Research Article

Selective Interference of Finger Movements on Basic Addition and Subtraction Problem Solving

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Abstract. Fingers offer a practical tool to represent and manipulate numbers during the acquisition of arithmetic knowledge, usually with a greater involvement in addition and subtraction than in multiplication. In adults, brain-imaging studies show that mental arithmetic increases activity in areas known for their contribution to finger movements. It is unclear, however, if this truly reflects functional interactions between the processes and/or representations controlling finger movements and those involved in mental arithmetic, or a mere anatomical proximity. In this study we assessed whether finger movements interfere with basic arithmetic problem solving, and whether this interference is specific for the operations that benefit the most from finger-based calculation strategies in childhood. In Experiment 1, we asked participants to solve addition, subtraction, and multiplication problems either with their hands at rest or while moving their right-hand fingers sequentially. The results showed that finger movements induced a selective time cost in solving addition and subtraction but not multiplication problems. In Experiment 2, we asked participants to solve the same problems while performing a sequence of foot movements. The results showed that foot movements produced a nonspecific interference with all three operations. Taken together, these findings demonstrate the specific role of finger-related processes in solving addition and subtraction problems, suggesting that finger movements and mental arithmetic are functionally related.

Keywords: mental arithmetic, finger counting, finger movement, embodied cognition

Hand and finger movements play an important role in the first counting experiences of children (Fuson, 1988). Gesturing provides children with a physical counterpart to the number sequence by producing a visual (Crollen, Mahe, Collignon, & Seron, 2011) and proprioceptive feedback after each number-word uttered (Graham, 1999). Using finger counting is the first or second most frequent strategy observed in preschoolers during arithmetic tasks to represent the operands and/or the result of problems, or to keep track of some steps of the solving procedure (Fuson, 1982), even when no explicit instructions are given to use the fingers (Siegler & Shrager, 1984). This specific role of fingers during the acquisition of arithmetic operations is corroborated by the finding that the ability of 5-year-old children to discriminate between their fingers is the best predictor of their calculation skills, but not of their reading abilities, up to 3 years later (Fayol, Barrouillet, & Marinthe, 1998; Noël, 2005; see also Costa et al., 2011; Reeve & Humberstone, 2011). Moreover, the performance of 6- to 8-year-old children in mental addition and subtraction tasks reveals that they often make mistakes with a difference of five units from the correct result (e.g., $2 + 7 = 14$, $18 - 7 = 6$), a finding interpreted as a failure to retrieve or keep track of the number of internalized "full hands" engaged in the calculation process (Domahs, Krinzinger, & Willmes, 2008). Finally, recent studies have demonstrated that training first graders to correctly differentiate their own fingers improved their untrained mathematical skills (Gracia-Bafalluy & Noël, 2008; but see Fischer, 2010).

The continuing influence of finger movements during the acquisition of calculation skills has led to suggest that mental arithmetic in adults could rely on cognitive processes and/or representations initially developed to serve finger movements (Michaux, Pesenti, Badets, Di Luca, & Andres, 2010). This view is supported by correlative data from brain-imaging studies showing increased activity in motor-related areas during arithmetic tasks (e.g., Dehaene et al., 1996; Pesenti, Thioux, Seron, & De Volder, 2000; Zago et al., 2001). Nevertheless, there is little direct evidence for the interdependence of the processes underlying mental arithmetic and finger control, except from studies of brain-damaged patients with Gerstmann's syndrome, which is characterized by the association of acalculia and finger agnosia (Gerstmann, 1940; Mayer et al., 1999). Localizationist accounts suggest, however, that this syndrome could result from the accidental conjunction of distinct deficits following lesions in a common vascular territory (Dehaene, Piazza, Pinel, & Cohen, 2003), or from damage to a convergence zone in the white matter (Rusconi et al., 2009). Further empirical evidence is thus needed to firmly support the view that mental arithmetic in adults relies on functional processes initially developed to support finger movements.

