, $F(1, 58) < 1$. The main effect of primary task was significant as well, $F(5, 54) = 16.53$, $MSe = 270$. Executing the CRT-R task without the primary task resulted in greater accuracy than CRT-R performance during naming, $F(1, 58) = 4.49$, which in turn led to greater accuracy than CRT-R performance during no-choice/retrieval, $F(1, 58) = 53.49$. Accuracy did not differ among the no-choice/retrieval, no-choice/transform, and choice conditions, all $F_s(1, 58) < 1$, but accuracy was lower in these three conditions than in the no-choice/count condition, $F_s(1, 58) = 10.47, 4.01, \text{ and } 13.36$, respectively.

Table 1

Mean accuracy (percentages) and mean correct reaction times (milliseconds) on the CRT-R task as a function of grade and primary task

	Fourth grade	Fifth grade	Sixth grade
<i>Accuracy</i>			
Naming	42 (7)	66 (7)	70 (7)
No-choice/retrieval	26 (6)	43 (6)	46 (6)
No-choice/transform	29 (6)	48 (6)	45 (6)
No-choice/count	26 (4)	59 (6)	50 (6)
Choice	25 (6)	44 (5)	44 (6)
<i>Reaction times</i>			
No primary task	772 (49)	739 (48)	743 (49)
Naming	944 (54)	786 (52)	790 (54)
No-choice/retrieval	1052 (50)	1028 (48)	1066 (50)
No-choice/transform	1026 (47)	1024 (46)	1010 (47)
No-choice/count	980 (40)	975 (39)	1001 (40)
Choice	1034 (36)	1054 (35)	964 (36)

Note. Standard errors are in parentheses.

A similar 3×6 ANOVA was conducted on correct reaction times (RTs) in the CRT-R task (Table 1). The main effect of grade did not reach significance, $F(2, 58) < 1$, $MSe = 75,586$, but the main effect of primary task did, $F(5, 54) = 25.99$, $MSe = 36,387$. Executing the CRT-R task without the primary task was faster than performance during naming, $F(1, 58) = 4.50$, which in turn was faster than performance during no-choice/retrieval, $F(1, 58) = 24.78$. There were no significant differences in RTs among the no-choice/retrieval, no-choice/transform, no-choice/count, and choice conditions, all $F_s(1, 58) < 1$, except that CRT-R performance was faster in no-choice/count than in no-choice/retrieval, $F(1, 58) = 4.24$. The Grade $\times$ Primary Task interaction was not significant, $F(10, 110) < 1$.

Strategy efficiency

Because accuracy was very high, (100% in no-choice/naming, 97% in no-choice/retrieval, 98% in no-choice/transform, 98% in no-choice/count, and 95% in choice), strategy efficiency was analyzed in terms of strategy speed. Only the RTs uncontaminated by strategy choices (i.e., no-choice RTs) were considered. A $3 \times 2 \times 4$ ANOVA was conducted on correct RTs with grade as a between-subjects factor and load (no load or load) and task (naming, retrieval, transformation, or counting) as within-subjects factors (Table 2).

The main effect of load was significant, $F(1, 58) = 83.53$, $MSe = 221,390$, with higher RTs under load than under no load. The main effect of grade was also significant, $F(2, 58) = 8.17$, $MSe = 4,145,150$. Fourth graders were significantly slower than fifth graders, $F(1, 58) = 9.30$, but there was no difference between fifth graders and sixth graders, $F(1, 58) < 1$. Finally, the main effect of task was significant as well, $F(3, 56) = 104.56$, $MSe = 1,451,894$. Naming was faster than retrieval, $F(1, 58) = 297.93$, retrieval was faster than transformation, $F(1, 58) = 43.02$, and transformation was faster than counting, $F(1, 58) = 28.62$.

Task further interacted with grade, $F(6, 114) = 4.08$, and with load, $F(3, 56) = 3.68$. The Task $\times$ Grade interaction indicated that the decrease in RTs over grades differed across strategies. Naming RTs decreased from fourth grade to fifth grade, $F(1, 58) = 12.08$, but did

Table 2

Mean correct reaction times (milliseconds) on the simple arithmetic task (in no-choice conditions) as a function of grade, load, and task

Strategy	Condition	Fourth grade	Fifth grade	Sixth grade
Naming	No load	641 (22)	525 (22)	511 (22)
	Load	989 (52)	794 (50)	790 (52)
Retrieval	No load	1650 (88)	1382 (86)	1115 (88)
	Load	2122 (106)	1763 (103)	1387 (106)
Transformation	No load	2550 (241)	2006 (235)	1816 (241)
	Load	3177 (325)	2610 (317)	2404 (325)
Counting	No load	4299 (360)	2684 (351)	2561 (360)
	Load	4778 (376)	2955 (367)	2644 (376)

Note. Standard errors are in parentheses.

not change from fifth grade to sixth grade, $F(1,58) < 1$. Retrieval RTs, in contrast, decreased from fourth grade to fifth grade, $F(1,58) = 5.95$, and from fifth grade to sixth grade, $F(1,58) = 6.24$. Transformation RTs did not change from fourth grade to fifth grade, $F(1,58) = 2.10$, or from fifth grade to sixth grade, $F(1,58) < 1$. Finally, counting RTs decreased from fourth grade to fifth grade, $F(1,58) = 11.86$, but not from fifth grade to sixth grade, $F(1,58) < 1$.

