Complex Mental Addition and Multiplication Rely More on Visuospatial than Verbal Processing

Tommy Kwun-leuk Cheung (tckl@connect.hku.hk)
Department of Psychology, University of Hong Kong, Pokfulam Road,
Hong Kong, China
Janet Hui-wen Hsiao (jhsiao@hku.hk)
Department of Psychology, University of Hong Kong, Pokfulam Road,
Hong Kong, China

Abstract

Recent imaging studies have found that in simple arithmetic processing, addition is lateralized to the right hemisphere, whereas multiplication to the left. Here we aimed to investigate the cognitive mechanism underlying complicated arithmetic processing with a dual task paradigm. Participants were asked to complete a calculation task (addition or multiplication) and a letter judgment task (rhyme or shape judgment) simultaneously. We found that participants' performance in addition and multiplication was interfered more by the simultaneous shape judgment task than the rhyme judgment task. This effect suggested that both complicated addition and multiplication relied more on right-lateralized visuospatial than left-lateralized phonological/verbal processing. The shift from left- to more right-lateralized processing in complicated multiplication suggests that participants may have adopted a visuospatial strategy to approximate numerosity when the calculation involved large numbers. These results suggest that the cognitive mechanism involved in arithmetic processing depends on both the operation and the context.

Keywords: arithmetic processing; hemispheric lateralization; dual task paradigm

Introduction

Mental representation of arithmetic processing

Although it is generally believed that logical reasoning or mathematical processing is lateralized to the left hemisphere (LH), the specific neural mechanism of arithmetic and number processing is still unclear. In general, Dehaene and Cohen's (1995) triple-code model of number processing has been widely used to conceptualize the anatomical and functional properties of human's number processing. In this model, there are three main components of mental representation of numbers and its manipulation within the human brain. The components are: (1) visual Arabic number form, where numbers are represented as strings of digits; (2) verbal word form, where numbers are represented with syntactic structure; (3) analogical magnitude representation, where numbers are associated with their "meanings" or quantities. Different studies have provided converging evidence for the existence of a modular structure of number processing, yet, the exact brain mechanisms for specific functions, such as arithmetic, remain unclear.

By studying patients with different lesions, Dehaene and Cohen (1997) argued that there is a double dissociation between storage and retrieval of arithmetic facts by verbal rote and by manipulation of numerical quantities mentally. While the former is believed to be attributed to a left subcortical network, the latter involves bilateral parietal network. A later study by Zago et al. (2008) have linked number processing, or calculation, to the model of working memory proposed by Baddeley and Hinch in 1974, that is, central executive, phonological loop and visuospatial sketchpad. By comparing participants' activation pattern using fMRI when they held or manipulated numbers and spatial patterns, they proposed that each of the components in the working memory model is essential for a complete calculation to work. While the central executive is needed to coordinate the two systems, the left-lateralized phonological component around the inferior fronto-temporal area is required for retrieval of arithmetic information, whereas the right-lateralized visuospatial component around the superior and posterior fronto-parietal area is essential for manipulation of numbers.

Some recent studies have examined how the components in the working memory model can be linked to specific arithmetic processing. For example, in an EEG study, Zhou et al. (2006) found that when performing single-digit arithmetic problems, multiplication relies more on the phonological processing than addition and subtraction. A subsequent paper by Zhou et al. (2007) has further extended the idea by testing participants with single-digit addition and multiplication problems using fMRI. Their findings showed that mental multiplication relied more on verbal processing, which is lateralized to the LH, and that mental addition relied more on visuospatial processing, which is lateralized to the right hemisphere (RH). One of the explanations given by the authors was that we are encouraged to learn addition through procedural strategies such as counting, and multiplication through rote learning (e.g. Dehaene & Cohen, 1997). While counting involves the manipulation of visual Arabic digits and their quantities, which requires visuospatial processing, rote learning and retrieval require verbal/phonological processing. However, since only single digit arithmetic was tested in the experiments, it remains unclear whether these findings also apply to complicated arithmetic processing involving more than one digit.

