The influence of problem features and individual differences on strategic performance in simple arithmetic

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Abstract

The present study examined the influence of features differing across problems (problem size and operation) and differing across individuals (daily arithmetic practice, the amount of calculator use, arithmetic skill, and gender) on simple-arithmetic performance. Regression analyses were used to investigate the role of these variables in both strategy selection and strategy efficiency. Results showed that more-skilled and highly practiced students used memory retrieval more often and executed their strategies more efficiently than less-skilled and less practiced students. Furthermore, calculator use was correlated with retrieval efficiency and procedural efficiency but not with strategy selection. Only very small associations with gender were observed, with boys retrieving slightly faster than girls. Implications of the present findings for views on models of mental arithmetic are discussed.

The influence of problem features and individual differences[1]

on strategic performance in simple arithmetic

Strategic performance of adults consists of two main components. If people want to solve a cognitive problem, they will first have to *choose* the most appropriate strategy to solve it (i.e., strategy selection). Subsequently, they will have to *execute* the chosen strategy with reasonable speed and accuracy (i.e., strategy efficiency). For a long time, mental arithmetic research assumed that adults used only memory retrieval to solve simple-arithmetic problems such as 8 + 3 or 5 x 4 (e.g., Ashcraft, 1987, 1992, 1995; Campbell, 1987, 1995; Campbell & Oliphant, 1992; Lebiere & Anderson, 1998; McCloskey, 1992; Siegler, 1989; Widaman & Little, 1992). Fairly recently however, LeFevre and colleagues (LeFevre, Bisanz, et al., 1996a; LeFevre, Sadesky, & Bisanz, 1996b; see also Baroody, 1994; Geary, Frensch, & Wiley, 1993; Geary & Wiley, 1991) showed that even skilled adults still make substantial use of procedures such as counting (e.g., 6 + 3 = 6 + 1 +1 +1) and transformation (e.g., 7 + 5 = 7 + 3 + 2) when solving simple-arithmetic problems. It is clear that retrieval and non-retrieval (i.e., procedural) strategies differ in their efficiency, as retrieval is generally much faster (i.e., more efficient) than any procedural strategy. Although people can still use other strategies to solve arithmetic problems (e.g., using a calculator), the present study investigates mental arithmetic and thus focuses on the two broad kinds of strategy mentioned above: retrieval strategies and procedural strategies.

Both strategy selection and strategy efficiency may depend on several factors such as problem features (e.g., operation, problem size) and individual differences (e.g., arithmetic skill and arithmetic practice). Although models have been proposed in which such experiential factors are the main determinants of mental representation, acquisition, and performance (e.g., Ashcraft, 1987; Campbell & Graham, 1985; Siegler, 1988; Siegler & Shipley, 1995), there are very few direct comparisons of the simple-arithmetic performance of adults differing in mathematical education, arithmetic skill, or arithmetic practice (see also LeFevre and Liu, 1997).

Moreover, up until now, no study investigated the effects of these factors in strategy selection and strategy efficiency separately. The present study therefore examined the effects of features differing across problems and across individuals on strategic performance in simple-arithmetic.

Problem features

Although adults rely on both retrieval and procedural strategies for the entire domain of elementary arithmetic (i.e., the four basic operations; e.g., Campbell and Xue, 2001), they adjust their strategy selection to the *operation* that has to be applied. Adult's solving of subtractions and divisions for example, relies more heavily on procedural strategies than either addition or multiplication, for which retrieval strategies are predominantly used (Campbell & Xue, 2001; Seyler, Kirk, & Ashcraft, 2003). Furthermore, multiplications are solved even more frequently by means of direct retrieval than additions (e.g., Hecht, 1999; LeFevre et al., 1996a, 1996b). This might be explained by the fact that multiplications are for the most part based on declarative knowledge whereas additions would be based on both declarative and procedural knowledge (Roussel, Fayol, & Barrouillet, 2002). Whatever the operation is, strategy selection also depends on the *problem size*. For smaller problems (e.g., 2 + 4), people generally retrieve answers from their long-term memory, but for larger problems (e.g., 8 + 6) they are more inclined to use procedural strategies. Because procedural strategies are less efficient than retrieval, longer latencies and higher error rates are observed on larger problems. This very robust effect is known as the problem-size effect, which indicates that solution times and error percentages increase as problem size increases. More frequent retrieval use on small than on large problems is not the only source for the problem-size effect, though. According to Campbell and Xue (2001), there are as many as three sources for the problem-size effect: more frequent use of procedural strategies for large than for small problems, a lower efficiency of retrieval strategies for large than for small problems, and a lower efficiency of procedural strategies for large than for small problems. Lower retrieval efficiencies can be explained by weaker associative connections between problem-answer pairs in the retrieval network (e.g., Siegler, 1988), whereas lower procedural efficiencies can be explained by the larger number of sub-operations to be performed. Nevertheless, the problem-size effect is not only based on strategic sources; the structure of the mental network (with different network strengths and spreading activation characteristics), and interference from competing associations are other contributing factors (e.g., Zbrodoff, 1995).

