# PRIMING EFFECTS OF ARITHMETIC SIGNS IN 10- TO 15-YEAR-OLD CHILDREN

**Abstract**

In this research, 10- to 12- and 13- to 15-year-old children were presented with very simple addition and multiplication problems involving operands from 1 to 4. Critically, the arithmetic sign was presented before the operands in half of the trials, whereas it was presented at the same time as the operands in the other half. Our results indicate that presenting the "×" sign before the operands of a multiplication problem does not speed up the solving process, irrespective of the age of children. In contrast, presenting the "+" sign before the operands of an addition problem facilitates the solving process, but only in 13- to 15-year-old children. Such priming effects of the arithmetic sign have been previously interpreted as the result of a pre-activation of an automated counting procedure, which can be applied as soon as the operands are presented. Therefore, our results echo previous conclusions of the literature that simple additions but not multiplications can be solved by fast counting procedures. More importantly, we show here that these procedures are possibly convoked automatically by children after the age of 13 years. At a more theoretical level, our results do not support the theory that simple additions are solved through retrieval of the answers from long-term memory by experts. Rather, the development of expertise for mental addition would consist in an acceleration of procedures until automatization.

**Keywords**

Numerical cognition; Mental arithmetic; Strategies; Retrieval networks

## INTRODUCTION

Arithmetic is part of our daily life. We perform additions, multiplications, subtractions and divisions all day long without even realizing it. We need to perform calculations in order to determine the remaining time before a meeting, the number of eggs needed for a cake depending on the number of guests, the number of pounds we have put on after eating the cake or the correct combinations of coins in order to pay. Somehow amazingly, researchers do not agree yet on the way individuals perform these relatively simple calculations. For example, a currently debated issue in the mathematical cognition literature is related to the strategies used by expert solvers when they perform simple additions.

From the 70's, the dominant view has been to consider that after repetitive counting practice, children from the age of 10 and adults can directly retrieve the answers of single-digit additions from long-term memory (e.g., $4 + 3 = 7$ or $7 + 8 = 15$; Groen & Parkman, 1972; Ashcraft & Battaglia, 1978; Ashcraft & Fierman, 1982). Nevertheless, soon after retrieval models have been put forward, an alternative view has been offered by Baroody (e.g., 1983; 1984; 1994), who suggested that very quick procedures and heuristic and rule applications could also be used by expert to solve simple problems. According to the author, these procedural strategies could sometimes be faster than retrieval and could therefore be preferred by individuals.

The first experimental set of data supporting this claim has been provided only a few years ago, using a priming paradigm of the arithmetic sign. Fayol and Thevenot (2012) asked individuals with a high level of arithmetic skills to solve simple operations. The authors showed that the presentation of the addition and subtraction signs 150 ms before the operands speeds up the solving process. On the contrary, no priming effect was found for multiplication problems. The authors concluded that the addition and the subtraction arithmetic signs can pre-activate "something", independent from the operands, which can be subsequently used to solve the problems. Obviously, this “something” is not activated for multiplication, or at least, is not used to solve multiplication problems. After having discarded several alternative interpretations, the authors concluded, in support to Baroody’s past assumptions, that abstract solving procedures were primed by the “+” and the “-” signs. For multiplication problems, such procedures are not used because they are mainly solved by retrieval of the answers from memory (e.g., Campbell & Xue, 2001; De Visscher & Noël, 2014; Verguts & Fias, 2005).