The Task $\times$ Load interaction showed that the effect of working memory load (i.e., RT load–RT no load) was the largest on transformation RTs (606 ms). This effect was larger than the effects on naming RTs (299 ms), $F(1,58) = 10.58$, retrieval RTs (375 ms), $F(1,58) = 5.39$, and counting RTs (278 ms), $F(1,58) = 7.57$. As hypothesized, the effect of load was larger on retrieval RTs than on naming RTs, $t(58) = 1.87$, indicating that the retrieval process requires extra executive working memory resources. It should be noted, however, that the effect of load was significant in each single task, $F(1,58) = 122.59$ for naming, $F(1,58) = 106.45$ for retrieval, $F(1,58) = 43.73$ for transformation, and $F(1,58) = 7.28$ for counting.

The Grade $\times$ Load and Grade $\times$ Load $\times$ Task interactions did not reach significance, $F(2,58) = 1.40$, and $F(6,114) < 1$, respectively. Planned comparisons were conducted, however, to test the development of working memory involvement in the different strategies. Whereas the effect of load on naming RTs did not change linearly² across grades, $F(1,58) = 1.08$, the effect of load on retrieval RTs decreased linearly across grades, $F(1,58) = 4.91$, with load effects of 472, 382, and 273 ms for fourth, fifth, and sixth graders, respectively. The effect of load on transformation RTs did not change either, $F(1,58) < 1$. Finally, the effect of load on the counting strategy tended to decrease linearly, $t(58) = 1.56$, $p = .062$ (one-tailed), with load effects of 479, 270, and 83 ms for fourth, fifth, and sixth graders, respectively.

To summarize, children require executive working memory resources to solve simple addition problems. Even the simple task of saying an answer displayed on the screen (“naming”) relies on executive resources. Retrieving an answer from long-term memory, however, needs even more executive resources. As children grow older, they become more efficient (faster) in the execution of retrieval and counting strategies but not in the execu-

² To test whether RTs changed linearly across grades, contrast values were -1 for fourth grade, 0 for fifth grade, and $+1$ for sixth grade.

tion of the transformation strategy. Increases in strategy efficiency are accompanied by decreases in working memory involvement. More specifically, higher retrieval and counting efficiencies reduced the requirements of executive resources, so that the negative impact of an executive load decreased with age. The executive resources needed in the naming task, however, remained the same across grades. The role of working memory in the transformation strategy (which relied most heavily on executive resources) did not change across grades either; all children relied equally heavily on their working memory to use this strategy.

Strategy selection

To investigate effects on strategy selection, a $3 \times 2 \times 3$ ANOVA was conducted on percentages strategy use (in the choice condition), with grade as a between-subjects factor and load and strategy (retrieval, counting, or transformation) as within-subjects factors (Table 3).

The main effect of strategy was significant, $F(2, 57) = 31.91$, $MSe = 2059$. Retrieval was used more frequently than transformation, $F(1, 58) = 25.28$, which in turn was used more frequently than counting, $F(1, 58) = 3.70$. Strategy further interacted with grade, $F(4, 116) = 2.64$. Retrieval use increased between fourth grade and fifth grade, $F(1, 58) = 6.85$, but did not change between fifth grade and sixth grade, $F(1, 58) = 1.63$. Transformation use decreased between fourth grade and fifth grade, $F(1, 58) = 10.79$, but did not change between fifth grade and sixth grade, $F(1, 58) = 1.31$. Finally, counting was used equally often between fourth and fifth grades and between fifth and sixth grades, both $F(1, 58) < 1$. The Load $\times$ Strategy and Load $\times$ Strategy $\times$ Grade interactions did not reach significance.

To summarize, all strategies were used by the children, although retrieval was used more frequently than were transformation and counting. Retrieval use also increased as children grew older. No effects of load on strategy selection were observed.