Individual differences

Strategy selection and strategy efficiency do not only depend on problem features, but also on individual traits and culture-based factors. Several studies indeed found differences between East-Asians' and North-Americans' simple-arithmetic performance (e.g., Chen & Uttal, 1988; Campbell & Xue, 2001; Geary, 1996; Geary, Fan, & Bow-Thomas, 1992; Geary, Bow-Thomas, Fan, & Siegler, 1996; Geary, Salthouse, Chen, & Fan, 1996; Geary et al., 1997; LeFevre & Liu, 1997; Penner-Wilger, Leth-Steensen, & LeFevre, 2002; Stevenson, Chen, & Lee, 1993; Stevenson et al., 1990; Stevenson, Lee, & Stigler, 1986; reviewed by Geary, 1994). Because North-Americans frequently use procedures whereas East-Asians rely primarily on memory retrieval, faster and less error-prone arithmetic performance is observed in the latter group than in the former group. Arithmetic performance differences are not only found across cultures though, but also within one culture. Persons may differ from each other in several respects such as mathematical education, daily arithmetic practice, arithmetic skill, et cetera. However, there has been little research examining such differences in adults' cognitive processes in arithmetic. In the following, we summarize the main results of studies examining effects of cognitive factors on arithmetic performance. We also consider the role of gender.

Differences in arithmetic performance have been found to depend on *arithmetic skill*. LeFevre and Bisanz (1986) for example, found that low-skill persons used less efficient and slower mental calculation processes than did high-skill persons. Therefore, the difference between low- and high-skill subjects was larger on items that required calculations than on items that could be solved without calculations. Furthermore, LeFevre et al. (1996a, 1996b) observed more frequent retrieval use in high-skill than in low-skill persons. More recently, high-skill subjects were shown to be more efficient (i.e., faster) in solving simple-arithmetic problems than low-skill subjects (Campbell & Xue, 2001; Kirk and Ashcraft, 2001, see also Geary & Widaman, 1987; Gilles, Masse, & Lemaire, 2001). Finally, LeFevre and colleagues (LeFevre & Kulak, 1994; LeFevre, Kulak, & Bisanz, 1991) found evidence for individual differences in the obligatory activation of addition facts. As associative connections are stronger in high-skill subjects than in low-skill subjects, they concluded that accessibility of arithmetic facts may contribute to individual differences in the solution of arithmetic problems.

Besides arithmetic skill, strategic performance may also depend on other factors such as math attainment, daily arithmetic practice, and calculator use. Hecht (1999), for example, showed that adults with higher levels of *math attainment* used retrieval strategies more frequently, were more accurate in solving math facts, and retrieved arithmetic problems faster than did adults with lower levels of math achievement. Roussel et al. (2002) found that people with high amounts of *daily arithmetic practice* (primary school teachers) exhibited smaller problem-size effects than people with low amounts of daily arithmetic practice (undergraduate psychology students). However, the highly practiced subjects were found not to differ from the less practiced subjects in the strategies they used (i.e., strategy selection). The frequency of *calculator use* might be another influencing factor. From primary school on, children are taught how to use a hand-held calculator. However, calculators themselves are at the centre of several controversies, not only educational (i.e., is it good for children to use calculators?) but also conceptual (i.e., are calculators designed and implemented well?, Thimbleby, 2000). Very few studies have investigated effects of calculator use on simple-arithmetic performance though. Campbell and Xue (2001) observed no reliable effect of the frequency of calculator use on simple-arithmetic strategy selection or strategy efficiency.

Gender differences have been found in young children's arithmetic strategy selection (e.g., Carr & Jessup, 1997; Carr, Jessup, & Fuller, 1999; Fennema, Carpenter, Jacobs, Franke, & Levi, 1998). More specifically, girls are more likely than boys to use procedural strategies whereas boys are more likely than girls to use retrieval strategies. These gender differences in simple-arithmetic strategy selection have shown to be driven not only by skill differences, but also by girls' and boys' strategy preferences (Carr & Davis, 2001). Furthermore, gender differences have been found in retrieval efficiency as well, with boys being faster than girls from fifth grade on (Royer, Tronsky, Chan, Jackson, & Marchant III, 1999). Carr and Davis (2001), however, observed no differences between boys and girls in retrieval efficiency. Although no study explicitly investigated whether gender differences in strategy selection and strategy efficiency exist in adults, Geary, Saults, Liu and Hoard (2000) re-analyzed simple-arithmetic performance data obtained in an earlier study by Geary et al. (1993). They observed a trend to more frequent retrieval use by men than by women (86% vs. 66%, $p < .07$) but no gender differences in retrieval efficiency.

