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The Effect of Task Settings on Phonological and Visual-spatial Working Memory Components and Solving Strategies in Mental Arithmetic

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Abstract

Objectives: In the current study, two experiments are conducted to compare the effects of several task demands on mental arithmetic performance and the choice of solving strategies. **Methods:** To achieve this goal the experimental method was adopted. Two experiments are performed using a series of mental arithmetic computer-based tasks. In the first experiment, the sample included 50 female university students, the first experiment assessed whether task settings related to working memory load and operation type could promote arithmetic performance and shift solving strategies. The second experiment included a sample of 33 female university students, and it was concerned with presentation format and complexity in addition and multiplication under loading of either visual or phonological working memory. **Results:** The results indicated the role of vertical presentation format can play in reducing the negative effects of task complexity and the negative impact that working memory loading had on arithmetic performance. In addition, vertical

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presentation format significantly encouraged the use of decomposition solving strategy in the arithmetic tasks. **Conclusion:** We concluded that the role of working memory components in mental arithmetic changes according to complexity and presentation format, and that involved strategies are flexible and are modified according to task demands..

Keywords: Mental arithmetic, Phonological working memory, Presentation format, Solving strategy, Visual-spatial working memory

Introduction

Despite their applications in ordinal activities, some people fail to effectively perform mental arithmetic tasks, especially complex ones, in situations in which high mental procedures are required. Indeed, several studies have found that task complexity limits mental arithmetic accuracy (Cavdarogle & Knops, 2015; Metcelfe & Campbell, 2011; Popescu et al., 2016; Prado et al., 2014; Seitz & Schumann-Hengsteler, 2000; Stanescu-Cosson et al., 2000). Previous studies have found that dependence on mental resources varies according to task features, including operation type (Cohen et al., 2000; Connaughton et al., 2017; Dehaene, 1992; Ischebeck et al., 2006; Mihulowicz et al., 2014; Prado et al., 2014), complexity (Campbell & Xue, 2001; Cavdarogle & Knops, 2015; Galy & Melan, 2015; Metcelfe & Campbell, 2011; Rosenberg-Lee et al., 2009; Setiz & Schumann-Hengsteler, 2000; Stanescu-Cosson et al., 2000) and presentation format (Imbo & LeFevre, 2010; Trbovich & LeFevre, 2003). The results of these studies question the extent to which task features impact arithmetic performance. Therefore, in the current research, we aim to directly compare the effects of several task demands related to operation type, working memory load (Experiment 1), and presentation format and complexity (Experiment 2) on mental arithmetic performance and ascertain whether the setting of the task impacts the solving strategies that are employed.

The role of working memory components in mental arithmetic has been a core topic of many numerical cognition studies. As working memory has separate phonological and visual-spatial components, among other components (Baddeley, 2000), previous studies (Cragg et al., 2017; Hubber et al., 2013; Imbo & LeFevre, 2010; Lee & Kang, 2002; Logie et al., 1994; Otsuka & Osaka, 2015) have used dual-task paradigms (arithmetic and working memory) to better understand the working memory resources that are crucial for solving mental arithmetic problems. A seminal study in this field that was performed by Logie and colleagues (1994) investigated the role working memory components played in addition operations that involved adding a series of two-digit numbers. The dual-task paradigm was used, with addition representing the main task that was combined with one of four secondary tasks: 1- Articulatory suppression (to load the phonological loop component), 2- Random generation (to load the central executive component), 3- Viewing irrelevant pictures, and 4- Hand movement (to load visual and spatial working memory components respectively). The results demonstrated that working memory components played a specific role in mental arithmetic. Addition ability was heavily impaired by central executive loading and mildly impaired by phonological loading, but not significantly affected by visual and spatial loading. The specific role working memory components play in mental arithmetic has been replicated in several studies (Clearman et al., 2016; Imbo & LeFevre, 2010; Lee & Kang, 2002; Otsuka & Osaka, 2015).

In a similar vein, Imbo and LeFevre (2010) explored the specific role that each working memory component had on arithmetic problems that were presented in different forms. They presented the arithmetic problems either horizontally or vertically and compared the performance on difficult subtraction and multiplication exercises. Participants, who were Chinese or Canadians, solved the arithmetic task either with no secondary task or while simultaneously recalling and retrieving visual patterns or verbal letters. The results showed that while both the arithmetic performance of both the Chinese and Canadian participants was impaired when they completed the secondary visual and verbal memory tasks, the impairing effect was selective in Chinese participants. They exhibited a higher level of impairment when performing vertical subtraction tasks with visual-spatial load and more impairment in horizontal multiplication tasks with verbal load. The difference in performance between Chinese and Canadians who performed the same tasks is most likely related to the strategies that they had acquired for solving mental arithmetic during their Mathematics education.

Indeed, studies have found discrepancies across cultural groups in terms of the effects concurrent working memory tasks have on subtraction and multiplication tasks. Lee & Kang (2002) recruited Korean participants for a study in which they compared the effects of a visual working memory task that required the participants to perform an arithmetic task as the main task alongside a secondary task. The aim of the study was to ascertain whether performing a secondary task impaired the participants' performance on the arithmetic task. For the visual task, the participants were presented with a visual pattern before the arithmetic problem and then asked to recall the pattern after solving the arithmetic problem. The verbal pattern test involved viewing a fabricated word and then recalling that word after completing the arithmetic problem. They found that the phonological dual task had a suppressive effect on the participants' multiplication performance, but not on their subtraction function, whereas the visual-spatial dual task had a negative reciprocal and exclusive influence on the participants' subtraction performance.

In a recent and more controlled study, Cavdarogle & Knops (2015) recruited participants who had been educated in Germany to perform a verification task on subtraction and multiplication by choosing from two alternative answers in conjunction with secondary phonological and visual-spatial working memory tasks. The verbal working memory tasks involved judging the similarity between two strings of letters before and after completing arithmetic tasks, whereas the visual-spatial working memory task involved comparing two patterns of matrices. The participants' working memory was assessed prior to the experiment to ensure that participants were presented with the working memory load suitable for their capacity. In addition, the complexity of the arithmetic task was controlled by compiling easy problem sets consisting of single-digit operant and difficult problem sets consisting of double-digit operands. The results demonstrated that reciprocal impairing effects were evident between the arithmetic tasks and both working memory components.