In the literature on arithmetic processing, the anatomical and functional mechanisms underlying mental arithmetic processing remains unclear because arithmetic processing is a complicated cognitive process that involves several different components, such as the ones proposed in the triple-code mode (Dehaene & Cohen, 1995; 1997) and its link to the working memory model. Different strategies/components may be used under different contexts, such as calculations with small versus large numbers. Thus, the type of strategy used by participants may contribute to the inconsistency in the literature. In one study, it was found that addition and its reverse operation, subtraction, rely more on RH processing (Zhou et al., 2006; Zhou et al., 2007). However, in another study examining strategy use during calculation, whole-calculation strategy, or exact approach in addition, was found to be lateralized to the LH, whereas approximate-calculation strategy involved both hemispheres (Yagoubi, Lemaire & Besson, 2003).

Indeed, some recent studies have suggested that the brain mechanism for mental arithmetic processing depends on the use of strategy given the context such as time constraint or difficulty level of the task. For example, an ERP study by Yagoubi, Lemaire and Besson (2003) found that different brain mechanisms were involved for different strategies employed in different contexts. Specifically, when participants were asked to judge whether the solution of a complicated addition problem was smaller than 100 or not, they showed two types of processing patterns depending on the discrepancy between the proposed sum and 100. If the proposed sum was close to 100 (2% or 5% away from 100; i.e., a small-split problem), participants adopted a whole-calculation strategy, which was slower and primarily done by the LH; however, if the proposed sum was far from 100 (10% or 15% away from 100; i.e., a large-split problem), participants adopted an approximate-calculation strategy, which was faster and involved bilateral brain activation. Although the study claimed to tap on arithmetic processing with large numbers, the task only required a comparison to a fixed number, which may not resemble how a more genuine complicated arithmetic problem looks like. Andres, Seron and Oliver (2005) examined similar topics using the TMS technique and found that comparison between digits close together involved the left posterior parietal cortex (PPC) only, while comparison between digits that were further away could be done by either left or right PPC. More specifically, participants were asked to compare single-digits ranging from 1 to 9 (excluding 5) against 5 and determine if the digit shown was smaller or larger than 5. It was found that disrupting the left PPC alone was enough to increase the reaction time for comparing numbers close to 5, whereas bilateral disruption was needed for numbers further away from 5. Using both fMRI and ERP designs, Stanescu-Cosson et al. (2000) found that small number addition, which involves mainly rote verbal memory, was lateralized to the LH, while larger number addition, which typically involves both approximation and exact calculation, relied on both hemispheres, especially the parietal regions. However, the larger numbers (operands) in the study were only ranging from 5 to 9, which are small as compared with double-digit calculation. As the study examined comparison of small numbers only, it remains unclear how arithmetic problems involving large numbers are processed as compared with those with small numbers.

Recent studies have shown that those who are extremely good at mathematics may also have a different neural mechanism when undergoing number processing. In particular, using different imaging techniques, it has been suggested that mathematically gifted adolescents may be attributed to a more bilateral activation pattern in their frontal and parietal areas. For example, Desco et al. (2011) found that mathematically gifted adolescents always show a bilateral activation and recruit more regions, especially in the RH, while performing different reasoning tasks. In particular, the precuneus, superior occipital lobe and medial temporal lobe in the Tower of London (TOL) task, and the right inferior parietal lobe, anterior cingulated gyrus, and frontal areas in the Raven’s Advanced Progressive Matrices (RAPM) task. O’Boyle et al. (2005) also found that when mathematically gifted adolescents performed mental rotation tasks, which has been shown to be lateralized to the RH among ordinary people, showed a bilateral activation pattern involving the parietal lobe and the anterior cingulate.