Overview of the Present Study

As described earlier, problem features have large effects on adults' simple-arithmetic performance. Individual differences have less frequently been studied, though. For example, gender effects in adults' simple-arithmetic performance have not been investigated thus far. Effects of the frequency of calculator use have not been observed either. The effects of arithmetic practice over and above those of arithmetic skill are still debated as well. Moreover, even if individual differences in simple-arithmetic performance were studied, no distinction was made between their role in strategy selection and strategy efficiency. Therefore, the present study investigated effects of both problem features and individual differences on simple-arithmetic strategy selection and strategy efficiency separately. In addition to the investigation of two typical problem features (problem size and operation), effects of four individual traits were tested: daily arithmetic practice, arithmetic skill, the amount of calculator use, and gender. The novelty here is the distinction between skill and practice. Whereas most previous studies selected low- and high-skill subjects based on arithmetic subtests only (e.g., Gilles et al., 2001; Hecht, 1999; LeFevre & Bisanz, 1986, LeFevre et al., 1996b), the present study incorporated the amount of daily arithmetic practice in addition to the measure of arithmetic skill. In fact, the operationalization of 'daily arithmetic practice' was based on the students' high-school curricula, which all differed in the number of mathematic and scientific classes per week. The Belgian education system, in which high-school students have to choose one main class every two years, offers a good opportunity to investigate such practice effects in an ecologically valid way. Indeed, all students in the present study were enrolled in a specific curriculum with a fixed amount of arithmetic classes each week. In contrast, arithmetic skill was measured by means of a frequently used pen-and-paper test (the French kit). A short questionnaire determined each student's habits concerning calculator use.

Based on previous research, we expected more frequent retrieval use and more efficient strategy use for the high-skill subjects compared to the low-skill subjects. We also expected simple-arithmetic performance to be related to daily arithmetic practice, with more frequent retrieval use and more efficient strategy execution in the more-practiced students than in the less-practiced students. Although there is no evidence for effects of calculator use on simple-arithmetic performance (Campbell & Xue, 2001), we expected less frequent retrieval use and lower strategy efficiencies for subjects frequently using the calculator than for subjects rarely using the calculator. Concerning gender differences, it was hard to make any predictions, because such differences are more pronounced more in children than in adults. However, on the basis of these developmental studies, if any differences were to appear in the present study, we expected more frequent and more efficient retrieval use for male than for female students.

Method

Participants

Sixty high-school students of the sixth year participated in this study[2]. The amount of daily arithmetic practice variable was operationalized by the number of hours per week dedicated to arithmetic and scientific classes. Scientific classes were considered because they are classes in which arithmetic is frequently used. The number of arithmetic and scientific hours per week was 3 (15 students, mean age: 17 years 8 months, 14 girls and 1 boy), 4 (16 students, mean age: 17 years 7 months, 14 girls and 2 boys), 9 (2 students, mean age: 17 years 6 months, 1 girl and 1 boy), 11 (8 students, 4 girls and 4 boys, 17 years 9 months), 13 (10 students, mean age: 17 years 6 months, 1 girl and 9 boys), or 15 (9 students, mean age: 17 years 8 months, 5 girls and 4 boys). At the time of measurement, all students were enrolled in their specific curriculum for at least one and a half years. All students participated voluntarily, with permission of their parents and the school teachers.

Procedure and Stimuli

Each participant was tested individually in a quiet class room for approximately 45 minutes. The test session was started with short questions about the participant's age, study curriculum, and the number of arithmetic and scientific classes per week. Three tasks were given to each participant. The first one was the simple-arithmetic task, which consisted of two blocks, one with addition problems and one with multiplication problems, the order of which was counterbalanced across participants. Subsequently, an arithmetic skill test (the French kit) was administered. The session ended with a short questionnaire about calculator use. In the following, each task is described more in detail.

Simple-arithmetic task. Stimuli of the simple-arithmetic task consisted of simple additions and simple multiplications. As in previous research, we used the so-called standard set of problems (LeFevre et al., 1996b), which excludes problems involving 0 or 1 as an operand or answer. Both addition and multiplication problems were composed of pairs of numbers between 2 and 9, with tie problems (e.g., 3 + 3) excluded. Because commuted pairs (e.g., 2 + 4 and 4 + 2) were considered as two different problems, this resulted in 56 addition problems (ranging from 2 + 3 to 8 + 9) and 56 multiplication problems (ranging from 2 x 3 to 8 x 9). Problem size was defined as the correct answer to the problem (from 5 to 17 for the sums and from 6 to 72 for the products). This continuous definition of problem size differs from the widely used dichotomous definition of problem size (i.e., a categorization into small and large problems).

A trial started with a fixation point, which appeared for 500 milliseconds. Then the arithmetic problem appeared in the center of the screen. The addition and multiplication problems were presented horizontally in Arabic format as dark-blue characters on a light-grey background, with the operation sign (+ or x) at the fixation point. The problem remained on the screen until the subject responded. Although participants were required to respond as quickly and as accurately as possible, no time deadline was set, because it has been shown that a fast deadline increased reported use of retrieval, especially for large problems (Campbell & Austin, 2002). Timing began when the stimulus appeared and ended when the response triggered the sound-activated relay. To enable this sound-activated relay, participants wore a microphone, which was activated when they spoke their answer aloud. This microphone was connected to a software clock accurate to 1 msec. On each trial, feedback was presented to the participants, a green ‘Correct’ when their answers were correct, and a red ‘Fout’ (i.e., Dutch for ‘Wrong’) when their answers were wrong.