Although Cavdarogle & Knops (2015) used a similar paradigm to that of Lee and Kang (2002), Cavdarogle and Knops found that working memory played a general role in mental arithmetic, whereas the latter study found that it played a selective role. It is still not clear whether the discrepancy in the findings of the two studies relate to different task demands (i.e., the working memory tasks and the method of response and operant difficulty in the arithmetic tasks) or whether the discrepancy can be traced back to variations in the participants' cultural and educational background and experience with Maths. Therefore, further studies are required to disentangle the effects of several task settings on arithmetic performance and solving strategies.

In an attempt to understand the role of visual-spatial working memory on mental arithmetics, particularly when performing addition operations, Hubber and colleagues (2013) controlled the use of solving strategies within arithmetic tasks. They instructed the participants to solve a series of addition problems while performing a second concurrent visual task (in which they were asked to detect a pattern). Additionally, they asked participants to utilize one of three different strategies: retrieval, counting, or decomposition. Their results revealed that the visual-spatial task had a significant impairing effect on addition performance only in situations in which the counting strategy was used. However, when they controlled the loading of the visual-spatial task on the central executive component, they found that the negative impact of the visual-spatial task employed in their experiment could be attributed to this loading of the central executive.

The Experiments Conducted as Part of This Research

Experiment 1

Experiment 1 was intended as an exploratory experiment to investigate the role of two working memory components (the phonological loop and the visuospatial sketchpad) in the four basic arithmetic tasks (addition, subtraction, multiplication, and division). Based on previous studies, we expected that participants would use calculation strategies in addition (Campbell & Xue, 2001; Mathieu et al., 2016; Metcelfe & Campbell, 2011; Thevenot et al., 2007) and subtraction (Campbell & Xue, 2001; Mathieu et al., 2016). However, we expected participants would rely on recall to solve multiplication problems. Retrieval has been reported for multiplication (Metcelfe & Campbell, 2011) and the neural regions responsible for verbal retrieval are activated when verifying multiplication equations (De Visscher et al., 2018). We could not make a clear prediction of the strategies the participants would use to solve the division problems. There was a chance that their approach would resemble that of multiplication because previous research found that multiplication and division share similar memory and learning processes (De Brauwer & Fias, 2011; Huber et al., 2013). Alternatively, division could be solved by recruiting calculation processes, as was shown by Campbell and Xue (2001).

Experiment one Method

Participants: A total of 50 healthy adult females, undergraduate and postgraduate students, aged between 19 years and 40 years (*M* = 22 years, *SD* = 3 years, 3 months) participated in the experiment. All participants gave their consent form, had normal or corrected-to-normal vision and were native Arabic speakers.

Materials and tasks: Materials for the arithmetic tasks. A set of 64 arithmetic problems divided into eight blocks were created for this experiment. Each of the four basic arithmetic tasks (i.e., addition, subtraction, multiplication and division) was assigned to two blocks; as such, each block incorporated eight arithmetic problems. The addition and subtraction problems were generated by randomly assigning a single-digit number to a double-digit number from the number line. The purpose of this was to ensure that both blocks included arithmetic problems of the same level of difficulty. For the multiplication and division tasks, the problems were randomly chosen from the multiplication table. The arithmetic tasks were matched in terms of difficulty by matching the size of the totals of the addition and multiplication sums. All arithmetic tasks were displayed in a 44 pt. black font in the center of a white background. The problems were written from right to left, with the double-digit number always appearing on the right side (all materials are available upon request).

Materials for the visual-spatial memory task: The visual-spatial memory task took the form of the Corsi block-tapping task (Claesen & Van der Ham, 2015). Participants were required to remember a sequence of four locations in each trial. Forty trials were generated for this experiment. Participants responded by pressing the corresponding key on the keyboard.

Materials for the phonological loading memory task*:* A collection of English letters were downloaded from a website (Evolution.voxeo) to create the sequences used in this short-term phonological loading memory task. Forty sequences, each of four letters, were randomly generated for use in this experiment. During each trial, four letters were presented through the laptop microphone at a rate of 1s per letter while a blank screen was presented. In both memory tasks, participants were not given feedback on their performance, and the window for each response was 30 seconds.

Design and procedures: Stimulus presentation and data collection were performed using a laptop that ran the Windows operating system and e-prime (v2) (Psychology Software Tools, Inc., 2016). Participants were randomly assigned to one of two conditions (a visual-spatial loading condition or a phonological loading task), each condition had 25 participants. Each condition consisted of three phases: The first phase consisted of arithmetic problems, the second phase was either a visual-spatial or phonological memory task, and the last phase included both arithmetic and working memory tasks (loading tasks). The first part was the same for both groups, while the second and third ones varied according to the memory task, either visual arrays or phonological arrays. Participants were tested individually, each in a single testing session that lasted for not more than 35 min. Then they were debriefed and asked to disclose the mental arithmetic strategies they used during the first phase of the experiment. They were asked to indicate whether they used counting, decomposition or recall strategies for each of the four types of arithmetic problems presented in these experiments. They were informed that counting represented the action of starting from the largest number and counting from there until the solution was revealed, decomposition involved separating tens and units to perform the calculation and then adding them together, and recall involved immediately answering the question without consciously engaging in any calculation procedure.

Results

Experiment one Results

Accuracy in arithmetic tasks: For the arithmetic task, the participants scored one point for each question they answered correctly and zero for any incorrect answers. Since there were eight problems in each condition, the maximum score for each condition was eight. See Table 1 for the means and standard deviations of each condition. To examine the effect of both working memory tasks (visual-spatial and phonological) on the four types of arithmetic tasks (addition, subtraction, multiplication and division), a 4 x 2 x 2 mixed measure ANOVA was used, with the types of arithmetic tasks (addition, subtraction, multiplication and division) and the loading task effect (single arithmetic task vs loading task) being the within-group factors, and the types of working memory tasks (visual-spatial working memory vs phonological working memory) being the between-group factor. The main effect of the loading task was not significant: F (1, 48) =.08, p =.779. The interaction between the loading task effect and the type of working memory task was also not significant: F (1, 48) =.03, p =.858, indicating that the effect of the loading task did not seem to vary according to the type of working memory task.