Given the greater involvement of the RH, in addition to the LH, in arithmetic with relatively larger numbers or involving non-verbal number processing (e.g. approximation), and the findings from mathematically gifted adolescents, who typically show a bilateral activation pattern in different reasoning tasks, it seems to suggest that bilateral activation, i.e., engagement of both hemispheres, may be generally beneficial to complicated mathematical processing, such as calculations with large numbers.

Dual-task paradigm

The use of a dual-task paradigm in psychological experiments can be dated back to the early 70s and 80s, where researchers tried to examine specific brain mechanisms responsible for a particular kind of cognitive processing. By asking participants to do two tasks simultaneously, the neural representation of a particular processing can be deduced. The underlying assumption of a dual-task paradigm is that if two tasks share the same neural mechanism, there will be greater interference than when they do not share the same mechanism (Shaillice, McLeod & Lewis, 1985).

Fernandes and Guild (2009) used the dual-task paradigm to investigate the underlying mechanisms responsible for retrieving words and visuospatial patterns. In the study, participants were interfered more by a visuospatial distracting task when retrieving visuospatial patterns, but interfered more by a phonological distracting task while doing retrieval of words. Hence, they argued that the representations of verbal and visuospatial episodic memories were different qualitatively. In a later study, Fernandes, Wammes and Hsiao (2013) have used the dual-task paradigm to examine the representation of linguistic information in a visual word recognition task. It was found that when bilingual Chinese-English speakers retrieved

Chinese characters, they were interfered more by the visuospatial distracting task than phonological task. In contrast, monolingual English speakers were affected more by the phonological task when they retrieved English words. The study has demonstrated how the representation of linguistic information can be addressed by examining the interference effect generated by the dual tasks.

Lee and Kang (2002) examined the connections between arithmetic functions and working memory using a dual-task paradigm, where the distracting task was to suppress either the phonological component or visuospatial component. Results showed that multiplication was significantly delayed by concurrent phonological rehearsal while subtraction was delayed by maintaining an image in the mind. This suggests that while multiplication is more related to phonological processing, subtraction is more related to visuospatial processing. However, their study used only single digit stimuli, which cannot fully demonstrate how people do mental calculation when facing more complex scenarios with larger numbers.

In sum, this study aims to examine the processes and representations involved in complicated arithmetic problem solving with large (two-digit) numbers using a dual task paradigm. According to the results from studies examining simple arithmetic problem solving with single-digit numbers, if complicated arithmetic processing shares similar neural mechanisms to simple arithmetic processing, we expect that participants may rely more on the RH processing for addition and more on the LH processing for multiplication (Zhou et al., 2006; Zhou et al., 2007). More specifically, they may be interfered more by a visuospatial task in addition and more by a phonological task in multiplication. However, given the potential benefit of bilateral processing in complicated calculations when using approximation (Yagoubi, Lemaire & Besson, 2003; Stanescu-Cosson et al.,2000), and in experts in mathematics (Desco et al., 2011; O'Boyle et al., 2005), it is likely that participants will show bilateral processing in a complicated arithmetic task. In our study, only addition and multiplication were examined because similar strategies are typically used between inverse operations, such as addition and subtraction, and multiplication and division. We hypothesize that participants will show more bilateral processing in both addition and multiplication with large numbers.

Method

Participants

Twenty-four local Chinese participants who had Chinese as their native language were recruited for the experiment (10 males and 14 females, mean age = 21.33, SD = 2.60 years). They received honorariums for their participation in the experiment. All participants had normal or corrected to normal vision and hearing. They were all right-handed according to the Edinburgh handedness inventory (Oldfield, 1971).

Materials

Calculation task Equations for addition and multiplication were created, such that 96 double-digit equations with one operation sign, where all numbers and signs were arranged horizontally (e.g. 12 + 24 = 36), were randomly formed for each operation sign and for the experimental session. There was no repetition of numbers within an equation. The range of numbers used in the left-hand side of the addition equations was from 11 to 99 and that of the multiplication equations was from 10 to 25. Half of the equations were correct and half were incorrect. For incorrect equations, the number shown on the right-hand side (the solution) was created by either adding 1 or 10 to, or subtracting 1 or 10 from, the correct answer.