Fayol and Thevenot (2012) suggested that the counting procedures used by expert adults to solve addition and subtraction problems could correspond to very fast moves along a left-to right oriented mental number line. More concretely, to solve a problem such as 4 + 3, individuals could place a mental counter on the quantity 4 and operate 3 quick moves on the right of the line in order to reach the answer 7 (see Figure 1). The existence of such an oriented mental line, on which quantities are represented by children and adults, is widely recognized (e.g., Dehaene, Bossini, & Giraux, 1993; Hoffman, Hornung, Martin, & Shiltz, 2013; Shaki, Fischer, & Petrusic, 2009; Thevenot, Dewi, Banta Lavenex, & Bagnoud, 2018; Thevenot, Fayol, & Barrouillet, 2018). Mathieu, Gourjon, Couderc, Thevenot, and Prado (2016) experimentally tested Fayol and Thevenot’s hypothesis and, accordingly, showed that addition problems are solved faster when the second operands of the problems is positioned on the right side of a computer screen rather than when it is on the left side. The reverse was observed for subtraction problems. The authors concluded that situations in which spatial mental moves are congruent with the side of the second operand facilitate the solving process (compared to incongruent situations). Interestingly, such facilitations were not observed for multiplication problems. This is again consistent with the widely accepted view that answers of multiplication problems are retrieved from long-term memory, because arithmetic fact retrieval is not supposed to require any mental spatial moves. Attentional moves along a mental number line during addition and subtraction solving has also been documented through manipulation of the locus of attention towards the left or the right side of space (e.g., Masson & Pesenti, 2016; Wiemers, Bekkering, & Lindemann, 2014), target detection tasks (Masson & Pesenti, 2014; Masson, Andres, Alsamour, Bollen, & Pesenti, 2020) or eye movement recording (Masson, Letesson, & Pesenti, 2018).

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Insert Figure 1 about here

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As already evoked, counting procedures could be extremely fast in expert adults. Barrouillet and Thevenot (2013) reached the conclusion that each move on the line could be executed in only 20 to 40 ms. Such a rapid process cannot reach individuals' consciousness and this is the reason why expert solvers could mistake automated counting procedures for retrieval (Uittenhove, Thevenot, & Barrouillet, 2016). In fact, only the result of the procedure could be consciously accessed but not the multiple steps involved during the solving process (Anderson, 1993).

Even if the existence of automated counting procedures is still under debate (see Chen & Campbell, 2018 for a review), it has been experimentally supported by several teams of researchers using various paradigms (e.g., Liu, Cai, Verguts, & Chen, 2017; Pinheiro-Chagas, Dotan, Piazza, & Dehaene, 2017; Zhou et al., 2007; Zhu, Luo, You, & Wang, 2018; Zhu, You, Gan, & Wang, 2019). However, most of the studies were conducted in adults and the age where automated counting procedures emerge still needs to be determined. It has been repeatedly described that counting procedures are slow and demanding in children at the beginning of learning (e.g., Groen & Parkman, 1972; Siegler & Shrager, 1984). However, if we are right in assuming that the development of addition skills consists in a shift from these conscious procedures to automated and unconscious ones, the point in time of this automatization during development can be and needs to be identified.

To achieve this goal, the use of the priming paradigm designed by Fayol and Thevenot (2012, see also Roussel, Fayol, & Barrouillet, 2002) seems appropriate because, as already explained, priming effects of the addition sign are likely to constitute the signature of the use of automated counting procedures. As a matter of fact, an adaptation of this paradigm was used by Mathieu, Epinat-Duclos, Leone et al. (2018) in a neuroimaging study. The authors showed that priming effects of the "+" sign appeared around the middle of 7$^{th}$ grade (12- to 13-year-old children) and were associated with increased sign-related activity in spatial regions of the right hippocampus. Younger children from 5$^{th}$ to the beginning of 7$^{th}$ grade (8 to 12 years) did not show such priming effects. These results therefore suggest that automated counting procedures appear around the age of 12 or 13. Nevertheless, in Mathieu et al.' study, children had to solve problems involving operands from 1 to 9 and the use of counting procedures could have been limited to the largest problems. Indeed, even proponents of retrieval theories recognize that large single-digit addition problems with a sum superior to 10 are sometimes solved through reconstructive strategies, even by expert children and adults (e.g., Campbell & Austin, 2002; Campbell & Xue, 2001; LeFevre, Sadesky, & Bisanz, 1996). It is therefore possible that Mathieu et al.'s results are due to the specific category of large simple addition problems when smaller problems are in fact solved by retrieval of the answers from long-term memory.