Table 1

Means and standard deviations for accuracy in each condition in Experiment 1

Group	Arithmetic task	Loading task	Mean	Standard deviation
Visual	Addition	Control	6.36	1.62
		Loading	5.68	1.67
	Subtraction	Control	5.32	1.57
		Loading	4.92	1.92
	Multiplication	Control	5.52	1.98
		Loading	5.48	1.82
	Division	Control	5.4	1.91
		Loading	5.8	1.84

Cont. Table 1

Means and standard deviations for accuracy in each condition in Experiment 1

Group	Arithmetic task	Loading task	Mean	Standard deviation
Phonological	Addition	Control	5.96	2.37
		Loading	5.64	2.41
	Subtraction	Control	5.36	1.99
		Loading	4.56	2.31
	Multiplication	Control	5.2	1.91
		Loading	5.36	1.82
	Division	Control	5.16	2.26
		Loading	5.44	2.1

Albeit not of core interest in this study, the main effect of arithmetic task type was significant: *F* (3,48) = 3.13, *p* =.028, *MSe* = 2.517, ç^2*p* =.06. Interestingly, there was a significant interaction between the loading task effect and type of arithmetic task: *F* (3,48) = 5.91, *p* =.001, *MSe* = 132.26, ç^2*p* =.11. This finding implies that loading tasks have a varying impact on the four arithmetic tasks. To further investigate, separate repeated measures ANOVAs were used for each of the visual-spatial and phonological working memory groups. The repeated measures ANOVA for the visual-spatial working memory group revealed a significant interaction between the loading task effect and the arithmetic tasks: *F* (3. 72) = 4.9, *p* =.001, *MSe* = 6.682, ç^2*p* =.17.

At the other end, a repeated measures ANOVA for the phonological working memory group revealed no significant effect of the loading task: *F* (1.48) =.11, *p* =.749, the arithmetic tasks: *F* (3.72) = 1.47, *p* =.230

Reaction time in arithmetic tasks: Regarding the reaction time, a mean reaction time for each condition was calculated for each participant. Reaction times for errors and no responses were excluded from the analyses. See Table 2 for the means and standard deviations of each condition. A mixed measure ANOVA revealed that there was a significant interaction between the working memory task and the effect of the loading task: $F\,(3, 48) = 4.25$, $p = .007$, $MSe = .573$, $ç^2p = .091$. Therefore, a within-group repeated measures ANOVA was used to examine the effect of each of the working memory tasks separately.

Table 2

Means and standard deviations for RT in each condition, presented in milli-seconds, for Experiment 1

Group	Arithmetic task	Loading task	Mean	Standard deviation
Visual	Addition	Control	8314.63	2701.89
		Loading	9165.35	3329.47
	Subtraction	Control	10053.86	3868.15
		Loading	10881.78	4771.79
	Multiplication	Control	6426.68	3030.71
		Loading	6729.63	3214.73
	Division	Control	6331.19	3283.57
		Loading	6447.30	3001.62
Phonological	Addition	Control	5809.82	*1618.80*
		Loading	10974.86	3330.77
	Subtraction	Control	7244.69	3434.95
		Loading	11724.09	5494.81
	Multiplication	Control	5974.21	2396.20
		Loading	9137.16	3771.36
	Division	Control	6793.11	3436.83
		Loading	9142.07	3905.52

For the visual-spatial working memory task, there was a significant interaction between the type of arithmetic task and the effect of the loading task: $F\,(3, 57) = 4.26$, $p = .010$, $MSe = .489$, $ç^2p = .16$.

Finally, a repeated measures ANOVA for the phonological working memory group revealed that neither the type of arithmetic task: $F\,(1, 19) = 2.33$, $p = .143$, or the interaction between the working memory task and the effect of loading task: $F\,(3,57) = 1.06$, $p = .372$ had a significant effect. However, the main effect of the dual task was significant: $F\,(3, 19) = 25.78$, $p = .001$, $MSe = .197$, $ç^2p = .58$. A series of *t* tests between single and loading task in each arithmetic type was performed. All comparisons were significant: *t* (23) = -6.44, *p* =.001, *t* (22) = -3.96, *p* =.001, *t* (22) = -3.52, *p* =.001, and *t* (23) = -2.67, *p* =.001.

Solving strategies. It appeared that both groups of participants tended to use calculation strategies (either counting or decomposition) to perform the addition and subtraction tasks. In the visual-spatial memory group, 64% of participants used counting and 16% used decomposition for addition and 64 % used counting and 24% used decomposition for subtraction, for the phonological memory group, 64% used counting and 16% used decomposition for addition and 64% and 32% used counting and decomposition for subtraction respectively. In contrast, they tended to use recall strategies for multiplication and division tasks, 88% of participants from the visual-spatial group and 64% from the phonological group used the recall strategy for multiplication and 76% of participants from the visual-spatial group and 60% from the phonological group used the recall strategy for division. A Chi-square test was performed to verify whether this correlation between arithmetic tasks and strategies was significant for all participants. The findings of this revealed that there was, indeed, a significant correlation, x =.48, *p* =.001.

Discussion: Experiment 1 aims to specify the effects of loading visual-spatial and phonological working memory on performance on four basic arithmetic tasks and to ascertain whether the solving strategies that are employed by participants vary according to task demands. Visual-spatial loading did not have any significant effects on accuracy or reaction time in spite of a notable trend for a larger decrease in accuracy and increase in reaction time on the addition and subtraction exercises caused by visual-spatial loading. In contrast, phonological loading did seem to significantly elongate reaction times in comparison with the control condition ’no load’ across all arithmetic tasks. The solving strategies mostly involved calculation strategies (counting and decomposition) for addition and subtraction activities in comparison to the use of recall for multiplication and division tasks.

Firstly, the results showed the expected non-specific impairing effect of phonological loading on arithmetic tasks. The initial comparisons between the participants’ performance on the visual-spatial and phonological working memory tasks when performed in isolation indicated that there was no significant difference between their performance on the two tasks. The comparison between performances in the four arithmetic tasks for both groups when completed without loading also did not reveal any significant differences between the groups. All four basic mental arithmetic tasks seemed to depend on the phonological loop. This is partially consistent with findings of previous studies, in which phonological loading impaired addition (Logie et al., 1994; Otsuka & Osaka, 2015), subtraction (Imbo & LeFevre, 2010) and multiplication (Imbo & LeFevre, 2010; Lee & Kang, 2002) abilities. This finding is partially consistent with the study of Cragg and colleagues (2017), who found that phonological loading had a general impairing effect on addition performance regardless of the solving strategy that was employed. However, we cannot ignore the fact that, in the study of Cragg and colleagues, both visual-spatial and phonological loading impaired arithmetic performance regardless of the used solving strategy. Hence, we are still far from resolving the question as to the several roles each of the components of working memory play in mental arithmetic exercises.