Individual differences

Table 4 displays means of each individual difference variable for each grade. The results of a one-way ANOVA, with grade as a between-subjects variable, are displayed in this table as well. The main effect of grade was significant for arithmetic skill and processing speed but not for digit span or math anxiety. Planned comparisons showed that the

Table 3
Mean percentages strategy use (in choice condition) as a function of grade and load

		Fourth grade	Fifth grade	Sixth grade
Retrieval	No load	46 (7)	67 (7)	60 (7)
	Load	48 (7)	76 (7)	60 (7)
Transformation	No load	41 (6)	15 (6)	22 (6)
	Load	40 (6)	6 (6)	22 (6)
Counting	No load	12 (5)	18 (5)	18 (5)
	Load	12 (5)	15 (4)	18 (5)

Note. Standard errors are in parentheses.

Table 4

Means of the individual difference variables across grades and results of ANOVAs with grade as a between-subjects factor

	Fourth grade mean	Fifth grade mean	Sixth grade mean	<i>F</i> (2, 58) main effect	<i>F</i> (1, 58) fourth grade vs. fifth grade	<i>F</i> (1, 58) fifth grade vs. sixth grade
Digit span	5.5 (1)	5.8 (1)	5.7 (1)	0.66	1.28	0.04
Processing speed	96 (14)	79 (15)	72 (10)	16.80**	15.73**	3.08*
Arithmetic skill	46 (5)	53 (7)	57 (6)	19.76**	15.99**	2.84*
Math anxiety	2.3 (1)	2.4 (1)	2.1 (1)	0.42	0.15	0.85

Note. Standard errors are in parentheses.

* $p < .10$.

** $p < .01$.

progress in arithmetic skill and processing speed was significant between fourth grade and fifth grade but not between fifth grade and sixth grade.

To test the influence of individual differences on children's arithmetic strategy use, correlations among strategy efficiencies, strategy selection, and the individual differences were calculated (Table 5).³ To consolidate the results presented in the previous sections, working memory load was also included in these correlational analyses.

The highest correlations appeared between the different types of strategy efficiency on the simple arithmetic task (range = .61–.62). Children who retrieved simple arithmetic facts from memory efficiently were also more efficient in employing nonretrieval strategies (counting and transformation).

Retrieval, transformation, and counting efficiencies further correlated with processing speed and arithmetic skill. Gender correlated with transformation efficiency only; transformation RTs were higher for boys than for girls. Fourth graders were slower than fifth graders on naming, retrieval, and counting but not on transformation. Fifth graders were slower than sixth graders on the retrieval strategy only. Working memory load correlated with naming RTs, retrieval RTs, and transformation RTs.

Strategy selection was also influenced by individual difference variables. The retrieval strategy was used more frequently by children with higher processing speeds and higher arithmetic skills. Direct fact retrieval was used more frequently by fifth graders than by fourth graders, but it did not correlate with the contrast between fifth graders and sixth graders. Finally, retrieval use was higher in low-anxious children than in high-anxious children and was higher in boys than in girls.

Thus, the relations between strategy efficiency and strategy selection, on the one hand, and grade and working memory load, on the other, are in agreement with the results reported previously. Children become more efficient in the execution of naming, retrieval, and counting strategies, whereas the efficiency of the transformation strategy does not increase across grades. The frequency of retrieval use also increases as children grow older.

³ Gender was coded as a dummy variable; girls were coded as -1 and boys were coded as $+1$. Grade was coded as two dummy variables. For the first one (fourth grade vs. fifth grade), fourth graders were coded as -1 , fifth graders were coded as $+1$, and sixth graders were coded as 0 . For the second one (fifth grade vs. sixth grade), fourth graders were coded as 0 , fifth graders were coded as -1 , and sixth graders were coded as $+1$. Working memory load was coded as a dummy variable as well; no load was coded as -1 , and load was coded as $+1$.

Table 5

Correlations between naming RTs, retrieval RTs, transformation RTs, counting RTs, percentages retrieval use, working memory load, and the individual difference variables

	Retrieval efficiency	Transformation efficiency	Counting efficiency	Retrieval percentage	Digit span	Processing speed	Arithmetic skill	Math anxiety	Gender	Fourth grade vs. fifth grade	Fifth grade vs. sixth grade	Working memory load
Naming efficiency	.52**	.42**	.37**	−.08	.00	.34**	−.30**	−.12	.12	−.26**	−.01	.62**
Retrieval efficiency		.62**	.61**	.00	−.01	.39**	−.59**	−.05	.11	−.24**	−.24**	.35**
Transformation efficiency			.61**	−.11	.01	.35**	−.56**	.02	.20*	−.17	−.06	.23*
Counting efficiency				−.07	−.02	.39**	−.49**	.03	.02	−.38**	−.04	.08
Retrieval percentage					−.02	−.27**	.32**	−.28**	.18*	.32**	−.16	.05
Digit span						−.23*	.14	−.20*	−.11	.15	−.05	—
Processing speed							−.58**	−.07	.30**	.42**	.18*	—
Arithmetic skill								−.19*	−.03	.05	−.12	—
Math anxiety									−.25**	−.28*	.05	—
Gender										—	—	—
Fourth grade vs. fifth grade											—	—
Fifth grade vs. sixth grade												—

Note. Efficiency and speed measures are expressed in reaction times (RTs), so higher values indicate less efficiency.