In the present study, we focused on the processes and representations shared by mental arithmetic and finger

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movements typically used by children while learning to calculate. To do this, we designed a dual-task experiment (Experiment 1) that required healthy adults to solve simple arithmetic problems either with their hands at rest (single-task condition) or while moving their right-hand fingers sequentially (dual-task condition). In order to specify the functional relationship between finger movements and mental arithmetic, we compared the time cost induced by the dual task between two operations usually solved by children through various finger-based calculation strategies, that is, addition and subtraction (Baroody, 1987; Siegler & Shipley, 1987; Siegler & Shrager, 1984), and one operation mostly solved by direct retrieval, that is, multiplication (Cooney, Swanson, & Ladd, 1988), presumably because of teaching programs emphasizing the memorization of multiplication facts by rote memory (McGinty, VanBeynen, & Zalewski, 1986). We predicted that solving addition and subtraction problems should be more impaired by concurrent finger movements, due to their early privileged interactions, than solving multiplication problems, for which the use of finger-based strategies is more anecdotal. Indeed, reports indicate that educated adults still make substantial use of procedural strategies in solving simple subtraction and, to a lesser extent, simple addition problems whereas they rely almost exclusively on direct retrieval of the answer from long-term memory for solving simple multiplication problems (Campbell & Xue, 2001). In a second experiment (Experiment 2), the specificity of the interference induced by finger movements was assessed by asking participants to perform foot movements instead of finger movements. As foot movements are not related to arithmetic solving procedures in any particular way, their possible interfering effect was not expected to be modulated by the type of arithmetic operation.

Experiment 1

Method

Participants

Sixteen French-speaking university students took part in Experiment 1 (8 females; mean ± *SD*: 21.75 ± 2.29 years old); they were not aware of the objectives of the study. They were all right-handed according to the Edinburgh Handedness Inventory (EHI; Oldfield, 1971) and had normal or corrected-to-normal vision. Additionally, they had all completed their entire primary and secondary schooling in Belgium without experiencing any problem in mathematics. The experiment was noninvasive and was performed in accordance with the ethical standards established by the Declaration of Helsinki.

Tasks and Stimuli

The participants were asked to answer aloud to visual arithmetic problems, presented in two different conditions, with instructions emphasizing both speed and accuracy. In the single-task condition, they had to solve the arithmetic problems with both hands lying at rest on a table. In the dual-task condition, they had to answer the same problems while successively flexing each of their right-hand fingers, from the thumb to the little finger, at a constant rhythm of 1 Hz (see Figure 1) and keeping their left hand at rest. They were instructed to repeat the same sequence of finger movements throughout each block of dual-task trials.

The arithmetic problems consisted of 18 additions, 18 subtractions, and 18 multiplications. They were selected on the basis of data collected in a pilot study so that the three operation sets were balanced in terms of median response latency (RL) and error rate. Tie problems (e.g., 3 + 3, 6×6, etc.) and problems involving 0 or 1 as operands (e.g., 7 − 0, 6×1, etc.) were excluded since they have been found to benefit from a distinct access in memory or to be solved through rule-based strategies (Blankenberger, 2001; Campbell & Gunter, 2002; LeFevre et al., 1996). The problems were thus composed of two single Arabic digits ranging from 2 to 9 and were always presented with the largest operand in the first place (for a complete list, see Appendix).

Experimental Procedure

Participants were seated at a viewing distance of 50 cm from a 15-inch computer screen. E-Prime (Schneider, Eschman, & Zuccolotto, 2002) was used to control stimuli presentation and collect RLs through an interfaced microphone. Response accuracy was assessed on-line by the