Although the analyses did not capture the expected interference between visual-spatial loading and addition and subtraction tasks, observing the means of accuracy and reaction times for performance in the arithmetic tasks revealed a trend towards larger differences between the control and loading conditions within addition and subtraction tasks than that observed during multiplication and division activities. We should also consider the finding that a large percentage of participants tended to use procedural strategies, including decomposition, during the addition and subtraction exercises. This is plausible as it is partially congruent with the findings of previous studies, which showed that when visual solving strategies were enhanced, visual-spatial loading interfered with addition (Hubber et al., 2013) and subtraction (Imbo & LeFevre, 2010) performance. We should note here that participants tended to use retrieval strategies when performing division tasks, and this is at odds with our initial expectations, which were based on the findings of a previous study (Campbell & Xue, 2001). However, as the study by Campbell and Xue involved Chinese and Canadian participants, our finding emphasizes the need for cross-cultural studies to delineate the factors that are responsible for participants' choice of solving strategies in mental arithmetic tasks.

Experiment 2

Experiment 2 was designed to examine parts of the speculations related to the specific roles of visual-spatial and phonological working memory components in mental arithmetic by manipulating arithmetic task demands. It investigated what types of strategies participants use when solving mental arithmetic tasks, either related to number-line (addition or subtraction) or repetition table (multiplication, or division) exercises that are presented in horizontal or vertical format. It manipulated the difficulty of arithmetic tasks under variant loading conditions.

In relation to the effects presentation format has on performance in addition and subtraction tasks, based on the findings of Imbo and LeFevre (2010) and Trbovich and LeFevre (2003), we expected the participants to exhibit a higher performance for complex arithmetic problems that were vertically presented than those that were horizontally presented. In contrast, we did not expect to find significant differences between the participants' performance on simple arithmetic tasks, regardless of how they were presented. This is because the beneficial effect of vertical presentation is thought to depend on people's high reliance on visual-spatial working memory, as suggested by Imbo and LeFevre. Simple arithmetic has been found to be dependent on the phonological loop as opposed to the visual-spatial component (Lee & Kang, 2001; Logie et al., 1994). Therefore, simple arithmetic does not benefit from the enhancement of the visual resources. Although some findings have suggested that phonological loading does not have a negative effect on simple arithmetic (Sctiz & Schumann-Hengsteler, 2000), we did not prescribe to this view as, in Experiment 1, we had found that phonological loading had a significant negative effect on the speed of performance in simple mental multiplication activities. Again, the differences between findings highlight the importance of careful examination of task settings.

As the findings from Experiment 1 showed that phonological loading had an interfering effect when the participants performed complex addition and simple multiplication, and previous findings suggest phonological loading has a negative effect on simple addition performance (Logie et al., 1994) and a general impairing effect for Canadians in both complex multiplication and addition (Imbo & LeFevre, 2010), we expected to observe that phonological loading had a general impairing effect on arithmetic performance in Experiment 2.

We expected visual-spatial loading to have a larger interference in complex mental arithmetic problems that were presented vertically in comparison to those presented horizontally. This prediction was based on the results of previous studies (Imbo & LeFevre, 2010: Trbovich & LeFevre, 2003), in which the vertical presentation was found to be more susceptible to being undermined by visual-spatial working memory.

Finally, our predictions related to the solving strategies employed were that the participants would use recall with simple arithmetic (Campbell & Xue, 2001), in either format of presentation. For the complex arithmetic, we expected the participants to use calculation strategies (Campbell & Xue, 2001).

Experiment two method.

Participants: A total of 33 healthy female university students, aged between 19 and 34 years (*M* = 22 years and 3 months, *SD* = 3 years and 3 months) participated in the experiment. No participant has taken part in experiment 1. All participants gave their consent form, had normal or corrected-to-normal vision and were native Arabic speakers.

Materials and tasks:

Materials for the arithmetic task: We chose a set of 240 arithmetic problems from each of the two basic arithmetic tasks (addition & multiplication), and partly followed the criteria of Tschentscher & Hauk (2015). Every arithmetic task contained six blocks, each of which consisted of 10 simple and 10 complex problems. The operant was equally divided into four types: even numbers, odd numbers, even-odd numbers, and odd-even numbers. Half of the problems in each arithmetic type involved a carry-on operation (e.g., $12+19 = 21$), & half did not involve any carry on. The complex addition tasks involved adding two numbers, each of two digits. In the complex multiplication task, the problems consisted of two-digit numbers; the first operant ranged between 12 and 29, and the second ranged between 2 and 5. The simple tasks consisted of two one-digit numbers in both addition and multiplication tasks.

Materials for working memory capacity*P* For each of visual-spatial and phonological working memory, eight sequences of varying lengths were generated from the same materials of the working memory tasks. There were two sequences of each length, and the sequences consisted of 3, 4, 5 or 6. The stimuli were presented using the same method and parameters as those used to present the loading tasks. Memory capacity was determined by the largest sequence successfully recalled by the participant for each of the working memory tasks.

Design and procedures: Stimulus presentation and data collection were performed using a laptop that ran the Windows operating system and PsychPy software (v.1.85) (Peirce, 2007). All participants were required to perform a capacity test of working memory and three phases of the experiment either in one session lasting up to 90 min or two separate sessions. In the event they performed the tasks in one session, they were given breaks between phases. At the beginning of the testing session, participants performed the working memory capacity test to determine the length of memory sequences in the loading tasks. The first phase of the experiment consisted of arithmetic problems with no loading task; the second involved a visual-spatial loading task and the third involved the phonological loading task. The order of experiment phases was counterbalanced across participants. In each phase, the participants performed 80 tasks divided into four blocks: 2 (horizontal vs vertical presentation format) x 2 (addition vs multiplication). The no-loading phase was the same for all participants. With regards to the visual-spatial and phonological loading phases, the number of items presented for the loading task was adapted according to the working memory capacity test. All other experimenting procedures were the same as those employed in Experiment 1.