In order to examine this possibility in the present study, we used the arithmetic sign priming paradigm and asked children aged from 10 to 12 years and from 13 to 15 years to solve multiplication and addition problems involving very small operands from 1 to 4. This very limited number of problems was chosen because they are considered undoubtedly as solved by retrieval of the answers by researchers defending retrieval theories (e.g., Campbell & Timm, 2012; Campbell & Xue, 2001; Van Beek, Guesquière, De Smedt, & Lagae, 2014). As described earlier, Mathieu, Epinat-Duclos, Leone, et al. (2018) showed that children after the age of 12 exhibit a priming effect with the “+” sign.  If we replicate this finding with smaller problems that those used in Mathieu, Epinat-Duclos, Leone, et al., we will be able to confidently conclude that automated counting procedures are used from this age onwards, even for problems that are the best candidate for retrieval in retrieval models. Whatever the age of children, multiplication should not present priming effect of the “×” sign because such small problems are solved through retrieval of the answers. Finally, a positive correlation between the size of priming effects for addition and arithmetical skills is expected because counting procedures are more likely to be already automatized in children presenting high arithmetical abilities.

## METHOD

### Participants

Sixty-one French children took part in this experiment. The sample was constituted of 33 5$^{th}$ and 6$^{th}$ graders, aged between 10 and 12 years (M= 11.23, SD = 0.67 years; 17 girls) and 28 7$^{th}$, 8$^{th}$ and 9$^{th}$ graders aged between 13 and 15 years (M= 14.00, SD = 0.74 years; 15 girls). This classification in two groups depending on the grades is based on the fact that in France, 5$^{th}$ and 6$^{th}$ graders belong to a learning cycle (“Cycle 3”) whereas 7$^{th,}$ 8$^{th}$, and 9$^{th}$ graders belong to the next cycle (“Cycle 4”). None of the participants suffered from learning disabilities.

Our study was conducted following the principles of the Declaration of Helsinki. Parental written consents were collected for each child. More precisely, parents consented to their children participation in our study and to the inclusion of their results in our analyses. They were informed that their children’s result will not be identifiable via the paper and we acknowledge that we have fully anonymized them.

## Material and procedure

### *Arithmetic sign priming task*

Children were instructed to solve arithmetic problems by giving their answer orally as quickly and as accurately as possible. The problems were constructed using operands from 1 to 4 but tie problems such as 2 + 2 or 2 x 2 were excluded. This decision was made because researchers all agree, whatever the theory they defend, that tie problems are solved by retrieval (e.g., Campbell & Xue, 2001; Fayol & Thevenot, 2012). Therefore, contrary to very small non-tie addition problems, there is no debate about the strategy used to solve them.

The couple of digits were presented in the addition and in the multiplication conditions. For both operations, the arithmetic sign was presented either 150 ms before the operands (i.e., – 150 ms Stimulus Onset Asynchrony (SOA) condition) or at the same time as the operands (i.e., null SOA condition). In this last condition the "@" sign was presented 150 ms before the problems. This manipulation ensures that potential priming effects are not due to mental preparation that would be possible as soon as a symbol, whatever its nature (i.e., arithmetical or not), is presented to participants. Each child was therefore presented with 48 problems (12 couples of digits x 2 operations x 2 SOA). The problems were randomly presented within each set.

The experiment was run under the DMDX software (Forster & Forster, 2003). Vocal responses were recorded with a voice key and individually checked off-line for accuracy using CheckVocal software (Protopapas, 2007). CheckVocal was also used to manually adjust the latencies recorded by DMDX. More precisely, for each response recorded, CheckVocal allows for the visualization of the sound played out through a waveform. When, despite pre-calibration of the voice key for sensitivity, the onset of the response given by participants is not accurately detected, the timing mark can be manually placed on the onset of the sound waveform. This checking and possible manual readjustments ensure a measure of solution time within a 1 ms precision.

Each trial began with the presentation of a 2500 ms dot fixation signal. The dot was white during 1500 ms and then turned red during 1000 ms. It was followed by the presentation of the arithmetic sign 150 ms before the operands in the negative SOA condition or by the presentation of the "@" sign 150 ms before the presentation of the problem in the null SOA condition. In the negative SOA condition, the two operands appeared on a next screen on each side of the sign and in the null SOA condition, the "@" sign was replaced by the problem in its whole. The problem was displayed on the screen until a verbal response onset was detected by the voice key. Before the experimental phase, 8 warm up problems were presented in order to familiarize the child with the task. Each child was tested individually in a quiet room within the schools and the completion of the task took about 20 minutes.

***Arithmetic fluency tests***

Children were tested collectively during a 10-minute session on two paper and pencil tests measuring general arithmetic ability. Using two different tests allowed us to collect reliable measures of children arithmetical skills.

