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Effects of multiplications on additions in children

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Abstract

Simple multiplications have been shown to interfere with the realization of simple additions in adults. There is also some evidence suggesting that children's performance in simple additions decreases when they are learning multiplications. This study aimed at directly examining multiplication-related interference in children who are learning to multiply. Thirty-eight fourth-graders had to solve additions presented alone (control condition) or immediately after a short multiplication task (interference condition). It appeared that, in the interference condition, children were slower and used direct memory retrieval less often to solve additions than in the control one, indicating that multiplication-related interference occurs even in a developing arithmetic facts network. Then, we examined two variables that could modulate these multiplication-related interference effects: Inhibition and multiplications skills. We found that multiplication-related interference did not vary as a function of inhibition capacities. On the contrary, when analysing children's performance in addition as a function of their abilities to solve the counterpart multiplications, we found that children with poorer performances showed greater interference effect. These findings are discussed in the light of current models of arithmetic facts.

Key words: arithmetic facts, interference, inhibition

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In the domain of simple mental arithmetic, simple multiplications have been shown to negatively influence the realization of simple additions.

In a recent experiment, Campbell and Timm (2000) administered undergraduate students two blocks of 36 additions following four blocks of either multiplications or divisions. They observed that, when performing the additions, participants who solved multiplications first presented longer latencies, greater error rates, and reported using direct memory retrieval less often than participants who solved divisions first. Yet adults have a well-established arithmetic facts network, in contrast to young children. One might wonder if this direct interference effect of multiplication on additions already occurs in children who are in the process of developing a mature associative network.

In a longitudinal study, Miller and Paredes (1990, Experiment 2) tested second-, third-, and fourth-graders with single-digit additions in three sessions (December, February, and May). When analysing children's error rates, they observed that, while fourth-graders became more and more accurate with time, second- and third-graders' error rates first decreased between the first and the second testing session, but increased again at the third session to become almost as high, and even higher (for third-graders) than in the first session. The authors also analysed children's latencies to additions as a function of their math level (children were attending either regular or advanced math classes) and testing time. They found that second-graders attending advanced math classes and third-graders attending regular classes performed the additions slower and slower over the year, whereas all the other children were faster to perform additions through the testing sessions. In sum, they found that, contrasting with the general developmental tendency for performance to improve with age, some children showed a significant decrease of performance over a six-month period. When consulting the children's teachers, they found that this decrease roughly corresponded to the time that children were engaged in learning multiplications. Thus, they concluded that learning to multiply had a deleterious effect on children's performance on previously learned (and mastered) additions. According to the authors, these results can be explained by the strategies used by children when performing simple arithmetic: Children may use reconstructive strategies (such as counting) to solve additions because they are easy to apply. However, these strategies are more difficult for multiplications, which could lead to a preferential use of retrieval in that case. Consequently, products might be more accessible for some addition problems than sums. When presented with addition problems, the more accessible products then create interference to the correct sums. And indeed, the work of Roussel (2000; see also Lépine, Roussel, & Fayol, 2003) has shown that additions were solved by reconstructive strategies whereas multiplications were solved by direct memory retrieval. Nevertheless, an alternative interpretation might be that, at the time children were engaged in learning to multiply, less emphasis was made on additions. Therefore, the decrease of performance observed for these problems might result more from a reduced practice on the additions than from multiplication-related interference.