Experiment two results

Accuracy in Arithmetic Tasks: We calculated the mean scores for each participant in each condition and submitted the data to a repeated measures ANOVA with four factors: loading condition (no load, visual spatial load & phonological load), type of operation (addition vs.

multiplication), presentation format (horizontal vs. vertical) and difficulty (simple vs. complex). The analyses revealed a significant interaction between the loading task, presentation format, and type of operation: *F* (2, 64) = 10.4, *p* =.001, *MSe* = 1.15, ç^2*p* =.25. The main effect of the loading task was significant: *F* (2, 64) = 29.15, *p* =.001, *MSe* = 7.7, ç^2*p* =.48. Post hoc analyses showed that performance in the control condition (*M* = 7.85, *SD* = 1.08) was higher than performance in visual-spatial loading (*M* = 6.52, *SD* = 1.57) and phonological loading (*M* = 6.08, *SD* = 1.37), *t* (32) = 4.62, and *t* (32) = 6.96, *p* =.001 conditions. Moreover, performance in the visual-spatial loading condition was slightly higher than performance in the phonological loading condition, albeit not significant: *t* (32) = 2.61, *p* =.168. The main effect of presentation format was significant: *F* (1, 32) = 13.99, *p* =.001, *MSe* = 2.5, ç^2*p* =.3. The main effect of type of operation was also significant: *F* (1, 32) = 116.9, *p* =.001, *MSe* = 5.44, ç^2*p* =.79. Finally, the main effect of difficulty was significant: *F* (1, 32) = 274.16, *p* =.001, *MSe* = 5.51, ç^2*p* =.9. See Figure 1, 2 and 3 for means and standard errors for participants' performance in each condition for the control, visual spatial load, and phonological load conditions respectively.

Figure 1

Illustrates means of accuracy of performance on mental arithmetic tasks in Experiment 2 in the visual spatial condition. Error bars represent standard errors.

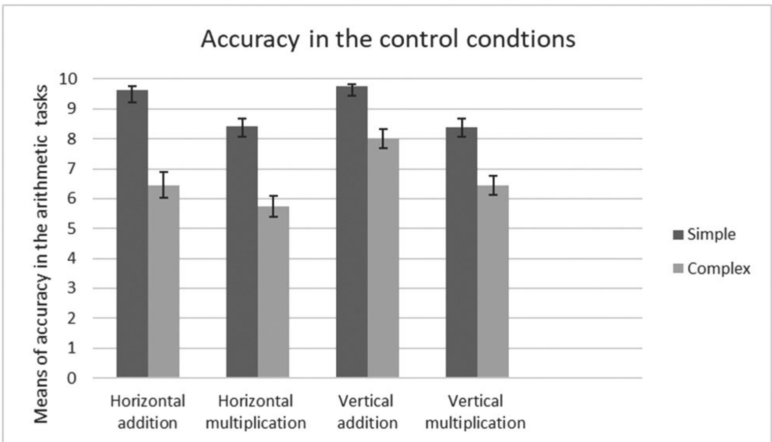


Figure 2

Illustrates means of accuracy of performance on mental arithmetic tasks in Experiment 2 in the phonological loading condition. Error bars represent standard errors.

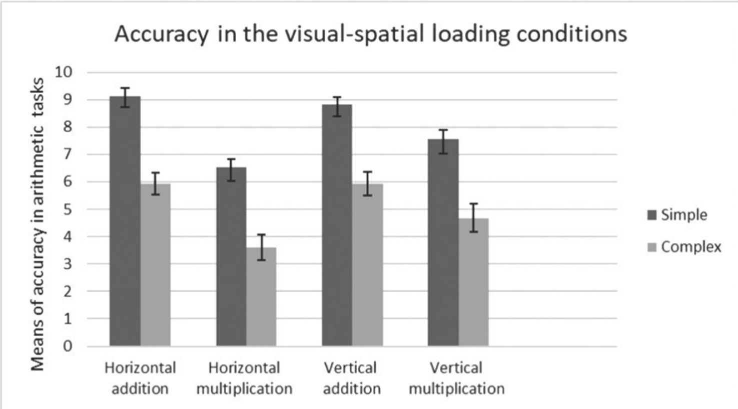
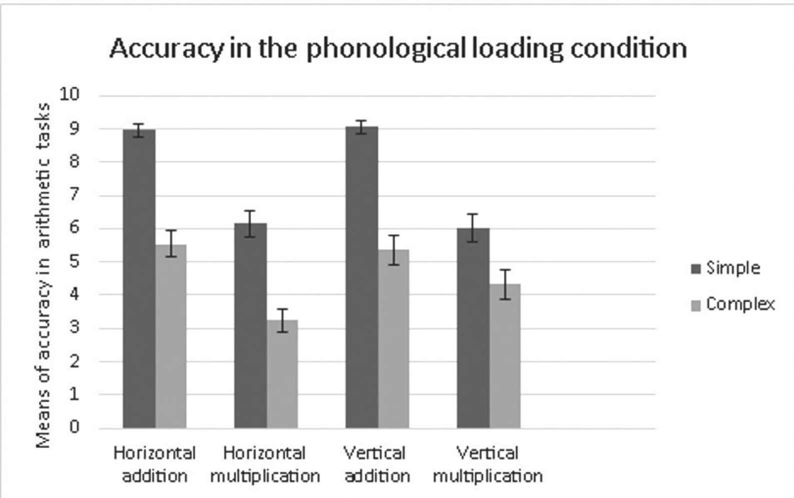


Figure 3

Illustrates Accuracy of phonological loading condition



To further investigate the interaction between loading, type of operation and presentation format, we ran a series of repeated measures ANOVA for each loading condition. For the 'no loading' control condition, a 2 (presentation format) x 2 (type of operation) x 2 (difficulty) revealed that the presentation format had a significant effect on arithmetic performance: F (1, 32) = 11.71, p =.010, MSe = 1.97, η^2p =.27. Similarly, the type of operation also had a significant effect on arithmetic performance: F (1, 32) = 48.09, p =.001, MSe = 2.02, η^2p =.6. Additionally, the main effect of difficulty was significant, F (1, 32) = 95.86, p =.001, MSe = 3.95, η^2p =.75. As there was a significant interaction between presentation format and difficulty: F (1, 32) = 13.55, p =.001, MSe = 1.45, η^2p =.29, we ran a series of dependent sample t tests to investigate the interaction between factors (all reported t tests were corrected for multiple pairwise comparisons). We found that participants exhibited a higher performance for both complex addition and complex multiplication in the vertical positions compared to complex addition and complex multiplication in the horizontal condition: t (32) = 3.36 and t (32) = 2.43, p =.006 respectively. The rest of comparisons were not significant.