* $p < .05$.

** $p < .01$.

Finally, working memory load predicted all strategy efficiencies except counting and did not predict strategy selection.

Table 5 revealed other noteworthy correlations as well. Math anxiety, for example, correlated with digit span and arithmetic skill; high-anxious children had lower digit spans and lower arithmetic skill scores. The correlation between math anxiety and digit span is in agreement with results obtained by Ashcraft and Kirk (2001), who observed that adults' working memory span was negatively correlated with math anxiety. Although working memory cannot be equated with short-term memory, both results indicate that higher math anxiety scores go hand in hand with lower capacities for information storage and/or processing. Math-anxious participants are often occupied by worries and intrusive thoughts when performing arithmetic tasks (Ashcraft & Kirk, 2001; Faust et al., 1996). Because such intrusive thoughts load on storage and processing resources, high-anxious participants exhibit lower short-term memory and working memory capacities. The correlation between math anxiety and arithmetic skill corroborates the results obtained by Ashcraft (1995; Ashcraft & Faust 1994; Ashcraft and Kirk 2001; Faust et al. 1996), who observed that complex arithmetic performance was worse in high-anxious adults than in low-anxious adults.

Gender correlated with processing speed and math anxiety. Girls scored higher on the math anxiety questionnaire than did boys. Girls were also faster on the processing speed task than were boys. The correlation between math anxiety and gender has been found previously; Ashcraft (1995) observed that highly anxious women (top quartile on anxiousness scale) scored almost one SD higher on a math-anxiety scale than did highly anxious men. However based on questionnaire results, it is impossible to rule out the possibility that females are just more honest in reporting their feelings than are males. The fact that girls were better on the processing speed test is in agreement with previous findings showing an advantage of females over males in perceptual speed (e.g., Kimura, 1992).

Subsequent hierarchical regression analyses assessed which variables contributed unique variance to the dependent variables naming efficiency, retrieval efficiency, transformation efficiency, counting efficiency, and retrieval frequency (Appendix A). In Model 1, we investigated whether the relation between the independent variables (arithmetic skill, working memory load, processing speed, math anxiety, gender, and digit span) and the respective dependent variable was maintained when accounting for age-related changes ($df=1, 118$). Age-related changes indeed explained a large part of the variance; grade accounted for 10% of the variance in naming efficiency, $F(2, 119)=6.40$, for 24% of the variance in retrieval efficiency, $F(2, 119)=18.10$, for 6% of the variance in transformation efficiency, $F(2, 119)=3.62$, for 22% of the variance in counting efficiency, $F(2, 119)=16.94$, and for 10% of the variance in retrieval frequency, $F(2, 119)=6.55$.

In Model 1, we see that unique variance was found for arithmetic skill in predicting all four measures of simple arithmetic strategic performance. Therefore, in Model 2 we investigated which variables were significant predictors when controlling for grade and arithmetic skill ($df=1, 116$). In Model 3 ($df=1, 115$), working memory load was added to Model 2, whereas in Model 4 ($df=1, 115$), processing speed was added to Model 2.

Model 4 revealed that working memory load contributed unique variance to naming efficiency, retrieval efficiency, and transformation efficiency even when controlling for grade, arithmetic skill, and processing speed. However, working memory load did not contribute unique variance to counting efficiency or retrieval frequency. Processing speed contributed unique variance to naming efficiency, transformation efficiency, and retrieval frequency when controlling for grade (Model 1). However, when working memory load

was entered into the model as well, processing speed was significant for naming efficiency only (Model 3). Math anxiety predicted retrieval efficiency and retrieval frequency. This contribution was significant even in Models 3 and 4. Finally, gender contributed unique variance to transformation efficiency (with boys being less efficient than girls), but this effect disappeared when controlling for processing speed (Model 4). However, gender did contribute unique variance to retrieval frequency in all four models.