The main purpose of this study is to establish, using a paradigm inspired by Campbell and Timm's experiment (2000), whether multiplications interfere with additions even in a developing arithmetic network. Accordingly, we tested fourth-grade children and asked them to solve a set of additions presented alone (the control condition) or immediately following multiplications (the interference condition). In order to maximize interference, all additions in the interference condition had exactly the same operands as the multiplications. Children's strategies to solve the additions were also taken into account. Finally, we wanted to see whether this interference effect varied as a function of interindividual differences. First, we examined differences between children with respect to inhibition ability. Indeed, since inhibition is commonly assumed to be the process by which interference is reduced or resolved (Harnishfeger, 1995), one might expect that children with high inhibition abilities show weaker multiplication-related interference effect. Therefore, a Color-Word Stroop Test was administered to the children. Second, in relation to theoretical models of arithmetic facts, we examined children's ability to solve the multiplication problems. Indeed, despite some differences between the extant models, there is a general consensus that arithmetic facts are stored in an interrelated network or associative structure in long-term memory from which retrieval is accomplished via a spreading-activation process (e.g., Ashcraft, 1987; Campbell, 1995; Campbell & Graham, 1985; Siegler, 1996/2000; Siegler & Shrager, 1984; for a review, see Domahs & Delazer, this issue). Each operand, problem, and answer represents a memory *node* and is associated to related nodes via connecting pathways. The presentation of a problem causes the corresponding nodes to be activated and activation then spreads along the connecting pathways to associated nodes. For example, the presentation of 3 Δ 4 causes the activation of 3 and its related nodes (6, 9, 12, etc.), and the activation of 4 and its related nodes (8, 12, 16, etc.). The probability of retrieving a particular answer is governed by the answer's associative strength: The answer with the highest level of activation will be selected as the problem's answer; the amount of activation being directly proportional to its associative strength. Of particular interest for the purpose of this paper are the multiple associations between one problem and related answers. In both Siegler and Shrager and Campbell and Graham models, retrieval efficiency is determined by the *relative* strengths of correct and competing answers, which is consistent with theories of semantic memory (e.g., J.R. Anderson, 1983; Raaijmakers & Shiffrin, 1981). As fact retrieval involves parallel activation of multiple associated facts, the activation of multiple facts reduces the correct answer's relative level of activation. In other terms, the activation of multiple associates increases the accessibility of these associates, hereby decreasing the accessibility of the target. Hence, activation of multiple associates interferes with the target because it renders these associates more accessible and the target less accessible.

Hence, because the multiplication-related interference is assumed to result from the increased activation of a problem's product, children with high skills in multiplications (i.e., children who are fast and accurate) should undergo more interference when solving the additions. Alternatively, one might also predict the reverse pattern, that is, that children with high skills in multiplication undergo the least interference effect. Indeed, consistent with the above mentioned theoretical models, good multiplications skills should not necessarily modulate the multiplication-related interference effect since it is the *relative* associative strength of the correct sum that is important and not the absolute strength of the product.

Method

Participants

Thirty-eight fourth-grade children (17 girls and 21 boys) took part in this experiment. All children attended the same upper-middle-class public school. Ages ranged from 9 years 2 months to 10 years 7 months (M = 116.71 months; SD = 4.41). Data were collected in March, after their instruction on all the one-digit by one-digit multiplications was complete (even though it had begun in the third grade).

Tasks material and procedure

Arithmetic Task

The stimuli were 36 single-digits multiplication problems ranging from 1 Δ 1 to 9 Δ 9 and 36 addition problems from 1 + 1 to 9 + 9, including six tie problems (e.g., 8 + 8, 3 Δ 3). These problems were divided in two perfectly comparable subsets of 18 single-digit problems, which had equal numbers of small problems (sum smaller than or equal to 10) and large problems (sum larger than 10) and equal numbers of ties. Also, the total sum of all the problems forming a set was equated (see Appendix). Moreover, in each subset, each single digit appears 4 times (with the exception of the digit 1 that appeared only once).

Inhibition task

The Stroop Test designed by Albaret and Migliore (1999) was used. This test consists of three pages that have to be completed in forty-five seconds. On the first page, color names are printed in black and the instructions were to read the words (reading condition). On the second page, colored squares (blue, red, and green) are printed and children were required to name the colors of the patches (naming condition). On the third page, color names are printed in different colors (e.g., the word “green” was written in blue) and children were required to name the color of the ink, ignoring the word itself (interference condition). In each condition, children were asked to proceed as fast as possible without making mistake and the number of correct responses was taken into account.

Design

Each child was tested individually in a single session lasting about 40 minutes, in a quiet room at their school. All children first received the 18 problems constituting set 1 as additions, representing the Control Condition. Then, after a 30-minutes delay (filled with the Stroop test and two non-numerical tasks not pertaining to this experiment), they had to perform the 18 problems constituting set 2 as multiplications, immediately followed by the same problems in the form of additions (Interference Additions/Condition). Children were told that they were tested on simple arithmetic problems and were instructed to answer as quickly and accurately as they could.