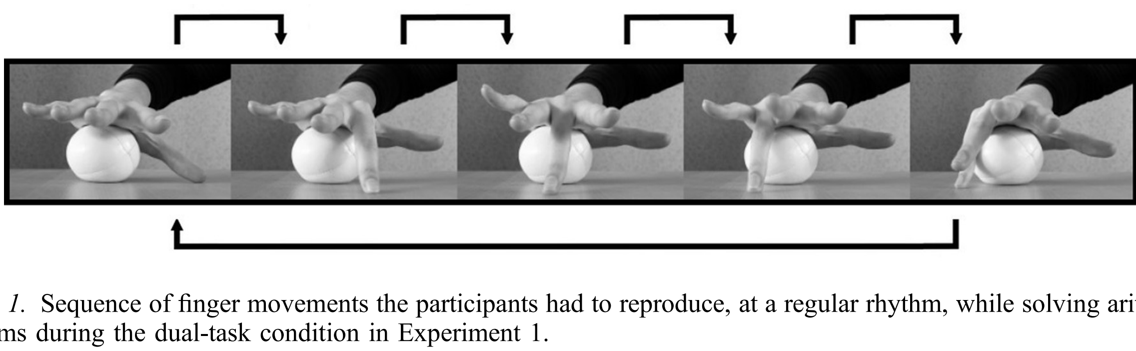

Figure 1. Sequence of finger movements the participants had to reproduce, at a regular rhythm, while solving arithmetic problems during the dual-task condition in Experiment 1.

experimenter. Finger movements were performed with the right hand placed on a juggling ball (see Figure 1) and were captured by a camcorder for off-line analyses.

Testing started with a training phase during which the participants learned to reproduce the finger movements paced with a metronome beat of 1 Hz, followed by a practice run to familiarize them with the tasks. Next, they were presented with six experimental runs in a counterbalanced order, each composed of six blocks of nine trials alternating between the two conditions (i.e., the single- and dual-task conditions) and the three operations (i.e., addition, subtraction, and multiplication). In each trial, an arithmetic problem was displayed centrally and remained on the screen until the participants responded. The intertrial interval was 4,000 ms. The problems were presented in a pseudorandom order with the constraint that an operand could not be used in the same place twice in a row. In total, each problem was solved three times in each condition.

The condition was cued for 6 s either by a video showing the finger movements to perform or by a picture of a hand at rest. Green and red squares, flashed at the center of the screen, were used as "start" and "stop" signals to indicate respectively the beginning and the end of finger movements in the dual-task condition. They were accompanied by auditory beeps that allowed the number of finger movements performed during a fixed time interval to be counted in the off-line analyses of the video recordings.

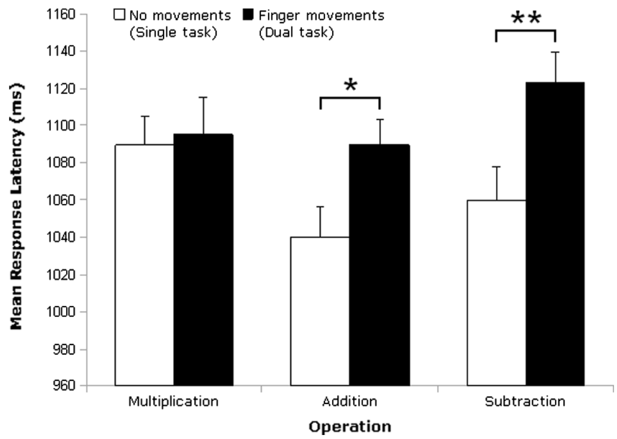

Figure 2. Mean response latency (+*SE* bars, adjusted for within-subject designs; see Loftus & Masson, 1994) as a function of the arithmetic Operation (addition, subtraction, or multiplication) and the experimental Condition (single task without finger movements or dual task with finger movements). Asterisks indicate the operations exhibiting a significant difference between conditions (*$p < .05$; **$p < .01$; one-tailed paired-sample t tests with Bonferroni correction).