Several results obtained in the hierarchical regression results stand out. First, although processing speed correlated with all four measures of simple arithmetic strategic performance, processing speed did not contribute unique variance to any of these variables after working memory load was entered into the analysis. Processing speed was significant for naming efficiency only. Second, arithmetic skill still contributed unique variance to the four simple arithmetic performance measures when controlling for grade-related differences. However, arithmetic skill did not predict naming efficiency, although both variables did correlate with each other. Third, partialing grade, arithmetic skill, and processing speed did not eliminate the significant role that working memory plays in predicting naming efficiency, retrieval efficiency, and transformation efficiency. Fourth, although math anxiety correlated with retrieval frequency only, regression analyses showed that it predicted both retrieval frequency and retrieval efficiency even in Models 3 and 4. When free to choose the strategy they want (i.e., in choice conditions), high-anxious children used the retrieval strategy less frequently than did low-anxious children, but when high-anxious children were required to use retrieval (i.e., in no-choice/retrieval conditions), they sped up their retrieval use. Finally, the regression analyses uncovered a possible underlying cause of the correlation between gender and transformation efficiency. Given that girls had higher levels of processing speed than did boys (Table 5), the correlation between gender and transformation efficiency might be caused by gender differences in processing speed. Indeed, gender did not contribute unique variance to transformation efficiency when processing speed was entered into the analysis. However, gender contributed unique variance to retrieval frequency even in Models 3 and 4. Retrieval use was more frequent in boys than in girls, and this effect persisted even when controlling for grade, arithmetic skill, processing speed, and working memory load.

Discussion

Role of working memory in children's strategy efficiency and strategy selection

The current results show that school-age children rely on working memory resources to perform simple arithmetic problems. Taxing children's executive working memory resources resulted in poorer arithmetic performance; children of all ages executed strategies less efficiently. The impact of an executive working memory load on children's retrieval efficiency is in agreement with comparable results obtained in adults (e.g., Anderson, Reder, & Lebiere, 1996; I. Imbo & A. Vandierendonck, unpublished results) and indicates that working memory resources are needed to select information from long-term memory (Barrouillet & Lépine, 2005; Barrouillet, Bernardin, & Camos, 2004; Cowan, 1995, 1999; Lovett, Reder, & Lebière, 1999). It is important to note that the impact of the executive working memory load was larger when answers needed to be retrieved from long-term memory than when answers were provided (i.e., the naming condition). Presumably, except for retrieval of the correct answer, the processes of digit encoding and pronouncing were equal in the naming condition and the retrieval condition. This result shows that retrieval of the correct answer and inhibition of

incorrect answers do rely on executive working memory resources. Recently, the executive function of inhibitory control has been shown to contribute to emergent arithmetic skills in preschool children (Espy et al., 2004).

The role of working memory was larger in nonretrieval strategies than in direct memory retrieval, a result obtained in adult studies as well (I. Imbo & A. Vandierendonck, unpublished results). Indeed, in addition to the fact that procedural strategies (transformation and counting) are composed of multiple retrievals from long-term memory, these strategies also contain several processes that might require extra executive resources such as performing calculations, manipulating interim results, and monitoring counting processes.

The arithmetic performance of normally developing children under executive working memory load can be compared with arithmetic performances of mathematically impaired children, who are slower in solving arithmetic problems (e.g., Geary, 1993; Hitch & McAuley, 1991; Passolunghi & Siegel, 2001; Siegel & Linder, 1984; Siegel & Ryan, 1989; Swanson, 1993). This impairment often has been attributed to limitations in working memory and especially to limitations in the executive working memory component (e.g., McLean & Hitch, 1999; Passolunghi & Siegel, 2004). That lower arithmetic performance can be caused by limitations in working memory was confirmed by the current results, in which executive working memory resources (of normally developing children) were limited experimentally.

Development of the role of working memory

The main goal of the current study was to investigate age-related changes in the ratio of available working memory resources against simple arithmetic task demands. The main conclusion is that the negative impact of an executive working memory load decreases as children grow older. This conclusion corroborates the assertion that more working memory resources are needed during the initial phases of skill acquisition and that fewer working memory resources are needed with learning, namely when procedural strategies are used less frequently and retrieval strategies are used more frequently (Ackerman, 1988; Ackerman & Cianciolo, 2000; Geary et al., 2004; Siegler, 1996). Based on the results obtained in the current study, we infer that the declining impact of working memory load is caused by age-related changes in strategy efficiency and strategy selection but not by age-related changes in overall processing costs. These effects are discussed in the remainder of this section.

First, frequency of retrieval use increased across grades; fifth and sixth graders used retrieval more often than did fourth graders. Because direct memory retrieval is less effortful and requires fewer working memory resources than do nonretrieval strategies such as counting and transformation (cf. no-choice data), more frequent retrieval use goes hand in hand with lower working memory involvement. Phrased differently, more frequent retrieval use leaves more working memory capacity free for other uses. This spare capacity can then be applied in the executive secondary task.