Participants were also told to report the strategy they used for each single problem. They could choose one of the following strategy categories ‘Retrieval’, ‘Counting’, ‘Transformation’, and ‘Other’ (see e.g. Campbell & Gunter, 2002; Campbell & Xue, 2001; Kirk & Ashcraft, 2001; LeFevre et al., 1996b; Seyler et al., 2003). At the beginning of the experiment, each strategy was described as follows: *(1) Retrieval: You solve the problem by just remembering or knowing* *the answer directly from memory. It means that you know the answer without any additional processing, or that the answer “pops into your head”, (2) Counting: You solve the problem by counting a certain number of times to get the answer (e.g., 6 + 3 = 6…7…8…9; 3 x 6 = 6…12…18), (3) Transformation: You solve the problem by referring to related operations or by deriving the answer from some known facts. You change the presented problem to take advantage of a known arithmetical fact (e.g., 6 + 7 = 6 + 6 + 1; 9 x 6 = 60 – 6), (4) Other: You solve the problem by using a strategy unlisted here (e.g., guessing), you used more than one strategy, or you do not know what strategy you used to solve the problem.* After each trial, the four category names were displayed on the screen. The participant also kept a copy of the strategy report instructions for reference during the study. It was emphasized that the presented strategies were not meant to encourage use of a particular strategy.

The answer of the participant, the reported strategy, 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 rerun at the end of the block. This procedure enabled us to minimize data-loss due to unwanted failures. Each block (addition or multiplication problems) started with 4 practice problems, followed by the experimental problems. As each problem was presented twice, each block consisted of 112 arithmetic trials, which were presented in a random order. After the first block and a short break, the second block (with the other operation) was administered, consisting of 4 practice problems and 112 experimental problems as well.

French kit. After the simple-arithmetic task, participants completed two arithmetic subtests of the French kit (Ekstrom, French, & Harman, 1976; French, Ekstrom, & Price, 1963), one page of complex addition problems and one page of complex subtraction and multiplication problems. Each page contained six rows of ten vertically oriented problems. Each participant was given two minutes per page to solve the problems as quickly and accurately as possible. Arithmetic skill was defined as the total number of problems solved correctly on both tests. This measure of arithmetic skill reflects the ability to quickly and accurately execute strategies on multi-digit problems. The French Kit is also used to measure arithmetic fluency and working memory management (e.g., carrying and borrowing; Geary & Widaman, 1992).

Calculator-use questionnaire. Participants received a page on which the following question was written: “How often did you use a calculator (or another electronically device, e.g. cell phone) when doing arithmetic problems (e.g., 65 + 34, 23 x 17)?” Participants had to provide an answer to this question by marking a 5-point rating scale ranging from “never” to “always”, once concerning their experiences during elementary school and once concerning their experiences during high school.

Results

Overall, 1305 trials (i.e., 9.09%) were spoiled due to failures of the sound-activated relay. Since all these invalid trials returned at the end of the block, most of them were recovered from data loss, which reduced the trials spoiled due to failures of the sound-activated relay to 425 (i.e., 2.96%). Further, all incorrect trials and all trials on which participants reported having used a strategy ‘Other’ were deleted (i.e., 3.03%). Finally, all the response times (RTs) more than 4 standard deviations from the participant’s mean (per operation) were discarded as outliers (0.5% for addition and 1.1% for multiplication). The final data set consisted of 13026 valid trials, which corresponds to a total data loss of less than 8%. In the following, all reported results are considered to be significant if $p < .05$, unless mentioned otherwise.

Regression analyses were performed to detect which factors contributed to strategy selection and strategy efficiency. Regression analyses were run for additions and multiplications separately on the three dependent variables: percentages retrieval use, retrieval RTs, and procedural RTs (see Table 1). Predictors in all regression analyses were: (1) problem size (defined as the correct answer to the arithmetic problem), (2) daily arithmetic practice (defined as the number of mathematic and scientific hours per week), (3) calculator use (as measured by the questionnaire), (4) arithmetic skill (i.e., score on the French kit), and (5) gender (male or female). The first predictor varies across problems whereas the other variables vary across individuals. Table 2 describes means, medians, minima and maxima of the independent variables varying across individuals (except gender)[3]. A paired-samples *t*-test showed that calculator use was more frequent in high school than in elementary school, $t(59) = 13.40$, $SE = .157$, with mean scores of 4.0 ($SD = .88$) and 1.9 ($SD = .90$), respectively. As we expected that only the current frequency of calculator use would influence strategic performance, the frequency of calculator use in high school was included in the regression analyses whereas the frequency of calculator use in elementary school was not. A summary of all the regression analyses is presented in Table 3.