A similar 2 x 2 x 2 repeated measure ANOVA was performed within the visual-spatial loading condition. No significant main effect was found for the presentation format: F (1, 32) = 4, p =.067. On the other hand, the main effect of type of operation was significant: F (1, 32) = 64.44, p =.001, MSe = 3.57, η^2p =.66, and the main effect of difficulty was also significant: F (1, 32) = 103.02, p =.001, MSe = 5.61, η^2p =.76. A significant interaction was found between presentation format and type of operation: F (1, 32) = 19.6, p =.001, MSe = 1.22, η^2p =.38. Therefore, we ran a paired sample t tests between horizontal addition (M = 15.06, SD =.45) and vertical addition (M = 14.76, SD =.61). This revealed that there was no significant difference between the two conditions: t (32) =.58, p =.174. In contrast, a significant difference was found between horizontal multiplication (M = 10.11, SD =.67) and vertical multiplication (M = 12.23, SD =.81), showing higher performance in the vertical condition compared to the horizontal condition, t (32) = 4.124, p =.001.

Another 2 x 2 x 2 repeated measure ANOVA was performed within the phonological loading condition. No significant main effect was found for presentation format: F (1, 32) = 1.72. p =.621. On the other hand, the main effect of type of operation was significant: F (1, 32) = 82.36, p =.001, MSe = 4.22, η^2p =.72, and the main effect of difficulty was also significant: F (1, 32) = 218.54, p =.001, MSe = 2.59, η^2p =.87. A marginally significant interaction was found between presentation format, type of operation and difficulty: F (1, 32) = 4.56,

p =.052, MSe = 1.99, η^2p =.13. Therefore, we ran a series of paired-sample t tests between the horizontal conditions and their counterpart in the vertical condition to further investigate the interaction between the three factors within the phonological loading condition. All comparisons were not significant apart from the comparison between the complex multiplication conditions, which revealed that the participants performed better on the vertical condition (M = 4.33, SD =.44) in comparison to the horizontal condition (M = 3.24, SD =.33), t (32) = 2.38, p =.040.

Mental arithmetics reaction time. A 2 (presentation format: horizontal vs. vertical) x 3 (loading task: control, visual spatial load & phonological load) x 2 (difficulty: simple vs. complex) x 2 (operation type: addition & multiplication) repeated measures ANOVA revealed a significant interaction between the loading task, presentation format, difficulty, and operation type: F (2, 64) = 4.72, p =.001, MSe = 4.21, η^2p =.129. The main effect of loading task on reaction time was significant: F (2, 64) = 5.98, p =.001, MSe = 36.34, η^2p =.158. The main effect of type of operation on reaction time was also significant: F (1, 32) =301.89, p =.001, MSe =754.28, η^2p =.904. Additionally, the main effect of difficulty on reaction time was significant: F (1, 32) = 11.35, p =.001, MSe =24.63, η^2p =.262. Nevertheless, the main effect of presentation format on reaction time was not significant: F (1, 32) = 2.35, p =.074.

To further investigate the interaction between the four conditions, we ran a 2 x 2 x 2 (presentation format x operation type x difficulty) repeated measures ANOVA for each of the three loading task conditions. For the control group, the results showed that the main effect of presentation format on reaction time was not significant: F (1, 32) = 1.12, p =.086. In contrast, the main effect of operation type on reaction time was significant: F (1, 32) = 18.26, p =.001, MSe = 17.61, η^2p =.364, showing longer reaction time for multiplication (M = 4.62, SD = 1.12) compared to the reaction time for addition (M = 3.74, SD =.89). The main effect of difficulty on reaction time was significant: F (1, 32) = 392.42, p =.001, MSe = 309.47, η^2p =.925, revealing longer time taken to perform complex mental arithmetic tasks (M = 5.1, SD = 1.22) compared to simple exercises (M = 2.92, SD =.71).

In the visual condition, the main effect of presentation format on reaction time was significant: *F* (1, 32) =4.48, *p* =.050, *MSe* =4.46, η^2p=.123. The main effect of type of operation on reaction time was significant: *F* (1, 32) = 6.24, *p* =.053, *MSe* = 6.42, η^2p =.163. The main effect of difficulty on reaction time was significant: *F* (1, 32) =126.76, *p* =.007, *MSe* = 278.97, η^2p =.798. Also, there was a significant interaction between the presentation format, difficulty, and type of operation: *F* (1, 32) = 11.92, *p* =.001, *MSe* = 8.62, η^2p =.271. To investigate the interaction between conditions in the visual-spatial loading condition, we ran a series of paired-sample t tests. We found that time taken to solve horizontal simple addition tasks (*M*= 3.19, *SD* =.78) was significantly shorter than that taken to solve vertical simple addition exercises (*M* = 3.66, *SD* =.89), *t* (32) = 3.5, *p* =.001. In contrast, the time required to solve horizontal complex addition tasks (*M*= 6.14, *SD*= 1.53) was significantly longer than that taken to solve vertical complex addition exercises (*M* = 5.30, *SD* =.98), *t* (32) = 3.32, *p* =.001. The reaction time for the horizontal simple multiplication tasks (*M* = 4.18, *SD* = 1.05) was roughly similar to that of the vertical simple multiplication condition (*M* = 3.78, *SD* = 1.21), *t* (32) = 1.82, *p* =.186. There was also no significant difference in terms of reaction time between the horizontal complex multiplication condition (*M* = 5.93, *SD* = 1.45) and the vertical complex multiplication condition (*M* = 5.66, *SD* = 1.86), *t* (32) =.97, *p* =.613.