The stimuli were presented on a personal computer using black characters against a white background. The problems were displayed horizontally at the center of the screen. The two operands of the problems appeared in Arabic digits and were separated by the operation sign (Δ or +) flanked by spaces. The problem appeared and remained on the screen until the subject's response. Response times (RTs) were recorded by the computer from a key press of the experimenter at the children's responses. This procedure was chosen in order to minimize spoiled data that are inevitable with a sound-activated relay. Indeed, children often talk aloud as they think or use counting strategies, rendering difficult the use of a voice key. Timing began with the presentation of the problem and ended when the experimenter pressed the key, causing the problem to disappear from the screen. Then, the experimenter noted the stated answer and if the response time (RT) was spoiled due to a delayed key press or to multiple responses of the child (e.g., when the child corrected himself right away, the last stated answer was always taken into account, whether correct or not, but the RT was marked as spoiled). No feedback about accuracy or RT was provided.

Before the following trial in the addition blocks, the experimenter asked the child if s/he simply 'knew' the answer by heart (retrieval strategy), or if s/he solved the problem by counting (counting strategy). If the child counted aloud or subvocally, or if there were lip movements, then this strategy was classified as verbal counting. If s/he was observed moving his or her fingers, then it was classified as finger counting. If the child stated having counted but without direct overt behavior, it was classified as mental counting. Finally, if the experimenter noted any overt behavior suggesting the use of reconstructive strategy, then the strategy was classified as counting whatever the children's statement (e.g., if a child stated he retrieved the answer but there were some vocalisations, the strategy was classified as verbal counting).

Five practice trials involving other operands than those being tested (i.e., problems with operand 0, 10 or 11) were administered prior to each task. Problems were presented in a pseudo-random order, with the constraints that no operand, sum or product were repeated on consecutive trials. In half of the non-tie problems, the smaller operand was situated on the left side of the operation sign.

Results

In total, 2.83% of RTs were spoiled and excluded from the following analyses. For each subject, median correct RTs and mean error rate were calculated for each condition (control additions, multiplications, and interference additions).

In the additions, errors were quite rare: Children made on average 1 error in each condition (M = 0.68 and 0.58 errors in the Control and in the Interference Additions, or 3.80% and 3.22%, respectively), which is much too infrequent to be statistically analysed. Hence, the following analyses will focus on response latencies and on strategies.

Do multiplications interfere with additions?

Latencies

Correct median RTs for additions were submitted to a 2 conditions (Control Additions vs. Interference Additions) Δ 2 problem size (small vs. large problems) repeated measures analysis of variance (ANOVA). There was a significant effect of problem size, F (1, 37) = 141.16, MSE = 486,131, $p < .001$, indicating that small problems elicited faster RTs than large problems (M = 1,643.82 ms vs. 2,987.63 ms, respectively). More interestingly, we found a significant effect of condition, F (1, 37) = 11.79, MSE = 374,584, $p < .001$. Children were 341 ms slower when solving the additions in the interference condition (M = 2,486.16 ms) than in the control one (M = 2,145.30 ms). Furthermore, the condition Δ problem size interaction approached statistical significance, F (1, 37) = 3.27, MSE = 323,448, $p < .08$ (see table 1 for corresponding means) and showed that the multiplication-related interference was weaker for small problems (+174 ms) than for large ones (+508 ms). However, as shown in Table 1, there is a great variability in the data. In order to check whether these effects were genuine or resulted from this variance, the same analysis was computed using a logarithmic transformation (base-e) of the data. The main effects remained significant (F_{log} (1, 37) = 15.24, MSE = 0.006, $p < .001$, for the condition effect and F_{log} (1, 37) = 328.08, MSE = 0.007, $p < .001$, for the size effect), but the condition by size interaction turned not significant, F_{log} (1, 37) = 0.46, $p > .5$, MSE = 0.005. Thus, although children's performance decreased on the interference additions, this decrease did not interact with the size of the problems.

Strategies

In total, children reported using mental counting on 35.45% of the trials of the Control and the Interference Conditions. Finger counting was used on 0.51% of the trials, and verbal counting on 0.50%. Given the small proportion of finger and verbal counting, these three counting strategies were collapsed into a single one. Finally, direct memory retrieval was reported to be used on 63.52% of all additions trials.