Letter judgment task The materials were adapted directly from Fernandes and Guild (2009), where audio files (.wav) of letters of the English alphabet (omitting A, M, and W) were recorded by the respective author EG via a microphone using SoundDesigner II software (Palo Alto, CA). The same stimuli were used for both the rhyme (phonological) and shape (visuospatial) judgment tasks. Each .wav file was approximately 1,500 ms in duration.

Procedure

The experiment is conducted using E-prime v.2 software (Psychology Software Tools Inc., Pittsburgh, PA), with the stimuli presented on a 19' Dell LCD Monitor. Participants were tested individually and completed all the sessions. They gave all their responses through a response box.

Full attention tasks Participants completed a calculation task and a letter judgment task under full attention. For the calculation task, they completed both addition and multiplication, separated into two blocks. In each block, equations were presented in black on a white background, in 18-point Arial font, at the centre of the screen one at a time, followed by a fixation cross for 500 ms. The presentation time for addition equations was 3,000 ms while that for multiplication equations was 4,500 ms. Different presentation times were used to avoid ceiling/floor effects since multiplication equations in general were more difficult to solve. In each trial, participants were asked to judge whether the equation was correct or not by pressing "1" for correct equations and "2" for incorrect equations. They were asked to respond as fast and as accurately as possible. .

Participants also completed two types of letter judgment tasks, namely rhyme (phonological) and shape (visuospatial) judgment tasks. For both tasks, a trial started with a fixation cross for 500 ms. Participants then listened to a female voice speaking one of a list of 16 letters aloud. Each letter sound was played at the beginning of a 3,000 ms interval. Participants were asked to respond by pressing "4" for "yes" and "5" for "no" within the 3,000 ms interval. For the rhyme judgment task, participants judged whether the letter presented rhymed with the long "e" vowel (e.g., letters B, C, D, E, G, P, T, and V). For the shape judgment task, participants judged if the letter presented contained a curved line, in the capitalized form (e.g., B, C, D, G, P, J, O, P, Q, R, S, and U). The experimenter referred to the letters on the computer keyboard for illustrating how participants should visualise the alphabet. For both letter judgment tasks, half of the trials required a “yes” response and half required a “no” response. They were asked to respond as fast and as accurately as possible.

Divided attention tasks Participants did four blocks of dual tasks, which were different combinations between the calculation tasks (addition and multiplication) and letter judgment tasks (rhyme and shape judgment). In each trial, they had to give response to both the equation and the letter simultaneously, using the same instructions as before. The two responses should be made within the respective time interval: 3,000 ms for blocks with addition equations and 4,500 ms for those with multiplication equations. Participants were told to give both responses as quickly and accurately as possible, regardless of whether the responses were given simultaneously or in different orders.

In the whole experiment, participants completed 8 experimental blocks, each with 32 trials. The block order and trial order within each block were randomized. In the dual task conditions, half of the trials were congruent (both responses requiring “yes” or “no” responses) and half were incongruent (the two responses contradicting with each other, i.e. one “yes” and one “no”). Participants were given a 45-second break between each block. The button pressing patterns were counterbalanced across participants. Practice sessions on all the full attention tasks and the dual task condition between addition and rhyme judgment were given before the experiment. Sample trial sequence for calculation task (addition), letter judgment task (rhyme judgment) under full attention (FA), as well as trial sequence for both tasks (addition and rhyme judgment) under divided attention (DA) were given in Figure 1.