*Tempo Test Rekenen (TTR).* This test contains five columns of 40 problems each. Every column covers a different arithmetical operation: addition, subtraction, division, multiplication, and a mixed column including all operations. In each of the column, problems increase in difficulty, starting with problems involving two one-digit numbers and ending with problems with two 2-digit numbers for addition, subtraction and division (e.g., 54 + 27; 43 - 27; 48:12). For multiplication, the most difficult problems are constituted of a one single digit number and a two-digit number (e.g., 5 x 17) For each column, children are instructed to solve correctly as many problems as possible within 1 minute. One point is given for each correctly solved problem.

*Math fluency subtest of the Woodcock-Johnson III*. In this test, children are presented with 160 problems consisting in addition, subtraction and multiplication of two single-digit numbers. At the beginning of the test, children are presented with a mix of additions and subtractions. After 60 problems, multiplication problems are introduced and intermixed between additions and subtractions. Children are instructed to correctly solve as many problems as possible within a period of 3 minutes. One point is given for each correctly solved problem.

# RESULTS

The datasets that were generated and analysed in the current study are available in the Open Science Framework (OSF) repository, (https://osf.io/9p4hn/?view_only=989d7b982e704205b8232a347aff91ce).

## Arithmetic fluency tests

Children's scores on the two arithmetic fluency tests were positively correlated, $r = .87$, $p < .001$. As expected, 13- to 15-year-old children scored higher than 10- to 12-year-old children on both of the arithmetic fluency tests, $t\ (59) = 5.05$, $p < .001$, $d = 1.30$ for the TTR and $t\ (59) = 5.20$, $p < .001$, $d = 1.34$ for the subtest of the Woodcock-Johnson III.

Moreover, the scores of the two tests negatively correlated with children's mean reaction times in the arithmetic sign priming task, $r = -.78$, p < .001 for the TTR and $r = -78$, p < .001 for the subtest of the Woodcock-Johnson III. The scores also negatively correlated with the percentages of errors in the sign priming task, $r = .31$, $p = .016$ for the TTR and $r = .22$, $p = .089$ for the subtest of the Woodcock-Johnson III.

## Arithmetic sign priming

### *Percentages of errors*

Overall, children performed very well on the task as they made less than 3% of errors. A 2 (Age Group: 10 to 12, 13 to 15) x 2 (Operation: addition, multiplication) x 2 (SOA: null, negative) ANOVA, with the first factor as a between measure was performed on these percentages (Table 1). The analysis revealed an effect of Age Group showing that 10- to 12-year-old children made more errors than 13- to 15-year-old children (+ 1.5%), $F(1, 59) = 4.35$, $n^2p = .07$, $p = .041$. The Operation x SOA interaction was also significant, $F(1, 59) = 4.96$, $n^2p = .08$, $p = .030$, showing that children made more errors on addition problems in the negative than in the null SOA condition (+ 1.9%), $F(1, 59) = 5.36$, $n^2p = .08$, $p = .024$, whereas for multiplication problems the difference between negative and null SOA conditions (0.4%) was not significant, $F < 1$. No other effect reached significance.

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***Solution times***

The analysis on solution times was carried out on correctly solved problems only (i.e., 97 % of the trials). Technical errors (corresponding to situations where no response was recorded: 4.4 % of the data) and outliers (below 200 ms and more than two standard deviations away from the participants' mean: 5 % of the data) were also discarded from the analysis, which was therefore conducted on 87.6 % of the data. A 2 (Age Group: 10 to 12, 13 to 15) x 2 (Operation: addition, multiplication) x 2 (SOA: null, negative) ANOVA, with the first factor as a between measure was performed on solution times (Table 1).

The analysis revealed an effect of Age Group showing that 13- to 15-year-old children were faster than 10- to 12-year-old children (- 207 ms), $F(1, 59) = 15.76$, $n^2p = .21$, $p < .001$. There was also an effect of Operation showing that addition problems were solved faster than multiplication problems (- 85 ms), $F(1, 59) = 30.04$, $n^2p = .34$, $p < .001$. More importantly, the Age Group x Operation x SOA interaction was marginally significant, $F(1, 59) = 3.41$, $n^2p = .06$, $p = .070$. Planned comparisons revealed that in 13- to 15-year-old children, solution times for addition were shorter in the negative than in the null SOA condition (45 ms), $F(1, 59) = 5.43$, $n^2p = .08$, $p = .023$, whereas for multiplications the difference between null and negative SOA conditions was only 6 ms and was not significant, $F < 1$. In contrast, there was no significant priming effect of the arithmetic sign in 10- to 12-year-old children, whatever the operation ($F$s < 1, for both addition and multiplication problems).