Results

Arithmetic Problem Solving

Trials where the answer was erroneous (4.48%) or where the microphone failed to trigger (3.14%) were not included in the following analyses. A repeated-measures analysis of variance (ANOVA) was carried out on the median RLs with Operation (addition, subtraction, or multiplication) and Condition (single or dual task) as within-subject variables. There was no main effect of Operation, $F(2, 30) = .835$, *ns*, but a significant main effect of Condition, $F(1, 15) = 7.16, p < .02, \eta^2 = .323$, indicating that responses to arithmetic problems were slowed down overall by concurrent finger movements (mean RL ± *SE* in single task: 1,063 ± 7 ms; in dual task: 1,103 ± 7 ms; *SE* adjusted for within-subject design following Loftus & Masson, 1994). There was also a significant Operation by Condition interaction, $F(2, 30) = 4.274$, $p < .03$, $\eta^2 = .222$. Paired-sample t tests (one-tailed, $p < .05$ with Bonferroni adjustment for multiple comparisons) revealed a significant difference in RLs between the two conditions for addition, $t(15) = -2.691$, $p < .03$, and subtraction, $t(15) = -3.51$, $p < .005$, but not for multiplication, $t(15) = -.262$, *ns*; see Figure 2. The participants took more time to respond to addition and subtraction problems when they had to simultaneously move their fingers than when they had to keep them at rest. In contrast, multiplication problems were solved equally fast with or without finger movements. There were no differences in RLs between operations in the ANOVAs with Operation as the within-subject factor performed at each level of Condition, that is, in either single- or dual-task condition (respectively, $F(2, 30) = 1.856$, *ns*; $F(2, 30) = .91$, *ns*).

A similar ANOVA carried out on the error rates revealed no significant main effect or interaction (all ps > .1), indicating that the mean error rates remained statistically identical across operations (addition: 3.94 ± 0.46%; subtraction: 4.17 ± 0.55%; multiplication: 5.33 ± 0.66%) and conditions (single task: 4.67 ± 0.31%; dual task: 4.29 ± 0.31%).

Finger Movements

To test the effect of the arithmetic task on finger movement production, the number of finger movement errors was computed for each participant. A finger movement was coded as erroneous when participants broke the sequence (e.g., the middle finger moved before the index), omitted a finger, or flexed the same finger twice in succession. A repeated-measures ANOVA with the factor Operation (addition, subtraction, or multiplication) revealed no main effect, $F(2, 30) = .403$, *ns*, indicating that the number of finger errors did not differ across operations (addition: 3.62 ± 0.84 errors; subtraction: 3.44 ± 0.89 errors; multiplication: 5.06 ± 1.56 errors).

A similar ANOVA was conducted on the mean movement frequencies, that is, the number of finger movements performed in the dual-task periods of each operation and averaged across runs, in order to assess whether participants moved their fingers at the same rhythm across all operations. This analysis showed no main effect of Operation, $F(2, 30) = .171$, *ns*, indicating that the participants kept a regular rhythm across the three operations (mean number of movements for addition: 75.45 ± 0.53; subtraction: 75.85 ± 0.44; multiplication: 75.32 ± 0.63).

Discussion of Experiment 1

Experiment 1 aimed at determining whether finger movements would interfere with basic arithmetic problem solving and whether this interference would be specific for the operations benefiting the most from the use of finger-based calculation strategies in childhood. The results showed that finger movements selectively interfered with the solving of addition and subtraction problems, as evidenced by the longer RLs for these operations when sequential finger movements were performed at the same time. By contrast, solving multiplication problems remained unaffected by the concurrent task. Importantly, the absence of interference effect on arithmetic accuracy scores indicates that dual-task-related RL increases were not due to a speed-accuracy trade-off. Moreover, the frequency and accuracy of finger movements remained stable across all operations, which rules out the possibility that finger movements led to increased RLs in addition and subtraction but not in multiplication because participants performed the motor task with a different speed or accuracy. Taken together, these findings suggest that finger-related processes support the ability to solve addition and subtraction problems.

As argued by an anonymous reviewer, this dissociation might merely reflect the fact that addition and subtraction are more sensitive than multiplication to the interference of any concurrent task because they rely on procedural strategies, which would be, by essence, more demanding on cognitive resources than retrieval strategies. However, contrary to this suggestion, there are plenty of procedural tasks much less demanding than retrieval tasks (e.g., riding a bicycle vs. recalling a long text from memory). More importantly, the sets of problems used in the present study showed no response latency and error difference across operations in the no-movement condition, which reasonably supports the claim that they imply the same cognitive load. Experiment 2 was designed to test the specificity of this finger-movement interference.