Insert Tables 1, 2, and 3 about here

The R^2 for percentage *retrieval use* was .298, $F(5,774) = 65.72$ for additions ($MSE = 764.08$) and .164, $F(5,1493) = 58.67$ for multiplications ($MSE = 639.55$). For both operations, retrieval use occurred more frequently with smaller problem sizes and with higher arithmetic skill. More frequent daily practice predicted more frequent retrieval use only for multiplications. The regression analyses on *retrieval RTs* resulted in an R^2 of .322, $F(5,722) = 68.51$ for additions ($MSE = 48515.37$) and an R^2 of .248, $F(5,1417) = 93.51$ for multiplications ($MSE = 307053.80$). For both operations, answers were retrieved faster with smaller problem size, higher arithmetic skill, and less frequent calculator use. More extensive daily practice predicted faster retrieval use only for multiplications. Furthermore, boys tended to be slightly faster in retrieving multiplication facts than girls. Finally, for *procedural RTs* an R^2 of .175, $F(5,328) = 13.87$ was obtained for additions ($MSE = 240580.01$) and an R^2 of .229, $F(5,350) = 20.77$ for multiplications ($MSE = 4013325.39$). For both operations, procedural strategies were performed faster when problem size was smaller, when arithmetic skill was higher, and when calculator use was less frequent.

Once more, high daily practice predicted faster procedural use only for multiplications but not for additions.

General Discussion

Results of the present study showed that Belgian high-school students used a variety of strategies to solve simple-arithmetic problems, which is in accordance with comparable research in non-European subjects (e.g., Campbell & Xue, 2001; Hecht, 1999; LeFevre & Liu, 1997; LeFevre et al., 1996a, 1996b), and – as LeFevre and collaborators reported – sharply in contrast with the assumption that adults always retrieve arithmetic facts from memory. There are, however, both similarities and differences between the present results and previous findings. We observed 78% retrieval use for addition and 87% retrieval use for multiplication. These percentages are at the high end of the range of percentages observed in North-America, reaching from 66% to 76% for addition and from 59% to 96% for multiplication (e.g., Campbell & Xue, 2001; Campbell & Timm, 2000; Geary, 1996; Hecht, 1999; LeFevre et al., 1996a, 1996b). They are, however, well beneath the percentages observed in East-Asia, with reported percentages of retrieval use of 92% for addition and 100% for multiplication (e.g., Campbell & Xue, 2001; Geary, 1996; LeFevre & Liu, 1997). The number of participants using retrieval on all trials was 6 (10%) for addition and 16 (26%) for multiplication, these figures are comparable to those of LeFevre et al. (1996a, 1996b) with 12.5% and 28% of the participants using retrieval on all trials, for additions and multiplications respectively.

Over and above confirming previous results, the present study yielded several new findings concerning individual differences in strategy selection and strategy efficiency. Concerning *strategy selection*, direct memory retrieval was used more often (a) by high-skill students than by low-skill students, and (b) by more-practiced students than by less-practiced students – the latter being true for multiplications but not for additions. Note that some previous studies did observe individual differences in strategy selection (e.g., Hecht, 1999; LeFevre et al., 1996b), whereas others did not (e.g., Roussel et al., 2002). *Strategy efficiency* also differed across individuals. Both retrieval efficiency and procedural efficiency increased (a) with the level of arithmetic skill and (b) with the level of daily arithmetic practice – the latter being true for multiplications but not for additions. Remarkably, the frequency of calculator use influenced strategy efficiency as well: students frequently using the calculator showed lower retrieval and procedural efficiency levels but did not differ in strategy selection. Gender only correlated with retrieval efficiency, indicating that boys were slightly faster than girls in retrieving multiplication facts from memory. In the following we first elaborate on the observed individual differences and then describe some implications for the present models of mental arithmetic.

Daily Arithmetic Practice

As most previous studies examined individual differences by means of pen-and-paper tests, the present study also incorporated a more 'ecological' variable, namely daily arithmetic practice. In fact, the amount of daily arithmetic practice was based on the number of arithmetic and scientific classes per week during the past years in high school. As outlined in the introduction, practice effects were expected on strategy selection, retrieval efficiency, and procedural efficiency. All these hypotheses were confirmed: All three measures of simple-arithmetic strategic performance were significantly linked to arithmetic practice, albeit only for multiplication problems.

The finding that less-practiced students used retrieval less often than more-practiced students is in agreement with previous studies assuming that practice may lead to increases in retrieval frequency (e.g., Siegler, 1988; Widaman & Little, 1992). Although strategy selection depended on arithmetic practice, both retrieval and procedural strategies were used irrespective of the level of practice. Moreover, more-practiced students used retrieval more efficiently than did less-practiced students. Frequently practiced problems may have developed stronger problem-answer associations than less frequently practiced problems (e.g., Siegler, 1988), and these stronger problem-answer associations may have resulted in faster retrieval use. Previous studies indeed showed that associative connections may differ across individuals (LeFevre & Kulak, 1994; LeFevre et al., 1991). Procedure efficiency was much higher for the more-practiced students than for the less-practiced students. LeFevre et al. (1996a) stated that practice may lead not only to more frequent retrieval use, but may lead to automatic activation of procedural strategies as well. If the successful use of procedural strategies increases the strength of the problem-procedure association, practice may thus also influence procedural efficiency, an effect that was observed here. More practiced students may thus have both stronger problem-answer associations and stronger problem-procedure associations, resulting in higher retrieval and procedural efficiencies, respectively. Because practice enhances procedural efficiency, procedural strategies can be maintained as alternatives of equal value as retrieval strategies. Distributions of problem-answer associations and problem-procedure associations should thus be viewed as continuously dynamic, rather than reaching a final static state (LeFevre et al., 1996a).