Given the very few errors committed on the additions (see above), and because analyses conducted on correct trials and on all trials provided identical results, we will limit our report

Table 1:
Mean Latencies in Milliseconds (Standard Deviation) for Small- and Large-Operand Additions in the Control and the Interference Conditions.

Condition	**Small Problems**	**Large Problems**	**Mean**
Control	1,556.82	2,733.78	2,145.30
	(354.56)	(770.87)	(840.30)
Interference	1,730.83	3,241.49	2,486.16
	(410.95)	(1,300.89)	(1,223.24)
I-C Difference	174.01	507.71	340.86
	(283.51)	(1,147.03)	(846.72)

to the analyses conducted when all trials were considered (see Campbell & Timm, 2000, for a similar procedure). Children reported using direct retrieval in 62.86% and 64.18% of the trials in the Control and the Interference condition, difference that was not statistically significant (t (37) = -0.75, $p > .1$). However, when looking closer at children's responses, we found some inconsistencies between their statements and the recorded latencies. Indeed, children stated having retrieved the answer for trials with latencies over 3,500 ms (with the longest 'retrieved' answer lasting more than 7 seconds!), which is much longer than reported in the literature. For instance, Siegler (1987) reported that second-graders solved addition problems in about 2 seconds when they directly retrieved the answers but in about 3 seconds when they used other reconstructive strategies. Geary (1996) tested American third-graders and reported mean retrieval RTs of about 1,900 ms for small problems and 2,300 ms for large problems (with a standard deviation of about 500 ms). We decided to apply strict criteria based on latencies derived from his study to determine children's strategies.[2] Responses with latencies less than 2,400 ms for small problems and 2,800 ms for large problems were classified as direct retrieval, corresponding to the mean latencies plus one standard deviation reported by Geary. Comparison of the children's initial classification and this time-based correction indicated an agreement on 80% of the trials in both the control and the interference conditions. Time-based classification was considered on the remaining 20% trials.

We then conducted a 2 conditions (Control vs. Interference Additions) Δ 2 problem size (small vs. large problems) repeated measures ANOVA on the percent of retrieval use (corrected with time-based criteria as indicated above). The main effect of condition was significant, F (1, 37) = 31.66, MSE = 144, $p < .001$. Retrieval was used more often for the control (M = 70.96%) than the interference additions (M = 59.94%). Main effect of problem size was also significant, F (1, 37) = 169.65, MSE = 246, $p < .001$, indicating that children used direct memory retrieval more often on small than on large problems (M = 82.16% vs. 48.68%, respectively). The condition by problem size interaction was, however, not significant, F (1, 37) = 0.65, $p > .4$ (means in the control and interference conditions were 86.84 and 77.48 for small problems; 54.97 and 42.40, for large problems). The same analysis was performed on transformed data (arcsine transformation of the retrieval rate), but the outcomes of this analysis were identical to the ones obtained on raw data.

Modulations of multiplication-related interference effect

Does multiplication-related interference vary as a function of inhibition abilities?

In Albaret and Migliore (1999) Stroop Test, the interference score corresponds to the difference between the scores (i.e., the number of correct responses) in the naming and the interference condition. However, in order to take into account children's processing speed, we computed an interference index by dividing this difference by the naming score and

[2] We decided to derive these criteria from Geary's study because this was the only description, to our knowledge, of older children's latencies for additions as a function of strategies and problem size. We are aware that these criteria might 'underestimate' fourth-graders' abilities since they were derived from third-graders' performances. However, the degree of agreement between children's statements and time-based criteria being quite high (80%), these criteria were applied on a small proportion of the responses (the remaining 20%).

multiplying this result by hundred. This index reflected the decrease, in percent, of correct responses in the interference condition compared to the naming one, indicating children's sensitivity to the Stroop interference. The higher this index, the greater the sensitivity.