Experiment 2

Experiment 1 showed that finger movements selectively interfered with addition and subtraction, but not with multiplication. To test whether this selective interference is specific to finger movements, we asked participants to solve the same arithmetic problems either with the right foot at rest or while moving it sequentially. If the selective interference observed in Experiment 1 is due to processes that are not specifically related to the motor control of fingers, then the same pattern of results should be found in Experiment 2. On the other hand, the absence of an interaction between Operation and Condition would allow us to attribute the selective interference observed in Experiment 1 to processes specifically related to fingers.

Method

Participants

Sixteen French-speaking university students took part in Experiment 2 (8 females; mean ± *SD*: 23.19 ± 1.97 years old); none had participated in Experiment 1 and they were not aware of the objectives of the study. All the participants were right-handed, as confirmed by the EHI, and right-footed, as shown by the Modified Waterloo Footedness Inventory (Elias & Bryden, 1998). They had normal or corrected-to-normal vision and they had completed their primary and secondary schooling in Belgium with no history of difficulty in mathematics. The experiment was noninvasive and performed in accordance with the ethical standards established by the Declaration of Helsinki.

Tasks, Stimuli, and Procedure

Experiment 2 was identical to Experiment 1 insofar as the tasks, stimuli, and general procedure were concerned, with the exception of the motor task used in the dual-task condition that required foot rather than finger movements. The participants were asked to give the answers to the same arithmetic problems as in Experiment 1 aloud, with both hands and feet at rest in the single-task condition, and while keeping their hands and left foot at rest but continuously moving the right foot across four different positions, from the left to the right at a constant rhythm of 1 Hz, in the dual-task condition. The positions were indicated by four regularly spaced bumps on a wooden platform delimited by 10 cm high borders on lateral sides. In the dual-task condition, the participants were required to initiate each sequence on the first bump with the foot against the left border, then to move it rightwards over the other bumps by rotating the heel, and to move back to the first bump as soon as they had reached the last position and hit the right border (see Figure 3). In each block, the condition was cued for 6 s either by a video showing the required sequence of foot movements or by a picture of a right foot at rest.

Results

Arithmetic Problem Solving

Trials where the answer was erroneous (3.45%) or where the microphone failed to trigger (5.77%) were excluded from the analyses. The Operation (addition, subtraction, or multiplication) by Condition (single or dual task) repeated-measures ANOVA carried out on the median RLs only revealed a main effect of Condition, $F(1, 15) = 5.896$, $p < .03$, $\eta^2 = .282$ (see Figure 4), indicating that the responses to arithmetic problems were generally slowed down by concurrent foot movements (mean RL ± *SE* in single task: 960 ms ± 9 ms;

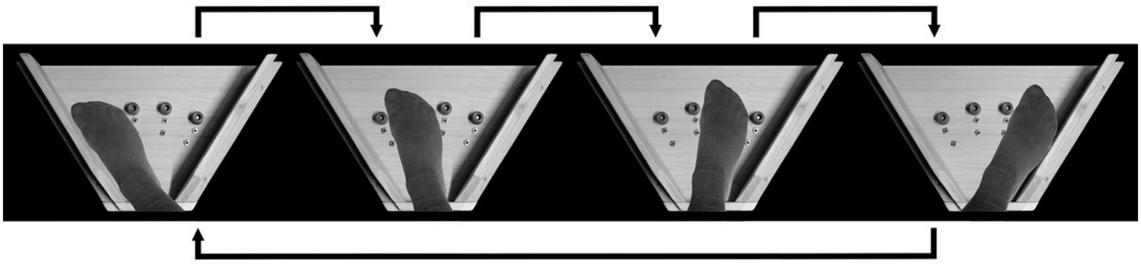

Figure 3. Sequence of foot movements the participants had to reproduce at a regular rhythm across four bumps, while solving arithmetic problems during the dual-task condition in Experiment 2.

in dual task: 1,003 ms ± 9 ms), regardless of the operation. There was no main effect of Operation, $F(2, 30) = 3.059$, $p > .06$, and no Operation by Condition interaction, $F(2, 30) = .705$, *ns*.