In the phonological loading condition, the main effect of presentation format was not significant: *F* (1, 32) = 1.44, *p* =.075. The main effect of type of operation was also not significant: *F* (1, 32) = 1.38, *p* =.068. The main effect of difficulty was significant: *F* (1, 32) = 78.88, *p* =.001, *MSe* = 176.22, η^2p =.711. In addition, there was a significant interaction between the presentation format, difficulty, and type of operation: *F* (2, 64) = 4.79, *p* =.050, *MSe* = 6.82, η^2p =.130. Further analyses by paired-sample *t* tests showed longer reaction times for both horizontal simple addition tasks (*M* = 3.61, *SD* = 1.05) and complex addition exercises (*M* = 5.9, *SD* = 1.58) compared to their counterpart vertical simple (*M* = 2.69, *SD* = 1.63) and complex addition (*M* = 4.31, *SD* = 2.67), *t* (32) = 3.32, and *t* (32) = 3.34, *p* =.001, respectively. Similarly, the reaction time for each horizontal simple multiplication task (*M* = 3.35, *SD* = 1.74) and complex multiplication exercise (*M* = 4.05, *SD* = 1.23) was significantly longer than that for the simple multiplication task (*M* = 4.5, *SD* = 2.67) and complex multiplication exercise (*M* = 5.53, *SD* = 1.97) in the vertical condition, t (32) = 2.47, p =.050, and t (32) = 2.37, p =.054.

Solving strategies. As each participant was debriefed about the solving strategies used in eight independent sets of arithmetic problems in each of the three loading conditions, we had a total of 24 reported strategies for each participant. Table 3 shows the frequency of uses of each strategy across the variant sets of arithmetic problems. We ran a Chi-square test to examine the correlation between the strategies employed and presentation format, type of operation, and difficulty. In the control condition, there was a marginally significant correlation between difficulty and solving strategies, x = 7.53, p =.057. Decomposition strategies were more commonly used to solve complex arithmetic problems while the use of recall strategies decreased. The correlation between frequency of use of strategies and both presentation format and type of operation was not significant: x = 3.76 and 5.19, p =.172. However, it seems that the participants exhibited a general propensity to employ a decomposition strategy to solve problems that were presented within the vertical presentation format and a counting strategy to solve addition operations. In the visual-spatial loading condition, the correlation between difficulty and use of strategy was significant: x = 19.48, p =.001, reflecting the participants' tendency to use an analyzing strategy to solve complex problems and recall to answer simple ones. Additionally, the correlation between presentation format and use of strategies was significant, x = 17. 48, p =.001, and this might be explained by the more frequent use of decomposition with vertical problems compared to the increase in the use of recall when solving horizontal problems. The correlation between the strategies used and the type of operation was not significant, x = 1.45, p =.077. Finally, no significant correlations were found within the phonological loading condition, x =.01,.66, and 3.62, for correlations with difficulty, presentation format, and type of operation, respectively.

Table 3

Percentile of strategies used across the 24 sets of arithmetic problems in Experiment 2

Loading condition	Complex-ity	Presentation & Operation	Counting	Decompo-sition	Recall	Mixed
Control	Simple	Horizontal addition	22.6%	19.4%	38.7%	19.4%
		Horizontal multiplication	9.7%	22.6%	54.8%	12.9%
		Vertical addition	29%	25.8%	35.5%	9.7%
		Vertical multiplication	9.7%	19.4%	58.1%	12.9%
	Complex	Horizontal addition	9.7%	25.8%	48.4%	16.1%
		Horizontal multiplication	3.2%	16.1%	64.5%	16.1%
		Vertical addition	12.9%	25.4M%	48.4%	12.9%
		Vertical multiplication	3.2%	22.6%	54.8%	19.4%
Visual-spatial	Simple	Horizontal addition	20%	20%	40%	20%
		Horizontal multiplication	16.7%	13.3%	53.3%	16.7%
		Vertical addition	23.3%	30%	33.3%	13.3%
		Vertical multiplication	13.3%	16.7%	56.7%	13.3%
	Complex	Horizontal addition	25.8%	45.2%	9.7%	19.4%
		Horizontal multiplication	19.4%	58.1%	9.7%	12.9%
		Vertical addition	22.6%	64.5%	3.2%	9.7%
		Vertical multiplication	12.9%	64.5%	9.7%	12.9%
Phonolo-gical	Simple	Horizontal addition	12.9%	64.5%	6.5%	16.1%
		Horizontal multiplication	9.7%	54.8%	19.4%	16.1%
		Vertical addition	19.4%	54.8%	12.9%	12.9%
		Vertical multiplication	9.7%	61.3%	9.7%	19.4%
Control	Complex	Horizontal addition	20%	53.3%	6.7%	20%
		Horizontal multiplication	23.3%	56.7%	3.3%	16.6%
		Vertical addition	26.7%	60%	0%	13.3%
		Vertical multiplication	20%	60%	6.7%	13.3%

Discussion: Experiment 2 investigated the effects of loading working memory components on two arithmetic tasks (addition and multiplication). Within this experiment, we manipulated task demands and debriefed participants about their solving strategies in an attempt to reconcile the contradictory findings of previous studies. The results revealed that participants' accuracy was lower and reaction time was longer in visual-spatial and phonological loading conditions than it was in the control condition. However, the impairing effect of loading was selective. The most intriguing finding was that presenting multiplication exercises in a vertical format reduced the impairment of performance whether under visual-spatial or phonological loading. In relation to the effects of task demands on participants' performance, it was apparent that vertical, in comparison to the horizontal presentation, improved performance in complex arithmetic tasks regardless of operant type. At the other end, the impairment in performance observed in the working memory tasks was larger for visual-spatial tasks in comparison to phonological working memory. Finally, it appeared that the participants exhibited a general preference, albeit not always significant, to use a decomposition strategy to solve complex problems and those presented in the vertical presentation format.

