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Commentaries

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A Commentary on “Not Toeing the Number Line for Simple Arithmetic: Two Large-n Conceptual Replications of Mathieu et al. (Cognition, 2016, Experiment 1)”

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A growing number of studies suggest associations between mental arithmetic and space (e.g., Andres, Salvaggio, Lefèvre, Pesenti, & Masson, 2020; Liu, Cai, Verguts, & Chen, 2017; Masson & Pesenti, 2014; Pinhas, Shaki, & Fischer, 2014). In Mathieu, Gourjon, Couderc, Thevenot, and Prado (2016), we contributed to this emerging body of evidence by showing that single-digit addition and subtraction problems were associated with rightward and leftward shifts of attention in a sample of French adults (see also Díaz-Barriga Yáñez et al., 2020 for a replication in French children). Campbell, Chen, and Azhar (2021) set out to replicate our original findings in a larger sample of adults recruited in Canada. We would like to highlight here three interesting aspects of Campbell et al.'s study.

First, Campbell et al. partially replicated our initial findings by showing that addition problems were associated with rightward shifts of attention in mixed blocks of both of their experiments. Together with Mathieu et al. (2016), this provides strong evidence that solving single-digit addition problems elicits rightward attentional movements across three different samples of participants, at least when these problems are mixed with subtraction problems. Interestingly, both our original findings and Experiment 1 in Campbell et al. suggest that these shifts are operation-specific because they were larger for addition than subtraction. Though Campbell et al.'s Experiment 2 shows that rightward shifts can sometimes be found for subtraction as well, such shifts still appear to be more consistently observed for addition than subtraction. This suggests that spatial associations during mental arithmetic may not simply be the byproduct of general factors, such as reading direction or attentional preference, but may have functional significance.

Second, Campbell et al. did not replicate our original finding of an association between subtraction and leftward shifts of attention. In our original study, this leftward association was also weaker than the rightward association observed with addition (Mathieu et al., 2016). It is possible that leftward shifts for subtraction are particularly sensitive to differences in cultural and educational backgrounds, as well as individual differences in skills and strategies. In the original study, we argued that associations between arithmetic and space might reflect the preparation of movements along a sequential representation of numbers, which may be triggered by the arithmetic sign itself. This is consistent with neuroimaging evidence showing that signs are associated with spatial processing (Mathieu, Epinat-Duclos, Léone, et al., 2018; Mathieu, Epinat-Duclos, Sigovan, et al., 2018). To the extent that numbers are mentally arranged from left to right (Toomarian & Hubbard, 2018), the rightward shift observed for addition reminds of the forward counting procedure that is extensively used by children across the world, and might therefore become either semantically associated with the plus sign (Pinhas et al., 2014) or automatized with practice in skilled adults (Uittenhove, Thevenot, & Barrouillet, 2016). Clearly, subtraction problems are not as consistently associated with backward counting over learning, suggesting that such a procedure may not necessarily be semantically associated with the subtraction sign or automatized. In fact, the use of forward counting (from the smallest operand) when solving subtraction could be consistent with the rightward association that was observed in mixed blocks of Campbell et al.'s Experiment 2. Overall, it is fundamental to consider that the strategies used to acquire arithmetic skills in children may depend on a number of contextual factors. These may shape the processes associated with mental arithmetic in proficient adults.

Third, Campbell et al. argue that the spatial associations found in mixed blocks might not reflect genuine associations between arithmetic and space. Instead, the mixed presentation of the operations coupled with the brief presentation of the arithmetic sign may encourage participants to encode arithmetic sign as a spatial cue indicating whether the answer is smaller (left) or larger (right) than the first operand (i.e., a heuristic; Shaki, Pinhas, & Fischer, 2018). According to Campbell et al., the lack of spatial associations in “pure” blocks supports this idea. We remain unconvinced by this hypothesis for two reasons. A first reason is that there is evidence that addition problems are associated with rightward attentional shifts when these problems are mixed with multiplication problems, which are not associated with any attentional shifts (Mathieu et al., 2016). This shows that addition problems do not elicit spatial biases (i) only because they are presented in a context where they are compared to subtraction problems and (ii) only because it is advantageous to encode addition signs as a rightward cue indicating than answers are larger than the first operand (this is also the case of multiplication, which shows no spatial association). Moreover, there is another explanation for the lack of spatial effects in pure blocks of addition and subtraction: These blocks make the arithmetic sign completely irrelevant to the task. If only addition (or subtraction) problems are presented in a block, participants have no need to pay attention to the arithmetic sign. Given that attentional shifts are likely to be triggered by the arithmetic sign (Mathieu, Epinat-Duclos, Sigovan, et al., 2018; Pinhas et al., 2014), it might not be entirely surprising that no attentional shift is observed in that condition. In a way, we agree with Campbell et al. that the spatial biases observed in mixed problems are task-dependent. They depend on a task that would make the arithmetic sign at least minimally relevant, which ‘pure’ blocks fail to achieve.

In summary, Campbell et al. show that single-digit addition problems are reliably associated with rightward biases of attention in mixed blocks of operations, but their results also extend our original findings by demonstrating that these biases are only elicited when operators are relevant to the task. This supports the idea that the processing of arithmetic signs is central to spatial biases during mental arithmetic. However, the lack of leftward shift for subtraction problems observed by Campbell et al. is also a reminder that associations between math concepts and space might hinge on cultural, educational and individual factors. Identifying these factors will be central to a better understanding of the relation between arithmetic and space.

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