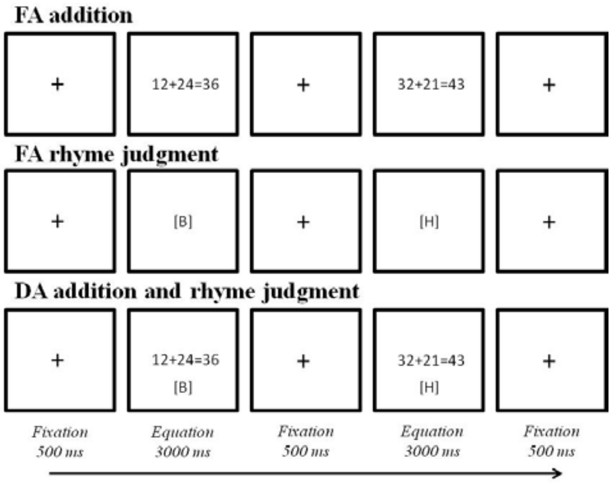

Figure 1: Trial sequence. Letter in brackets denotes the respective letter presented in that trial.

Results

Full attention tasks

Calculation tasks Paired-sample *t*-test on the task accuracy showed that participants did significantly better in addition (*M* = .811, *SE* = .025) than in multiplication (*M* = .737, *SE* = .014), *t*(23) = 3.073, *p* = .005.

Letter judgment tasks The accuracy of the two letter judgment tasks, rhyme judgment (*M* = .945, *SE* = .087) and shape judgment (*M* = .951, *SE* = .095) did not differ from each other significantly, *t*(23) = -.276, *p* = .785.

Divided attention tasks

Calculation tasks To see the effect of the two distraction (letter judgment) tasks on the calculation of the two operation signs, a 2 (letter judgment: rhyme vs. shape) x 2 (operation sign: addition vs. multiplication) repeated measures ANOVA was conducted on the accuracy of the calculation tasks. It was revealed that there was a significant main effect of letter judgment, *F*(1,23) = 10.075, *p* = .004, where calculation performance under phonological distraction (*M* = .704, *SE* = .017) was significantly better than visuospatial distraction (*M* = .654, *SE* = .019); however, there was no significant main effect of operation sign (*F*(1,23) = .543, *p* = .469) or interaction between letter judgment and operation sign (*F*(1,23) = .937, *p* = .343). Figure 2 showed the mean accuracy within each operation sign under divided attention. In order to investigate the degree of interference from the distractions on each operation sign, two additional paired-sample *t*-tests were conducted. Performance in addition under phonological distraction was significantly better than that under visuospatial distraction, *t*(23) = 2.281, *p* = .032; and performance in multiplication under phonological distraction did not differ significantly from that under visuospatial distraction, *t*(23) = 2.281, *p* = .212.

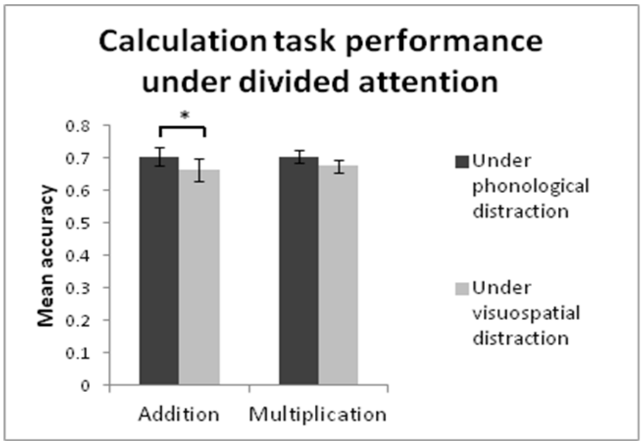

Figure 2: Mean accuracy of the calculation tasks under divided attention (* *p* < .05).