General Discussion

The two experiments of the study aimed to examine the effects of task settings on the arithmetic performance, and how this is related to working memory components and solving strategies. We predicted that a vertical presentation of complex arithmetic problems would have a positive impact on participants' performance in terms of accuracy and latency and the findings were consistent with our prediction. In the control 'no loading' condition, the participants' accuracy when solving arithmetic problems was higher when these problems were in vertical presentation conditions than it was for horizontal presentation formats for both complex addition and multiplication tasks, although the reaction time was almost identical across both horizontal and vertical presentation formats. In fact, previous studies have illustrated the positive effect that vertical presentation has on speeding up mental arithmetic processing in addition (Trbovich & LeFevre, 2003) and multiplication (Imbo & LeFevre, 2010) exercises. Although we found a superior positive effect of vertical presentation, this effected accuracy as opposed to speed. Given that cultural and educational factors should be taken into account when discussing the effects of task demands on mental arithmetic (Imbo & LeFevre, 2010), we might conclude that the positive role of the vertical presentation is due to variant factors. Participants might shift their ordinal solving strategy to the most optimal strategy. As the results of this investigation indicate, participants tended to use a decomposition strategy when solving problems that were presented in the vertical format. This might suggest that vertical presentation shifts the strategy to a more efficient process by arranging the tens and units in complex tasks; hence, decomposition becomes a plausible strategy for solving complex arithmetic problems. We assume that the decomposition strategy required longer latency compared to other strategies, such as retrieval, but using the vertical presentation eliminated the steps required to arrange the tens and units.

Although we found that phonological loading had a general impairing effect on performance latency, the impairing effect was found to be selective depending on the presentation format. A larger impairing effect was observed when the problems were presented in a horizontal presentation than when they were presented in a vertical presentation. However, we cannot explain the findings according to the use of particular solving strategies. No clear tendency toward using a specific type of strategy was identified. This finding is congruent with the findings of the study by Imbo and LeFevre (2010), in which phonological loading was found to have larger impairing effect on Chinese participants' performance on horizontal multiplication tasks. This finding emphasizes the differences between how people approach problems that involve different operant types (Lee & Kang, 2002). The differences between the approach used to solve multiplication and addition tasks can be the result of education. Multiplication is normally taught by memorizing the multiplication table. Hence, the ordinal root for solving multiplication problems involves recalling facts from the times table, even when decomposing tens and units. This mixture of strategies could explain the absence of evidence to suggest that people shift strategies under the phonological loading condition.

We should consider the nonselective impairing effect of visual-spatial loading on the accuracy of performing addition tasks, as opposed to finding longer latency for simple addition in vertical presentation in comparison to horizontal presentation and longer latency for horizontal complex addition in comparison to vertical complex addition. In combination, these findings suggest that participants can shift their solving strategies to successfully solve addition problems based on task demands. Simple addition is based on recall. Therefore, we did not expect the participants' performance to be affected by visual-spatial loading (Logie et al., 1994). One possible explanation for the increase in latency in vertical presentation could be that the participants did not use decomposition strategies when performing simple addition tasks. However, when the simple addition task was presented in vertical format, this presentation forced participants to use a decomposition strategy. Maintaining the level of accuracy with an increase in latency suggests that the participants required time to shift back to their ordinal recall strategy. On the other hand, complex addition generally requires decomposition, which might benefit from both phonological and visual-spatial working memory. Hence, participants were able to maintain their accuracy at the same level in both vertical and horizontal presentation exercises; however, they required more time to solve horizontal problems.

In relation to the differences in accuracy and latency that were observed between addition and multiplication exercises, it was obvious that participants solved addition problems faster and more accurately. Additionally, vertical presentation reduced the impairing effects of visual-spatial and phonological loading in complex multiplication, but not in addition. However, these differences were not apparent in simple arithmetic tasks, emphasizing complexity as a modifier for solving strategy and, hence, the engagement of working memory components in mental arithmetic tasks. Indeed, it was found that decomposition was the strategy that was most commonly used during complex tasks.

Conclusion

The results presented here indicate that participants can shift their solving strategy to a specific operation type according to the complexity of the task. Additionally, the presentation format, which is irrelevant to the nature of operation and complexity, is a crucial factor in determining the strategy that is used. These findings illustrate the importance of presentation format in determining the role of working memory components and solving strategies. However, they also highlight the interaction that takes place between presentation format and other task demands. Thus, solving strategies cannot be simply matched to types of operands. It was clear from our findings that vertical presentation encourages the use of decomposition of complex problems and simultaneously reduces the negative effect of visual-spatial loading. However, other task demands should be explored to determine related strategies and, hence, the involvement of working memory components. We admit that serious consideration should be taken before generalizing implications related to use of strategies in mental arithmetic, as they were found to vary according to cultural differences (Campbell & Xue, 2001; Imbo & LeFevre, 2010) and gender (Pletzer, 2016; Pletzer et al., 2016).

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أثر إعدادات المهام في مكونات الذاكرة العاملة السمعية والبصرية المكانية
واستراتيجيات الحل في الحساب الذهني

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الملخص

الأهداف: في الدراسة الحالية، أُجريت تجربتان لمقارنة آثار عدة متطلبات للمهام على الأداء في الحساب الذهني، واختيار استراتيجيات الحل. **المنهج**: لتحقيق هذا الهدف تم اتباع المنهج التجريبي. **النتائج**: أجريت تجربتان، باستخدام سلسلة من مهام الحساب الذهني على الحاسب. فالتجربة الأولى شملت العينة متطوعة من طالبات الجامعة وهدفت لتقييم ما إذا كان يمكن لإعدادات المهمة المتصلة بعبء الذاكرة العاملة، ونوع العملية التأثير على الأداء الحسابي، وتبديل استراتيجيات الحل. وفي التجربة الثانية تضمنت العينة 33 متطوعة من طالبات الجامعة، وعنيت بطريقة العرض والتعقيد في الجمع والضرب أثناء تحميل الذاكرة العاملة الصوتية أو الذاكرة العاملة البصرية المكانية. وبينت النتائج دور طريقة العرض في تقليل الأثر السلبي لتعقيد المهمة، والأثر السلبي لتحميل الذاكرة العاملة على الحساب الذهني. إضافة لذلك، فطريقة العرض العمودية شجعت بشكل دال استراتيجية التحليل في المهام الحسابية. **الخاتمة:** خلصنا إلى أن دور مكونات الذاكرة العاملة في الحساب الذهني يتغير تبعًا للتعقيد وطريقة العرض، وأن الاستراتيجيات المتصلة بها مرنة وتتغير تبعًا لمتطلبات المهام.

الكلمات المفتاحية: الحساب الذهني، الذاكرة العاملة الصوتية، طريقة العرض، استراتيجية الحل، الذاكرة العاملة البصرية المكانية

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