But why were the effects of arithmetic practice significant for multiplications and not for additions? One explanation for this operation-dependent effect is based on the fact that strategy efficiencies differ between addition and multiplication. More specifically, compared to retrieval, procedures are less efficient for multiplications than they are for additions (Campbell & Xue, 2001). Because people always try to select the most efficient strategy (Siegler & Shipley, 1995), they will especially limit the use of procedures in order to solve multiplications. Otherwise stated, they will try to use retrieval more often, and more so for multiplications than for additions. Daily arithmetic practice may have enhanced this effect. Indeed, more-practiced students did retrieve multiplications more frequently than did less-practiced students. Moreover, since procedures are less efficient for multiplications than for additions, multiplication procedures are more susceptible to amelioration than addition procedures are. Two other factors may account for the operation-dependent effect on strategy efficiency as well: (a) the more frequent usage of multiplication in arithmetic and scientific classes and (b) the more declarative nature of multiplication (Roussel et al., 2002). Consequently, the more-practiced students may have built up stronger problem-answer and problem-procedure associations for multiplication than for addition, resulting in higher retrieval efficiency and higher procedural efficiency, respectively.

Arithmetic skill

Arithmetic skill was measured by means of a pen-and-paper test, and thus differed from the practice measure which was based on the number of arithmetic and scientific classes per week. According to LeFevre et al. (1996a), arithmetic skill can be viewed as a continuum from novice to expert, with high-skill subjects retrieving arithmetic facts more frequently and more efficiently than low-skill subjects (see also Ashcraft, Donley, Halas, & Vakali, 1992; Kaye, 1986; Kaye, de Winstanley, Chen, & Bonnefil, 1989; LeFevre & Kulak, 1994); these effects were observed in the present study as well. Indeed, regression analyses showed that arithmetic skill was the only individual trait that was highly predictive of strategy selection and strategy efficiency in both additions and multiplications. One may thus conclude that both strategy selection and strategy efficiency are potentially important indexes of individual differences in skill.

Differences across our subjects may also be compared with differences across cultures, as East-Asian and North-American students differed in retrieval efficiency, procedural efficiency, and retrieval use as well (LeFevre & Liu, 1997). LeFevre and Liu (1997) however, do not believe that these differences between East-Asians and North-Americans are due to overall differences in arithmetic skill. They state that if arithmetic skill differences were the cause, “a comparison between any groups of less- and more-skilled individuals would yield similar patterns of effects” (p. 51). LeFevre and Liu (1997) therefore supposed that fundamental differences in the organization of basic arithmetic facts in memory were responsible for the observed differences between East-Asian and North-American students. In the present study, we did observe comparable patterns across our single-culture subjects as have been observed across cultures (i.e., differences in both strategy selection and strategy efficiency). This result might imply that our same-culture subjects differed in the organization of basic arithmetic facts in memory, an issue that merits future research.

Finally, it should be noted that the influence of arithmetic skill was greater than the influence of daily arithmetic practice. One may thus argue that arithmetic skill largely determines simple-arithmetic performance, with some space left for another, more experience-based individual trait as daily practice. To what extent arithmetic skill may depend on variable factors such as daily arithmetic practice and on more ‘stable’ factors such as general intelligence, is an issue that future research may pursue. Future research may also try to disentangle effects of arithmetic skill and effects of arithmetic practice, possibly by controlling arithmetic skill and manipulating the amount of practice.

The Frequency of Calculator Use

Although cultural differences in the frequency of calculator use have been found (LeFevre & Liu, 1997), this study was the first to relate differences in calculator use to arithmetic performance within one single culture. A first observation was that the frequency of calculator use increased as children grow older (see also Campbell & Xue, 2001). One may further assume that this frequency will increase even more as nowadays most people (even children) always have cell phones at hand, which are also suited to calculate answers to various arithmetic problems. The frequent use of calculators may pose problems, however, as the present study showed a negative relationship between calculator use and strategy efficiency: Both retrieval and procedural strategies were executed less efficiently as the frequency of calculator use grew larger. One caution has to be made with this assertion, however: regression analyses show the relationship between calculator use, on the one hand, and strategy selection and strategy efficiency, on the other, which is insufficient to infer the direction of causality. Future studies are thus needed to investigate whether frequent calculator use results in poorer arithmetic performance or whether students poorer in mental arithmetic are more inclined to use the calculator.