A similar ANOVA carried out on the error rates also showed a main effect of Condition, $F(1, 15) = 4.59$, $p < .05$, $\eta^2 = .234$, indicating that the participants made more arithmetic errors when they had to move their right foot (3.78 ± .15%) compared to when they had to keep it at rest (3.12 ± .15%). There was no main effect of Operation, $F(2, 30) = 2.138$, $p > .1$, and no Operation by Condition interaction $F(2, 30) = .979$, *ns*.

Foot Movements

A repeated-measures ANOVA with the single factor Operation (addition, subtraction, or multiplication) was performed on the individual numbers of foot movement errors. A foot movement was coded as erroneous when participants broke the sequence, omitted a position, or touched the same position twice in succession. This ANOVA revealed no main

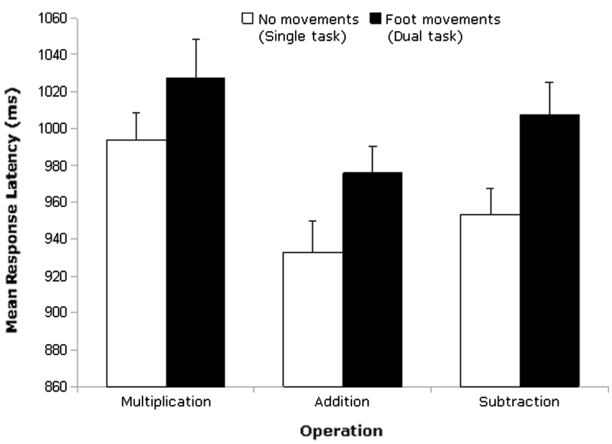

Figure 4. Mean response latency (+*SE* bars adjusted for within-subject designs) as a function of the arithmetic Operation (addition, subtraction, or multiplication) and the experimental Condition (single task without foot movements or dual task with foot movements).

effect of Operation, $F(2, 30) = 1.238$, $p > .3$, indicating that the participants made approximately the same number of movement errors irrespective of which arithmetic operation they were performing (addition: 0.62 ± 0.21 errors; subtraction: 0.31 ± 0.12 errors; multiplication: 0.87 ± 0.26 errors).

A similar ANOVA was conducted on mean movement frequencies, that is, the numbers of foot movements performed in the dual-task periods of each operation and averaged across runs. There was no main effect of Operation, $F(2, 30) = .623$, *ns*, indicating that the rhythm of foot movements remained identical across operations (mean number of movements for addition: 52.29 ± 0.29; subtraction: 51.92 ± 0.26; multiplication: 52.42 ± 0.25).

Discussion of Experiment 2

To assess whether the selective interference observed in Experiment 1 was specific to fingers, the participants of Experiment 2 were asked to respond to the same arithmetic problems, either with both hands and feet at rest, or while moving their right foot. The results showed that foot movements interfered equally with the solving of all three operations, as shown by a similar increase in RLs and error rates. This pattern was observed in the context of equal movement frequency and accuracy across operations. It is worth noting that multiplication was here slowed down by foot movements to the same extent as the other operations, consequently eliminating the possibility that the dissociation observed between operations in Experiment 1 was simply due to a difference in the attentional demands required to solve each operation.