Children with an index under the 40^{th} percentile were considered as high inhibition abilities (i.e., low sensitivity to Stroop interference) and children with an index above the 60^{th} percentile as children with low inhibition skills (i.e., high sensitivity to Stroop interference) (N = 15 in both groups). Mean interference indexes were 33.97% (SD = 5.66) and 52.45% (SD = 6.77) for children with high and low inhibition abilities, respectively. Note that the two groups did not differ on the score of the reading condition of the task, indicating equivalent reading skills, t (28) = -0.41, p > .5, M = 86.67 and 88.33 for children with high and low inhibition abilities, respectively.

First, correct median RTs for additions were submitted to a 2 conditions (Control vs. Interference Additions) Δ 2 groups (high vs. low inhibition skills) ANOVA with condition as a repeated measures factor. Main effect of condition was significant, F (1, 28) = 18.91, MSE = 121,613, p < .001, but the main effect of group and the condition by group interaction were not significant, F (1, 28) = 0.08, MSE = 875,420; and F (1, 28) = 0.87, ps > .3, respectively. Mean latencies, in milliseconds, for control and interference additions were 1,934.23 and 2,409.93 for children with high inhibition abilities; and 1,948.53 and 2,255.90 for children with low inhibition abilities (SDs = 533.29, 937.91; 513.57; and 730.31, respectively). Identical results were obtained when transformed RTs (base-e logarithm), instead of raw RTs, were taken into consideration.

Second, a similar 2 Δ 2 ANOVA was performed on the mean retrieval rate for additions (corrected with time-based criteria). Main condition and group effects were significant, F (1, 28) = 50.21, MSE = 42, p < .05; F (1, 28) = 7.83, MSE = 532, p < .01; as was the condition by group interaction, F (1, 28) = 4.90, p < .05. Mean retrieval rate for control and interference additions were 77.41% and 69.26% (SDs = 15.92 and 16.52) for children with high inhibition abilities; and 64.44% and 48.89% (SDs = 17.03 and 18.21) for children with low inhibition skills. However, when computing this ANOVA on transformed data (arc sine), only the main condition effect remained significant, F_{arsin} (1, 28) = 27.95, p < .001.[3]

Does multiplication-related interference vary as a function of multiplication skills?

In the multiplication bloc, children made an average of 10.82% errors (SD = 10.65) and their mean latency was 2,428.03 ms (SD = 594.05), which suggests that children were retrieving most answers from memory.[4] To distinguish between children with good and poor performances in multiplications, the 40^{th} and 60^{th} percentiles were computed for response times and error rates. Children who had both scores under the 40^{th} percentile were considered as having high multiplication skills. Conversely, children who had both response time and error rate above the 60^{th} percentile were considered as having low multiplication skills (N = 11 in each group).

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3 For the main effect of group, F_{arsin} (1, 28) = 0.01, MSE = 0.17 and for the group by condition interaction, F_{arsin} (1, 28) = 0.3, MSE = 0.02, both ps > .8.

4 As an indication, Lemaire and Siegler (1995) tested second-graders on multiplications and found that, after some formal instruction with multiplication problems, the mean retrieval time was 2.8 second.

Mean multiplications RTs were 1,851.82 ms (*SD* = 232.16) and 2,954.59 (*SD* = 393.50) for high and low multiplication skills children and mean error rates were 0.51% (*SD* = 1.68) and 19.70% (*SD* = 5.76), respectively. Note that high abilities children also solved the control additions faster than low abilities children (t (28) = -3.09, p < .01, *M* = 1,721.91 ms, *SD* = 314.74 and *M* = 2,283.95 ms, *SD* = 591.76 for high and low abilities children, respectively). It should be also mentioned that the two groups did not differ on the reading and the naming conditions of the Stroop Test, t (19) = 0.01 and 1.29, respectively, *p*s > .2. Mean scores in the reading and naming conditions for children with high multiplications skills were 89.70 and 55.30 (*SD*s = 10.35 and 8.65) and for children with low skills were 89.64 and 50.54 (*SD*s = 9.86, and 7.97). Nor did the two groups differ on the interference index, t (19) = -0.4, p > .1, means for high and low abilities children: 42.63% and 42.78% (*SD*s = 12.04 and 8.09), respectively.[5]