Gender Differences

Although we did not really expect to observe differences between our male and female young adults in simple-arithmetic performance, regression data indicated that boys were somewhat more efficient in retrieving multiplication facts from memory than girls were. As any cognitive difference between males and females is of scientific and social importance, this issue is discussed further in the following. Royer and his colleagues (1999) also observed more efficient retrieval use in boys than in girls, but the present study was the first one to observe comparable effects in young adults. It has been argued however, that any gender difference in retrieval efficiency is not likely to be directly based on biological factors such as sex hormones or primary memory systems (e.g., Geary, 1999; Royer et al., 1999). Geary (1999) rather proposed that sexual selection might *indirectly* influence gender differences in mathematical cognition. More specifically, he proposes that the cognitive systems enabling movement in and the representation of three-dimensional space are more highly elaborated in males than in females. As these brain systems may support mathematical cognition, they may account for the observed differences in mental arithmetic between males and females. Further testing confirmed that the male advantage in mental arithmetic was mediated by gender differences, favoring males, in both spatial abilities and retrieval efficiency (Geary et al., 2000).

It should be noted, however, that arithmetic performance is not only determined by retrieval efficiency, but also by procedural efficiency and retrieval frequency, and based on present results males and females would not differ in these latter aspects. Further research, however, is needed to confirm or reject gender differences in speed of retrieval, and to further investigate sources of these and other differences between males and females in various cognitive domains.

Other Variables

Although the present study examined various individual differences, others still remain unexamined. We chose to focus on cognitive differences across people, who may – of course – also vary regarding their emotionality. Previous studies indeed showed that strategic aspects of simple arithmetic might be influenced by people's affect towards mathematics (LeFevre et al., 1996a) and by their math anxiety (Ashcraft & Faust, 1994; Ashcraft & Kirk, 2001; Faust, Ashcraft, & Fleck, 1996). If we assume that high-anxiety students choose curricula with fewer hours of mathematics whereas low-anxiety students choose curricula with more hours of mathematics, such emotional factors should be seen as confounding variables, because they were not controlled in the present study. Besides such effects of self-selection, the effects of parental selection should not be denied either. It can be assumed that parents influence their children to choose a study curriculum with low or high amounts of arithmetic and scientific classes per week. It would be worthwhile to investigate whether arithmetic practice interacts with the enthusiasm with which students have chosen their study curriculum. Finally, general intelligence might have been an additional confounding variable. As with the factors mentioned earlier, it is difficult to control for intelligence. The present study thus cannot exclude effects of general intelligence completely. Future research should aim at disentangling effects of emotional, parental and cognitive factors (including general cognitive ability) on strategic performance in simple arithmetic.

Implications for Simple-Arithmetic Models

When solving simple-arithmetic problems, multiple strategy use appears to be common in young adults (see also Campbell & Xue, 2001; Hecht, 1999; LeFevre & Liu, 1997; LeFevre et al., 1996a, 1996b). Because most present models of mathematical cognition simply account for retrieval-only data, such models cannot account for all simple-arithmetic performance in adults. Some form of a multiple-strategy model is required. The majority of current models cannot explain multiple strategy use, have not included experiential or educational factors in order to explain performance differences across subjects, or both. Measures of associative strength for example, may be associated with individual differences such as daily arithmetic practice or arithmetic skill. However, as Hecht (1999) noted, most associative network models assume that the problem-answer associations are quite similar among adults because adults all share common experiences that influence the formation of their associative network. These ‘common experiences’ refer to how math facts are practiced and studied in childhood. The present study, however, showed that effects of experience do not stop after childhood, as practice still influenced simple-arithmetic performance in young adults. Incorporating the on-going development of human being would be a true enrichment for models of mental arithmetic. Together with other researchers (e.g., LeFevre et al., 1996a; LeFevre & Liu, 1997) we thus believe that theories of mathematical cognition should include the possibility that reasonably skilled adults with different experiential backgrounds may vary in patterns of performance. Therefore, adequate models of mental arithmetic must make additional assumptions to account for both retrieval and non-retrieval responding, and must incorporate a role for individual differences and their consequences on arithmetic performance.

One model that – after some small modifications – would be able to account for our and other data (e.g., LeFevre et al., 1996a) is the Adaptive Strategy Choice Model (ASCM; Siegler & Shipley, 1995). According to this model, problems, strategies, and problem-strategy strengths are stored in a database. Each time a problem is solved, information about the strategy efficiency (e.g., time and accuracy) is added to the database, which can be modified accordingly. The probability of choosing a particular strategy is based on the strategy’s strength relative to the strength of all other strategies. Furthermore, each time a particular strategy is used to solve a problem, the association between the problem and the strategy used gains in strength. In such a model, adults are no longer assumed to uniquely rely on retrieval. If we further assume that the amount of daily arithmetic practice influences problem-strategy associations (e.g., practice might strengthen the problem-retrieval association and weaken the problem-procedure association), ASCM would predict performance differences across subjects with different amounts of practice. Therefore, we do not propose that the basic structure of the models should be changed, but that they should be updated by not only including problem features (e.g., problem size), but also strategy selection characteristics (e.g., single or multiple strategy use), and individual traits (e.g. arithmetic skill, arithmetic practice), in order to develop complete models of mental arithmetic that are able to explain various effects in simple-arithmetic performance. Previous studies already suggested some ideas for modifications to present models (e.g., Hecht, 1999; LeFevre et al., 1996).