***Correlation analyses***

Correlations between the size of priming effect in the addition condition and arithmetic skills were performed on the full sample of children and for each Age Group. As shown in Table 2, priming effects did not correlate with TTR scores, even when we considered only the addition part of the test, nor with the score in the arithmetic subtest of the Woodcock-Johnson III. We also calculated a mean score combining the results of each child on both arithmetic fluency tests but it did not correlate either with the size of the addition priming effects.

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## DISCUSSION

This research was conducted in order to identify the age at which priming effects of an arithmetic sign can be observed for very simple problems. A previous study suggested that these effects emerge around 13 years of age for single-digit addition problems involving operands from 1 to 9 (Mathieu, Epinat-Duclos, Leone et al., 2018). The goal of the present study was to determine whether the same conclusions can be reached when only very simple non-tie problems with operands from 1 to 4 are considered. Our results reveal that it is the case. Specifically, we found that whereas 10- to 12-year-old children did not show priming effects for additions, 13- to 15-year-old children solved small addition problems faster when the "+" sign was presented before the operands.

Arithmetic sign priming effects are typically interpreted as the result of an automatic activation of a counting procedure triggered by the arithmetic sign (Fayol & Thevenot, 2012; Mathieu, Epinat-Duclos, Sigovan et al., 2018; Roussel, Barrouillet, & Fayol, 2008; Thevenot, Dewi, Bagnoud, Wolfer et al., 2020). Therefore, our results suggest that such procedures are automatically activated for addition problems by children from the age of 13. This suggests that arithmetic development may be characterized by the progressive replacement of conscious and demanding counting procedures (used by children at the beginning of learning) by unconscious and automatic counting procedures after repetitive practice (Bagnoud, Dewi, Castel, Mathieu, & Thevenot, 2021; Thevenot, Barrouillet, Castel, & Uittenhove, 2016; Thevenot, Dewi, Bagnoud, Uittenhove, & Castel, 2020). As already explained in our Introduction, these procedures are likely to correspond to step-by-step attentional moves on a mental number line (Figure 1). The process of automatization by which initial conscious counting procedures are eventually run onto completion (without conscious access) can be understood within the theoretical framework of expertise development. At the beginning of learning, the execution of a procedure is slow, stoppable, and cognitively costly but, through extensive practice, the speed of the procedure execution increases drastically (Newell & Rosenbloom, 1981). Moreover, once the procedure is launched, it is impossible to stop it and it is no more cognitively demanding (e.g., Schneider & Schiffrin, 1997, see Perruchet, 1988 for a review). Our results show that this level of automaticity is reached by children for the execution of simple additions at the age of 13.

The idea that the development of arithmetic expertise allows for procedure automatization led us to examine the relation between the size of the priming effects observed in the addition condition and children's arithmetic skills. These skills were measured through two different arithmetical fluency tests, which results correlated with performance in the arithmetic sign priming task. Contrary to what we expected, we did not find any correlation between these two variables, whatever the age of children. It is therefore possible that priming effects, and therefore automated procedures, emerge as a result of development or cognitive maturation rather than increase in arithmetic fluency *per se* (see also, Díaz-Barriga Yáñez et al., 2020 for similar results and conclusions). Still, such an interpretation might seem at odds with the way Fayol and Thevenot (2012, Exp.2) and Thevenot et al. (2020) had to select their participants to observe addition sign priming effects in young and older adults. In both populations, there was no priming effect of the arithmetic sign when the entire sample of participants was considered. The effect on addition appeared only when participants with the best arithmetic fluency scores were taken into account in the analyses. It is therefore puzzling that these effects can be observed in 13 to 15-year old children without any selection. Still, results showing priming effect of the addition sign and absence of priming effect of the multiplication sign have been replicated in numerous experiments reported in several papers (Fayol et al., 2002; Fayol & Thevenot, 2012; Mathieu, Epinat-Duclos, Léone et al., 2018; Thevenot, Dewi, Bagnoud, Wolfer et al., 2020) and conducting further research to disentangle and better understand the role of age, education and expertise in the appearance of arithmetic sign priming effects and automated procedures is therefore important.