Second, retrieval efficiency increased across grades; direct memory retrieval took longer in fourth grade than in fifth grade and took longer in fifth grade than in sixth grade. More efficient retrieval use results from stronger problem–answer associations for the correct answer and weaker problem–answer associations for the neighboring incorrect answers. Stronger associations between the problem and its correct answer reduce the amount of executive working memory resources needed to inhibit incorrect answers.

Third, counting efficiency increased across grades; counting was slower in fourth grade than in fifth and sixth grades. As counting becomes more efficient, fewer working memory

resources are needed, thereby reducing the working memory involvement across ages. The increase in counting efficiency might be caused by increases in retrieval and procedural efficiency, increases in processing speed, and increases in speech rate. The faster children can count, the less information needs to be protected from decay. Importantly, transformation efficiency did not change across grades, and neither did the effect of working memory load on transformation efficiency.

Finally, results showed that the age-related decline in the impact of working memory load could not be due to developmental changes in overall processing costs. Although naming RTs were larger in fourth grade than in fifth and sixth grades, the effect of working memory load on naming did not decrease with age. To conclude, the changing ratio between working memory involvement, on the one hand, and simple arithmetic performance, on the other, was due to age-related changes in strategy selection and strategy efficiency (for retrieval and counting) but not to age-related changes in general processes such as encoding and pronunciation.

Importantly, our conclusions are in agreement with a recent functional magnetic resonance imaging (fMRI) study. Rivera, Reiss, Eckert, and Menon (2005) tested 8- to 19-year-olds on arithmetic tasks and found that activation in the prefrontal cortex decreased with age, suggesting that younger participants need more working memory and attentional resources to achieve similar levels of mental arithmetic performance. Activation of the hippocampus, the dorsal basal ganglia, and the parietal cortex decreased with age as well, suggesting greater demands on declarative, procedural, and visual memory systems in younger children than in older children (Qin et al., 2004; Rivera et al., 2005).

Future research may use the method adopted here (i.e., a combination of the dual-task method and the choice/no-choice method) to investigate which executive resources come into play in children's arithmetic strategy performance. Previous (correlational) research suggests that both inhibition and memory updating play a role in children's arithmetic problem solving (e.g., Passolunghi et al., 1999; Passolunghi & Pazzaglia, 2005).

Influence of individual differences on children's strategy use

Digit span

Digit span did not correlate with strategy efficiency or strategy selection measures. This is at variance with previous studies in which a relation between short-term memory and arithmetic ability was observed (e.g., Geary et al., 1991; Hecht et al., 2001; Hitch & McAuley, 1991; Passolunghi & Siegel, 2001; Siegel & Ryan, 1989; Swanson & Sachse-Lee, 2001). It should be noted, however, that a number of these studies included mathematically disabled children without taking reading ability or general intelligence into account. As in many other studies, no relation between short-term memory and mathematical ability was observed (e.g., Bayliss, Jarrold, Gunn, & Baddeley, 2003; Bull & Johnston, 1997; Geary, Hamsou, & Hoard, 2000; Passolunghi et al., 1999; Passolunghi & Siegel, 2004; Swanson, 2006; Temple & Sherwood, 2002), in agreement with the current results. Individual differences in short-term memory apparently do not play an important role in children's simple arithmetic performance. Individual differences in working memory, in contrast, do play a role in children's simple arithmetic strategy use. Indeed, correlations between working memory measures and arithmetic ability have been found

consistently (e.g., Bull et al., 1999; Bull & Scerif, 2001; Geary et al., 1999; McLean & Hitch, 1999; Noël et al., 2004; Passolunghi et al., 1999; Passolunghi & Siegel, 2004; Swanson, 2004, 2006; Swanson & Beebe-Frankenberger, 2004; Swanson & Sachse-Lee, 2001; van der Sluis et al., 2004).

In our study with normally developing children, working memory (as loaded by the CRT-R task), but not short-term memory (as tested with the digit span), was related to arithmetic performance. Thus, we agree with Steel and Funnell (2001) in asserting that the number of items that can be stored in memory is less important than the ability to control attention and maintain information in an active, quickly retrievable state (see also Engle, 2002). The current results are also in agreement with most of the recent studies on mathematically disabled children. Children with arithmetic learning difficulties may suffer from a working memory deficit (Geary, 2004) rather than a short-term memory deficit.

Processing speed

We observed that retrieval efficiency, transformation efficiency, counting efficiency, and retrieval frequency were lower in children with slower processing speed than in children with faster processing speed. Correlations between processing speed and arithmetic ability have been observed previously (e.g., Bull & Johnston, 1997; Durand, Hulme, Larkin, & Snowling, 2005; Kail & Hall, 1999). Kail and Hall (1999) hypothesized that faster processing is associated with faster retrieval of problem-solving heuristics. The current research is consistent with their hypothesis in that we observed that faster processing children were more likely than slower processing children to select fast retrieval strategies. It should be noted, however, that the current results disagree with the results of Noël et al. (2004), who observed that slower processing children used retrieval more frequently than did faster processing children. Our results, however, are consistent with the expectation that faster processing children develop stronger problem-answer associations in long-term memory, resulting in more frequent retrieval use.