Conclusions

Even though it has been suggested that experiential factors may influence the performance at early stages of learning whereas problem size would influence the performance of highly practiced adults (e.g., Geary, 1996), we believe that the influence of experiential factors will never disappear completely. Practice can influence both strategy selection and strategy efficiency in children (e.g., Siegler, 1986) and young adults (present study). We therefore believe that future research should not confine itself to the investigation of skill variables but should also concentrate on other individual differences such as daily arithmetic practice. More general, and in agreement with other researchers (e.g., Kirk & Ashcraft, 2001; LeFevre et al., 1996b), we believe that investigations of individual differences and their relationship to on-line performance should be a priority for the field.

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Footnotes

1. In the present paper, the term ‘individual differences’ is used to refer to differences inherent in individuals (e.g., gender) as well as to differences resulting from the environment (e.g., arithmetic practice, calculator use).

2. In Belgium, high-school education starts at 12 years of age and normally takes six years to finish. After their second year of high school, students have to choose among different study options, such as Humanities, Economics, Languages, Mathematics, or Sciences. The amount of daily arithmetic practice (defined as the number of hours per week dedicated to arithmetic and scientific classes) varies across these study options. More specifically, students enrolled in a Mathematics curriculum have more arithmetic-related classes than students in an Economics curriculum, which have in their turn more arithmetic-related classes than students in a Humanities curriculum.

3. It should be noted that some predictor variables correlated with each other. More specifically, the correlation between daily arithmetic practice and arithmetic skill, between calculator use and arithmetic skill, and between daily arithmetic practice and calculator use were significant ($r = .256$, $r = -.347$, and $r = -.297$, respectively). These correlations are not problematic for the regression analyses, however. Indeed, omitting one of these predictors in the regression model did not result in dramatic changes of the parameter estimates or significance results for the remaining predictors.

Table 1

Means, standard deviations (SD), medians, minima, and maxima of the three dependent variables used in the regression analyses.

Addition	Mean	SD	Median	Minimum	Maximum
Retrieval use (%)	78	4	81	31	100
Retrieval RTs (msec)	874	296	857	601	1382
Procedural RTs (msec)	1114	680	1035	710	2464
Multiplication	Mean	SD	Median	Minimum	Maximum
Retrieval use (%)	87	3	89	53	100
Retrieval RTs (msec)	1376	688	1343	689	2573
Procedural RTs (msec)	2865	2368	2184	889	7453

Table 2

Means, medians, minima, and maxima of the individual-characteristic variables (except gender) used as predictors in the regression analyses.

	Mean	Median	Minimum	Maximum
Daily arithmetic practice (hours)	8	4	3	15
Calculator use high school [a]	4	4	1	5
Calculator use elementary school [a]	2	2	1	5
Arithmetic skill (score on the French kit)	28	26	15	58

[a] The frequency of calculator use was questioned for both the years at the elementary school and the years in high school. Only the current frequency of calculator use (i.e., in high school) was used in the regression analyses, however.

Table 3

Summary of the regression analyses for variables predicting percentage retrieval use, retrieval RTs, and procedural RTs.

Retrieval use	Addition			Multiplication		
	B	*SE B*	*ß*	*B*	*SE B*	*ß*
Problem size	-4.348	.265	-.495**	-.595	.037	-.380**
Arithmetic skill	.697	.131	.174**	.367	.087	.109**
Calculator use	-.099	.052	-.066	.065	.034	.052
Daily practice	.044	.244	.006	.422	.161	.074**
Gender	3.061	2.614	.044	.732	1.725	.013
Retrieval RTs	Addition			Multiplication		
	B	*SE B*	*ß*	*B*	*SE B*	*ß*
Problem size	30.873	2.231	.424**	14.177	.849	.385**
Arithmetic skill	-9.206	1.068	-.288**	-18.302	1.930	-.238**
Calculator use	1.510	.423	.125**	2.037	.779	.069**
Daily practice	-1.011	2.042	-.018	-7.751	3.625	-.059*
Gender	-38.779	22.061	-.070	-80.402	38.564	-.060*
Procedural RTs	Addition			Multiplication		
	B	*SE B*	*ß*	*B*	*SE B*	*ß*
Problem size	40.437	9.270	.220**	19.154	6.203	.146**
Arithmetic skill	-9.072	3.740	-.138**	-108.738	17.571	-.309**
Calculator use	3.401	1.740	.127*	12.721	5.235	.146**
Daily practice	-13.553	7.366	-.114	-103.214	28.510	-.214**
Gender	-131.687	76.057	-.109	344.256	346.783	.070

* $p < 0.05$. ** $p < 0.01$.