A 2 conditions (Control vs. Interference Additions) Δ 2 groups (high vs. low multiplication skills) ANOVA with condition as a repeated measures factor was computed on correct median RTs (see Table 2 for the corresponding means) as well as on transformed RT (base-e logarithm) for additions. In both analyses, main effects of condition were significant, F (1, 20) = 16.47, *MSE* = 82,413; F_{log} (1, 20) = 20.34, *p*s < .001; as well as main group effects; F (1, 20) = 10.71, *MSE* = 616,205; F_{log} (1, 20) = 12.74, *p*s < .01. More interestingly, the condition Δ group interaction was significant in both analyses, F (1, 20) = 6.03; F_{log} (1, 20) = 4.18, *p*s < .05. As shown in Table 2, children with low multiplication skills showed a greater multiplication-related interference effect than children with high skills (+ 425 ms).

A similar 2 Δ 2 ANOVA was performed on the mean retrieval rate for additions. Main condition was significant, F (1, 20) = 30.53, *MSE* = 77.30, p < .001; mean retrieval rates for control and interference condition = 72.22% and 71.72% for children with high multiplication skills and 59.60% and 55.05% for children with low multiplication skills. On the contrary, the effect of group and the condition by group interaction were not significant, F (1,20) = 0.11, *MSE* = 626, and F (1,20) = 0.58, *p*s > . 4.

When performing this ANOVA on transformed data (arc sine), the main group effect turned significant (F_{log} (1, 20) = 27.04, p < .001). Mean retrieval rates for children with high and low multiplication skills were 65.91% and 63.38%, respectively. The significant effect of condition and the non-significant interaction found on raw data remained, however, unchanged.

[5] Non-parametric Mann-Whitney Test was also applied on these data and revealed identical results (U = 37 and 34.50 for the naming score and the interference index, respectively, *p*s > .1).

Table 2:
Mean Latencies in Milliseconds (Standard Deviation) in the Control and Interference Additions for Children with High and Low Multiplication Skills.

Condition	**High Skills**	**Low Skills**
Control	1,721.91	2,283.96
	(314.74)	(591.76)
Interference	1,860.68	2,847.73
	(376.19)	(898.04)
I-C Difference	138.77	563.77
	(195.09)	(540)

Discussion

This experiment investigated the effect of multiplications on additions in fourth-grade children. Fourth-graders were slower to solve additions when they were administered directly after multiplication problems than when the additions were presented alone (as a baseline). Moreover, they used direct memory retrieval less often when the additions were directly following multiplications. Thus, having to perform multiplications prior to additions has a deleterious effect on children's addition performance. The present findings indicate that multiplication-related interference occurs even in a developing network of arithmetic facts, and also, even when only a few multiplications have been presented prior to the additions. Indeed, in Campbell and Timm's experiment (2000), participants had to solve a large number of multiplications or divisions (144 problems) before having to solve the (72) additions, whereas in the present design only 18 multiplications were presented. The present experiment shows that presenting and asking to solve a limited number of multiplications suffices to create interference that hinders the subsequent production of additions, at least in children. It might be possible that, in adults, more experts in arithmetic facts, extended practice with multiplications would be necessary to create this interference.

This result can be interpreted in the theoretical framework of the arithmetic network. As mentioned earlier, retrieval efficiency is determined by the *relative* strengths of correct and competing answers in both Siegler and Shrager (1984) and Campbell and Graham (1985) models. As fact retrieval involves parallel activation of multiple associated facts, the activation of multiple facts reduces the correct answer's relative level of activation. Thus, in this framework, presenting multiplications interferes with additions because it creates additional competitors when subsequently presenting the additions, hereby decreasing the relative associative strength of the addition and its correct answer. Consequently, retrieval will take longer or even will be replaced by other reconstructive strategies.

In their experiment, Campbell and Timm (2000) found that the multiplication-related interference effect was greater for small problems than for large ones. These authors interpreted their results as reflecting the fact that small multiplication problems have greater strengths of association with their correct answers than large problems (Siegler, 1988; see also Ashcraft, 1987; Campbell & Graham, 1985). Therefore, these small multiplication problems create more interference than do large problems. In the present experiment, we failed to reproduce Campbell and Timm's finding since the interference effect of multiplications on additions did not interact with problem size (with respect to latencies or to retrieval rate). However, it should be mentioned that, in Campbell and Timm's experiment, this finding was only found with respect to error rates, which we could not analyse in the present experiment.