Importantly, as the foot movement task also involved a comparable left-to-right progression and the same defined rhythm as the finger movement task, the nonselective interference observed in Experiment 2 allows us to ensure that uncontrolled visuospatial and/or temporal processes were not responsible for the selective interference observed in Experiment 1. This is of great importance, given that some studies have suggested that solving addition and subtraction problems could be analogous to attentional shifts along a horizontal "mental number line" representing the numerical magnitudes as a distribution of local activations (Hubbard, Pinel, Piazza, & Dehaene, 2005; Knops, Thirion, Hubbard, Michel, & Dehaene, 2009; Pinhas & Fischer, 2008), while others have reported common mechanisms for duration and numerosity processing (Brown, 1997; Dormal, Dormal, Joassin, & Pesenti, 2012; Dormal, Seron, & Pesenti, 2006).

The reason why moving the foot had such a main effect on arithmetic processing is unclear but it may reflect an additional attentional load related to unspecific control processes, which may be due to the unusual nature of the foot movement task. Still, the main finding of the present experiment is that the effect in the dual-task condition is not modulated by the arithmetic operation, as one would have expected in case of a specific relationship between foot movements and counting.

To sum up, by showing a nonselective interference of foot movements, Experiment 2 has demonstrated the specificity of the selective interference induced by finger movements in mental arithmetic in Experiment 1.

General Discussion

This study aimed to determine whether mental arithmetic in adults relies on functional processes related to those controlling finger movements, and whether this functional overlap is more pronounced for the arithmetic operations that benefit the most from finger-based calculation strategies in childhood. This hypothesis was tested in Experiment 1 by asking participants to solve simple addition, subtraction, and multiplication problems either with their hands at rest or while performing sequential finger movements. The results showed that finger movements selectively disrupted the solving of simple addition and subtraction problems, but not of simple multiplications problems. To assess the specificity of this finger movement interference, we asked the participants in Experiment 2 to solve the same arithmetic problems, either with both hands and feet at rest or while moving their right foot. This experiment revealed a nonselective interference: sequential foot movements equally interfere with the solving of addition, subtraction, and multiplication problems, as shown by the similar time costs and error rates induced across all three operations in the dual-task condition. These findings demonstrate the finger specificity of the selective interference on addition and subtraction in Experiment 1, and support the view that finger-related processes play a selective role in solving these two types of problems.

This study adds to previous data suggesting that finger movements continue to interact with number processing in adults (Andres, Seron, & Olivier, 2007; Badets & Pesenti, 2010, 2011; Mayer et al., 1999) and provides new evidence that the involvement of finger-related processes extends to the field of mental arithmetic. A recent behavioral study revealed a sub-base-five effect in adults solving addition problems (i.e., RL increase when the sum of the unit digits of the problems exceeds 5), which was considered as reflecting implicit finger-based representations in mental arithmetic (Klein, Moeller, Willmes, Nuerk, & Domahs, 2011). Another recent study also showed that finger movements interfere with the solving of addition and subtraction problems when participants are explicitly asked to solve them by procedural rather than retrieval strategies (Imbo, Vandierendonck, & Fias, 2011). However, those studies lacked an appropriate control task to specifically attribute their effects to fingers and, as they did not test multiplication, the contribution of finger-related processes/representations in regard to the different operations remained unclear. Because those issues were addressed in the present study by contrasting the three main arithmetic operations and testing the specificity of finger-number interactions, we were able to demonstrate an interference effect specifically related to fingers and selective for addition and subtraction.

There is now a large agreement that solving multiplication problems relies on the retrieval of the association between the operands and the solution from long-term memory. These associations might be of a verbal nature (Dehaene & Cohen, 1995) as suggested by the fact that verbal repetition interferes with the processing of multiplication problems, but not with the solving of subtraction problems (Lee & Kang, 2002; Moeller, Klein, Fischer, Nuerk, & Willmes, 2011). Together with the present findings, these results suggest a double dissociation between finger-based and possibly language-based knowledge of arithmetic problems.