According to Bull and Johnston (1997), slower processing children may experience several difficulties. They may be slower in general information processing; however, they may also simply lack the automaticity to perform basic arithmetic operations. Based on the results obtained in the hierarchical regression analyses, the first explanation seems more plausible. Indeed, when controlling for age and working memory, processing speed did not contribute unique variance to any of the four arithmetic performance measures. Hence, the relation between processing speed and arithmetic performance is due to age-related speed and general working memory deficits rather than to specific deficits in processing and automatizing numbers and number facts.

Arithmetic skill

High correlations between arithmetic skill, on the one hand, and strategy selection and strategy efficiency, on the other, were observed. Moreover, arithmetic skill contributed unique variance when partialing age from the analyses. Obviously, children who frequently use direct memory retrieval, retrieve answers from long-term memory efficiently, and execute nonretrieval strategies efficiently are in a good position to acquire general computational skills, resulting in good performance on general math attainment tasks. This agrees

well with Hecht and colleagues' (2001) finding that, in elementary school children, simple arithmetic efficiency is a significant predictor of later variability in general computational skills even when controlling for phonological skills.

Math anxiety

Math anxiety did not correlate with the efficiency with which children used different strategies. This is in agreement with the assertion that math anxiety affects only complex arithmetic performance and not simple arithmetic performance (Ashcraft, 1995; Faust et al., 1996). Math anxiety did indeed correlate with performance on the (more complex) arithmetic skill test; high-anxious children solved fewer problems than did low-anxious children, indicating more efficient complex problem solving in the latter than in the former.

Math anxiety further correlated with simple arithmetic strategy selection; high-anxious children used retrieval less often than did low-anxious children. This effect of math anxiety on strategy selection can easily be explained on the basis of the strategy choice model of Siegler and Shrager (1984). In their model, each participant has his or her own confidence criterion. When solving simple arithmetic problems, the strength of the problem–answer association is compared with this subjective confidence criterion. If the problem–answer associative strength exceeds the confidence criterion, the answer is emitted. If the problem–answer associative strength does not exceed the confidence criterion, the child may continue to search his or her memory for other candidate answers or may resort to a procedural strategy to compute the answer. If we suppose that anxious children set very high confidence criteria so as not to produce any incorrect answers, problem–answer associations will meet those criteria infrequently, resulting in less frequent retrieval use and more frequent procedural use.

Gender

Girls were more efficient in transformation use, whereas the retrieval strategy was used more frequently by boys. More frequent retrieval use in boys has been observed in previous studies (Carr, 1996; Carr & Jessup, 1997; Davis & Carr, 2002) and has been attributed to the effect of temperament (Davis & Carr, 2002). More efficient transformation use in girls than in boys has not been reported previously, but the current study showed that this observation might be related to gender differences in processing speed (cf. the hierarchical regression analyses). The more efficient transformation use in girls than in boys might also help to explain the gender difference in strategy selection; because girls are reasonably fast in applying the transformation strategy, they might opt not to switch to the retrieval strategy, which is only slightly faster for them. In boys, in contrast, the retrieval strategy is considerably faster than the transformation strategy, leading them to choose the fastest strategy (retrieval) more often. It is noteworthy that no gender differences were observed in retrieval efficiency. In previous studies, males were observed to be faster retrievers than females, both in children (Royer et al., 1999) and in adolescents (Imbo et al., *in press*). Thus, more efficient retrieval use in boys than in girls is not found consistently across studies.

What causes such gender differences in arithmetic performance? According to Geary (1999) and Royer and colleagues (1999), gender differences in arithmetic performance are not likely to be biologically based. Social and occupational interests seem to be a more reasonable cause.

Royer and colleagues supposed that boys engage in out-of-school activities that provide them with additional practice on the manipulation of mathematical information. Geary, Saults, et al. (2000) maintained that the male advantage in mathematical problem solving is due to a male advantage in spatial cognition. In sum, it is clear that gender differences in arithmetic performance and their sources are not understood well and should be investigated further.