In the second part of the experiment, we investigated two variables that could modulate the interference effect of multiplications on additions: inhibition and the ability to solve multiplications. First, we found that multiplication-related interference did not vary as a function of inhibition abilities. This result suggests that the activated competitors are not to be actively inhibited or suppressed. This may seem quite surprising since inhibition is commonly assumed to be the process by which interference is reduced or resolved (Harnishfeger, 1995). Yet, one could possibly assume that the inhibition present in arithmetic facts is more of a passive nature, as the one assumed in associative memory or connectionist models (see M. C. Anderson & Bjork, 1994, for a presentation of several inhibition models).

Second, we found that multiplication-related interference varied as a function of the child's ability to solve the multiplication problems. Yet, contrary to what we expected, children who solved the multiplications more rapidly and more accurately exhibited weaker multiplication-related interference effects – on additions – than children with poorer performances. This result is nevertheless consistent with the assumptions of the network organization of arithmetic facts, in which interference effects are assumed to result from the decrease of the relative associative strength of the addition problem and its correct answer. One has to bear in mind that children with good multiplications skills also had good performances in the control additions. Following that, one might assume that, in good performers, the decrease of this relative strength was not great enough to impair their additions' performances to a large extent. This might also explain why adults, who have more expertise in additions than children, show interference effects, which are much smaller in magnitude than the one observed in fourth-graders (e.g., 138 ms in Campbell and Timm's experiment (2000), as opposed to the 340 ms overall effect found in the present experiment). Still, children with good arithmetic skills, as well as young adults, exhibit poorer addition's performances after having to perform multiplications, indicating that within a developing arithmetic facts network, strengthening incorrect, associated answers creates interference to some extent.

In summary, our results provide a direct evidence of multiplication-related interference effects in children. Fourth-graders' performances to additions decreased when those additions were performed after their counterpart multiplications: They showed longer latencies and less use of direct memory retrieval than in the baseline condition. Moreover, those children who performed the multiplications better endured the least interference effects, suggesting that multiplication-interference effects are not due to the retrieval of the competing answer *per se* but to the decrease of the correct answer's associative strength relative to the ones of the incorrect, associated answers.

Although this multiplication-related interference effect occurs even in a perfectly mature arithmetic network, these findings have direct implications for the teaching of arithmetic facts, in an attempt to reduce it. Indeed, the deleterious effect of learning to multiply on children's performance in additions is particularly important in children with poor arithmetic skills: When they will learn to multiply, not only they will show difficulties with the multiplications, but their additions, already weak, will be altered too, enlarging the difference between them and children with good skills. This might have a devastating, discouraging effect on their arithmetic learning. Then, it is important to ensure that children, especially the weakest ones, have a good mastery of the additions before teaching them the multiplications tables.

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Appendix

Set of Problems used in the Experiment

	Set 1 (n = 18)	***Set 2*** (n = 18)
Small problems	2 + 4 = 6	2 + 2 = 4
	2 + 5 = 7	2 + 6 = 8
	2 + 8 = 10	3 + 2 = 5
	3 + 3 = 6	4 + 3 = 7
	3 + 6 = 9	5 + 3 = 8
	4 + 4 = 8	5 + 5 = 10
	5 + 4 = 9	6 + 4 = 10
	6 + 1 = 7	7 + 2 = 9
	7 + 3 = 10	9 + 1 = 10
	Total Sum = 71	Total Sum = 72
Large problems	5 + 7 = 12	3 + 9 = 12
	6 + 7 = 13	4 + 8 = 12
	6 + 9 = 15	4 + 9 = 13
	7 + 4 = 11	5 + 6 = 11
	8 + 3 = 11	5 + 8 = 13
	8 + 8 = 16	7 + 7 = 14
	8 + 9 = 17	7 + 9 = 16
	9 + 2 = 11	8 + 6 = 14
	9 + 5 = 14	8 + 7 = 15
	Total Sum = 120	Total Sum = 120

Note: Set 1 was always presented as Control Additions and Set 2 as multiplications and Interference Additions.

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