Letter judgment tasks The mean accuracy of letter judgment tasks for each operation sign under divided attention was shown in Figure 3. For performance under divided attention in addition, rhyme judgment did not differ from shape judgment significantly, $t(23) = -1.007$, $p = .324$. For performance under divided attention in multiplication, again rhyme judgment did not differ from shape judgment significantly, $t(23) = -.589$, $p = .561$. Similar performance in the letter judgment tasks suggests that the interference observed in the calculation task was due to the difference in processing addition and multiplication, rather than the difficulty of the letter judgment tasks.

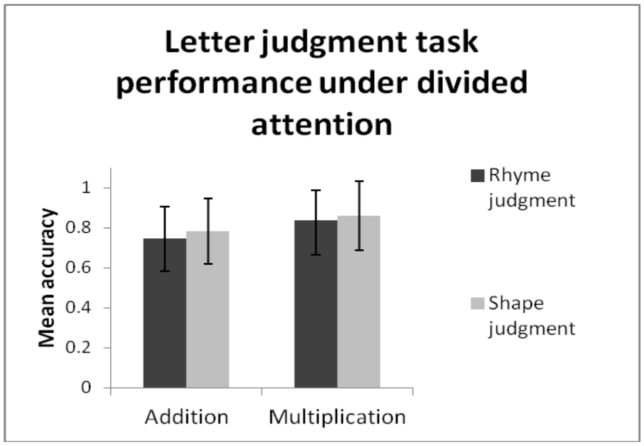

Figure 3: Mean accuracy of letter judgment tasks under divided attention.

Discussion

In this study, we have examined the processes and representations involved in complicated arithmetic problem solving (involving two-digit numbers) using a dual task paradigm. It was hypothesized that number processing, in particular arithmetic, is multi-modal, involving both visuospatial and phonological processing. Previous research has suggested that addition is linked to visuospatial processing more whereas multiplication relies more on phonological processing (Zhou et al., 2006; Zhou et al., 2007). Nevertheless, these findings were based on simple arithmetic processing with single-digit numbers. If a similar neural mechanism is involved in solving complicated arithmetic problems, we expected that in the dual task participants would be interfered more by the visuospatial task in addition and by the phonological task in multiplication. Our results showed that, in contrast to simple arithmetic processing, participants were interfered by the visuospatial task more in the calculation tasks, suggesting that they in general adopted a visuospatial strategy. This effect also suggests that RH processing may become more important for solving complicated than simple arithmetic problems. Since the performance in two letter judgment tasks did not differ significantly under either full attention or divided attention, the difference in calculation performance between these two distracting conditions was unlikely to be due to difference in task difficulty between the two distracting tasks.

When we examined the results of the two operation conditions separately, in the addition condition, participants performed significantly better under phonological distracting task than visuospatial distracting task; however, this difference was not significant in the multiplication task. The result that participants relied more on visuospatial processing than phonological processing in addition calculation is consistent with previous studies with simple calculation questions, which typically show that addition is lateralized to the RH, suggesting more involvement in visuospatial processing (Zhou et al., 2006; Zhou et al., 2007). This result was also in line with the Triple-code model proposed by Dehaene and Cohen (1995) that people tend to perform addition visually by manipulating numbers in visual Arabic form through the coordination of the analogue magnitude representation.

Nevertheless, in contrast to the left-lateralized processing observed in simple multiplication problem solving (Zhou et al., 2006; Zhou et al., 2007), suggesting the involvement of verbal processing, here we found that for complex multiplication calculation participants engaged more right-lateralized visuospatial or bilateral processing. This effect suggests that, instead of relying solely on the left-lateralized phonological/verbal strategy as reported in previous studies using simple one-digit multiplication (e.g. Zhou et al., 2006; Zhou et al., 2007), complicated multiplication problems involving two-digit numbers may rely more on the RH for visuospatial processing. This result also suggests that visuospatial processing may be particularly important for complicated arithmetic problem solving. A possible explanation for this phenomenon is that participants have utilized the visuospatial component to approximate the numerosity when the multiplication calculation involved large numbers. This processing was found to be lateralized to the RH, covering the frontal and parietal cortexes (Piazza, Mechelli, Price, & Butterworth, 2006).