Conclusion

In the present study, two approved methods were combined in order to investigate the development of working memory involvement in children’s arithmetic strategy use. The dual-task method permitted an online investigation of working memory involvement in arithmetic performance, and the choice/no-choice method permitted achieving reliable strategy selection and strategy efficiency data. As far as we know, the combination of both methods has not yet been used in child studies. The results showed that, across development, the effect of an executive working memory load decreased when retrieval was used more frequently and when strategies were executed more efficiently. However, the age-related decline in working memory use was not due to developmental changes in other, more general processes, which required working memory resources across all ages. Individual-difference variables (gender, math anxiety, arithmetic skill, and processing speed) accounted for differences in strategy selection and strategy efficiency as well. Arithmetic skill and working memory contributed more unique variance to arithmetic performance than processing speed and short-term memory did. Math anxiety and gender predicted some but not all of the arithmetic performance measures. Future research on working memory, strategy use, and mental arithmetic may investigate other arithmetic operations (subtraction, multiplication, division), other working memory resources (phonological loop and visuo-spatial sketchpad), and other individual differences (e.g., motivation, intelligence, etc.).

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Appendix A

Hierarchical regression analyses for naming efficiency, retrieval efficiency, transformation efficiency, counting efficiency, and retrieval frequency

	Model 1			Model 2			Model 3			Model 4		
	ΔR	F	Beta	ΔR	F	Beta	ΔR	F	Beta	ΔR	F	Beta
Naming efficiency												
Working memory load	.382	86.63**	.618	.386	90.32**	.622				.385	94.41**	.621
Processing speed	.041	5.66*	.256	.027	3.69	.219	.026	6.47*	.217			
Math anxiety	.017	2.22	−.130	.027	3.65	−.169	.026	6.34*	−.166	.018	2.44	−.140
Gender	.006	0.81	.081	.009	1.14	.096	.010	2.45	.105	.002	0.28	.049
Digit span	.002	0.20	.040	.003	0.35	.052	.003	0.68	.055	.007	0.92	.085

Appendix A (continued)

	Model 1			Model 2			Model 3			Model 4		
	ΔR	F	Beta	ΔR	F	Beta	ΔR	F	Beta	ΔR	F	Beta
Retrieval efficiency												
Arithmetic skill	.138	26.26**	-.474									
Working memory load	.124	22.85**	.353	.122	28.87**	.350				.122	28.62**	.350
Processing speed	.016	2.58	.161	.000	0.00	.001	.000	0.00	.000			
Math anxiety	.007	1.03	-.082	.030	6.03	-.179	.030	7.41	-.178	.032	6.24*	-.187
Gender	.000	0.01	.007	.001	0.17	.031	.001	0.30	.037	.001	0.19	0.34
Digit span	.001	0.15	.032	.004	0.68	.061	.004	0.89	.063	.004	0.70	0.63
Transformation efficiency												
Arithmetic skill	.208	35.24**	-.582									
Working memory load	.053	6.97**	.229	.048	8.58**	.218				.047	8.66**	.218
Processing speed	.063	8.47**	.316	.014	2.42	.158	.014	2.55	.157			
Math anxiety	.000	0.01	.009	.018	3.15	-.139	.018	3.30	-.138	.013	2.22	-.119
Gender	.028	3.58	.171	.029	5.11	.177	.030	5.67*	.180	.020	3.52	.154
Digit span	.002	0.20	.040	.005	0.78	.069	.005	0.86	.070	.008	1.43	.094
Counting efficiency												
Arithmetic skill	.069	11.38**	-.335									
Working memory load	.006	0.88	.076	.006	1.01	.078				.006	1.00	.078
Processing speed	.019	2.93	.173	.003	0.45	.070	.003	0.45	.069			
Math anxiety	.000	0.04	.016	.002	0.28	-.042	.002	0.27	-.042	.001	0.16	-.033
Gender	.003	0.45	-.056	.001	0.14	-.031	.001	0.13	-.030	.002	0.37	-.052
Digit span	.002	0.27	.043	.004	0.69	.065	.004	0.69	.066	.006	0.93	.078
Retrieval frequency												
Arithmetic skill	.053	7.30**	.293									
Working memory load	.003	0.38	.054	.004	0.49	.060				.004	0.50	.060
Processing speed	.030	4.13*	-.219	.010	1.43	-.135	.010	1.43	-.136			
Math anxiety	.091	13.31**	-.304	.065	9.58**	-.262	.064	9.51**	-.261	.079	11.96**	-.295
Gender	.038	5.15*	.199	.035	4.94*	.193	.035	4.97*	.194	.051	7.52**	.246
Digit span	.004	0.52	-.063	.006	0.89	-.082	.006	0.88	-.081	.010	1.41	-.104

Note. Model 1 = age controlled (df per test = 1, 118); Model 2 = age + arithmetic skill controlled (df per test = 1, 116); Model 3 = age + arithmetic skill + working memory load controlled (df per test = 1, 115); Model 4 = age + arithmetic skill + processing speed controlled (df per test = 1, 115).

* $p < .05$.

** $p < .01$.

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