In the present study, the fact that we focused our attention on problems involving very small operands from 1 to 4 is crucial because the results associated to these problems are viewed by retrieval theory proponents as undoubtedly retrieved from memory by children from the age of 20, whatever the operation in which they are included (e.g., Ashcraft & Fierman, 1982 for addition; Koshmider & Ashcraft, 1991 for multiplication). Therefore, within this theory, very small addition and multiplication problems should be subjected to the same arithmetic sign priming effects, which is not the case in our experiment. Indeed, whereas, as already discussed here, addition can be primed by the "+" sign in older children, this is not the case for multiplication, which is never primed by the "×" sign, whatever the age of children. The associations between operands and results are classically learnt by rote learning at school for multiplication and our results confirm that they are not solved by automated procedures. As unanimously recognized by researchers in the domain of numerical cognition, our results confirm that retrieval of the answers from memory is the dominant strategy in order to solve multiplications (e.g., Campbell & Xue, 2001; Prado, Mutreja, & Booth, 2014; Prado et al., 2011; 2013; Thibodeau, LeFevre, & Bisanz, 1996).

It is important to note here two limitations of our study. First, we are left in a situation wherein a lack of arithmetic sign priming effect is interpreted as the use of a retrieval strategy for multiplication whereas a lack of priming effect for addition in younger children is interpreted as the use of non-automated procedures. We acknowledge that this is a weakness of our paradigm. Nevertheless, whereas the lack of priming effect can lead to several interpretations, we are confident that the presence of priming effects of the arithmetic sign constitutes the signature of the use of automated procedures that can be activated in the absence of the operands. Second, our sample size is substantially larger than the one analyzed in Mathieu, Epinat-Duclos, Leone et al. (2018) (n=61 vs. n=34). However, it is still limited, especially given the complex nature of our design, which involves assessing differences in SOA as a function of operation and age (Brysbaert, 2019). Thus, these results should be seen as providing the groundwork for future studies that might investigate the development of automatized procedures with larger sample sizes. Nevertheless, the present study suggests that such procedures can be used by children to solve very simple addition problems from the age of 13 years.

## Disclosure of interest

The authors report no conflict of interest

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**Table 1**. *Mean solution times (in ms) and percentages of errors as a function of age group, operation, and SOA (Standard Deviations between brackets).*

| | 10- to 12-year-olds | | 13- to 15-year-olds | |
|---|---|---|---|---|
| Conditions | Addition | Multiplication | Addition | Multiplication |
| | *Percentages of errors (%)* | | | |
| Null SOA | 2.02 (3.63) | 4.80 (5.90) | 0.89 (2.62) | 2.68 (4.57) |
| Negative SOA | 4.04 (5.94) | 4.04 (6.29) | 2.68 (4.57) | 2.68 (4.57) |
| | *Solution times (ms)* | | | |
| Null SOA | 1253 (214) | 1342 (230) | 1067 (165) | 1135 (208) |
| Negative SOA | 1255 (269) | 1330 (251) | 1022 (141) | 1129 (204) |
| Priming effects | - 2 | 12 | 45* | 6 |

Note. Priming effects corresponded to the difference between solution times in the null SOA and the negative SOA conditions. * $p < .05$.

**Table 2.** *Correlations between arithmetic skills and scores in the fluency tests for the full sample of children (n = 61), 10- to 12-year-old children (n = 33) and 13- to 15-year-old children (n = 28).*

| Variables | Full sample | 10- to 12-year-olds | 13- to 15-year-olds |
|---|---|---|---|
| TTR addition score | .128 | .220 | - .297 |
| TTR total score | .166 | .268 | - .293 |
| Subtest of the Woodcock-Johnson III | .161 | .220 | - .325 |
| Mean score across the two tests | .159 | .262 | - .299 |

**Figure caption**

Figure 1. *Illustration of a counting procedure for the problem 4 + 3*