The question arises as to whether the functional interactions between finger movements and arithmetic are driven by phylogenetic or ontogenetic factors. According to the phylogenetic view, the most recent functions in human development build on preexisting processes that are already available in other domains with suitable properties, and sensorimotor interference is just an artifact of this evolutionary process (Anderson, 2010; Penner-Wilger & Anderson, 2008). In this view, number and finger interactions occur because motor control involves processes that already have useful representational and/or procedural properties for arithmetic functions, such as an incremental counter that keeps track of sequential movements. The ontogenetic view states that finger-related processes come to underlie mental arithmetic during child development because of the use of fingers to represent and/or manipulate numbers (Butterworth, 1999; Michaux et al., 2010). Solving an arithmetic problem can then be viewed as implicitly eliciting mental activations of finger-based representations and/or procedures acquired during childhood (Andres et al., 2007; Sato, Cattaneo, Rizzolatti, & Gallese, 2007), or even the final state of a finger-based calculation strategy in which the raised fingers correspond to the solution of a given arithmetic problem (Badets, Pesenti, & Olivier, 2010). We argue that the present findings support the ontogenetic view by underlining the critical impact of personal sensorimotor experience. Indeed, if mental arithmetic grew on finger-related processes simply because the latter preexisted in the human brain, there would be no reason to observe an operation-specific interference, whereas the fact that the operations affected by concurrent finger movements correspond to those learned through finger-based strategies is a direct prediction of the sensorimotor perspective.

The selective interference of finger movements with arithmetic operations also extends current knowledge of the functional interactions between bodily experience and conceptual processing. Previous studies have shown that tools (Almeida, Mahon, & Caramazza, 2010) and action verbs (Willems, Hagoort, & Casasanto, 2010) can induce fast and automatic recall of the sensorimotor experiences they refer to. The interference observed in the present study implies that sensorimotor experience could also underlie conceptual processing, such as adding or removing quantities.

Future studies will have to clarify the exact nature of the finger-related processes that are crucially involved in mental arithmetic and further define the role they play. A representational role of finger-related processes was already evidenced in previous behavioral studies showing that mental finger configurations are implicitly activated when numbers or results to arithmetic problems are processed (Badets et al., 2010; Di Luca, Granà, Semenza, Seron, & Pesenti, 2006; Di Luca & Pesenti, 2010; Sato et al., 2007). On the other hand, it has been suggested that finger-related processes could also play a procedural role in counting procedures by contributing to establish a one-to-one correspondence between counted items and any ordered series (Andres et al., 2007). More recently, an fMRI study showed that arithmetic and finger discrimination tasks induce common activations in parietal areas whose contribution to finger discrimination was not specific to the left or right hand, suggesting that this neural overlap in the parietal cortex is not related to representational aspects (Andres, Michaux, & Pesenti, 2012). Whether the representational or procedural mechanisms shared by mental arithmetic and finger control are crucial for both activities still needs to be investigated. For instance, future studies could examine the differential effect of various types of finger movements (e.g., by manipulating their direction, their complexity, or the hand used to perform them) on mental arithmetic.

In conclusion, the present study demonstrates a specific interference of finger movements on solving basic arithmetic problems, selective for those arithmetic operations learned through finger-based calculation strategies. This provides a new insight into the functional interactions between bodily experiences and mental calculation.

Acknowledgments

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Appendix

Arithmetic Problems for Experiment 1 and Experiment 2

Multiplication	Addition	Subtraction
4 × 2	4 + 2	4 − 3
4 × 3	4 + 3	5 − 3
5 × 2	5 + 2	6 − 2
5 × 3	5 + 4	6 − 4
5 × 4	6 + 2	7 − 2
6 × 2	6 + 3	7 − 3
6 × 4	6 + 4	7 − 4
6 × 5	6 + 5	7 − 5
7 × 2	7 + 3	8 − 2
7 × 3	7 + 4	8 − 3
7 × 4	7 + 5	8 − 5
7 × 5	8 + 2	8 − 6
8 × 2	8 + 3	9 − 2
8 × 5	8 + 6	9 − 3
8 × 6	9 + 2	9 − 4
9 × 2	9 + 5	9 − 5
9 × 3	9 + 6	9 − 6
9 × 5	9 + 7	9 − 7