On the other hand, from our findings, it seems that no matter how large or small the numbers are, mental addition may still rely more on visuospatial processing. This phenomenon may be because of the way we learn arithmetic (e.g. Dehaene & Cohen, 2007; Zhou et al., 2007). As mentioned earlier in the Introduction, children are encouraged to use procedural strategies such as counting and visual imagination of the quantities to perform addition, which relies more oh right-lateralized visuospatial processing. Our results suggest that this phenomenon may apply to both simple and complicated addition calculations. Future work will examine whether similar effects can be obtained with numbers of more than two digits.

In general, our results seem to suggest that the brain mechanism underlying arithmetic processing depends on the strategy use, which in turn, is driven by the context, such as the operation involved and whether it is a simple or complicated calculation that involves small or big numbers.

In the current study, we also found that under full attention, performance in addition calculation was significantly higher than that of multiplication, suggesting that although the time interval for response in multiplication trials was adjusted to 150% (4.5s) of the respective addition trials (3s), the multiplication task was still more difficult than the addition task to the participants. Indeed, the product of two double-digit numbers can be as 2 to 3 times larger than the sum of two double-digit numbers. To better understand the difference in the underlying cognitive mechanism between the two operation conditions, future studies can try to match the performance level of the calculation tasks.

In conclusion, in this study we have investigated the brain and cognitive mechanism underlying large number mental arithmetic processing using a dual-task paradigm. It was found that in addition calculation, consistent with previous studies examining simple arithmetic processing with single-digit numbers, participants engaged more right-lateralized visuospatial processing. In contrast, in multiplication calculation, different from previous studies showing more involvement of LH/verbal processing in simple multiplication with one-digit numbers, here we showed that participants relied more on visuospatial strategies in performing large number multiplication calculations. This effect may be related to the use of visuospatial processing to approximate numerosity when a multiplication calculation involves large numbers. Our results suggest that the cognitive mechanism involved in arithmetic processing depends on both the operation and the context. Future work will investigate arithmetic processing using a wider range of numbers with different operation signs to further examine specific points of strategy switch.

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References

Andres, M., Seron, X., & Oliver, E. (2005). Hemispheric lateralization of number comparison. *Cognitive Brain Research, 25*, 283-290.

Dehaene, S., & Cohen, L. (1995). Towards an anatomical and functional model of number processing. *Mathematical Cognition, 1*, 83–120.

Dehaene, S., & Cohen, L. (1997). Cerebral Pathways for Calculation: Double Dissociation between Rote Verbal and Quantitative Knowledge of Arithmetic. *Cortex, 33*, 219-250.

Desco, M., Navas-Sanchez, F. J., Sanchez-Gonzàlez, J., Reig, S., Robles, O., Franco, C., … Arango, C. (2011). Mathematically gifted adolescents use more extensive and more bilateral areas of the fronto-parietal network than controls during executive functioning and fluid reasoning tasks. *NeuroImage, 57*, 281-292.

Fernandes, M., & Guild, E. (2009). Process-Specific Interference Effects During Recognition of Spatial Patterns and Words. *Canadian Journal of Experimental Psychology, 63*, 24-32.

Fernandes, M. A., Wammes, J. D., & Hsiao, J. H. (2013). Representation of linguistic information determines its susceptibility to memory interference. *Brain sciences, 3*, 1244-1260.

Lee, K.-M., & Kang, S.-Y. (2002). Arithmetic operation and working memory: differential suppression in dual tasks. *Cognition, 83*, B63-B68.

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia. 9*, 97-113.

O'Boyle, M. W., Cunnington, R., Silk, T. J., Vaughan, D., Jackson, G., Syngeniotis, A., & Egan, G. F. (2005). Mathematically gifted male adolescents activate a unique brain network during mental rotation. *Cognitive Brain Research, 25*, 583-587.

Piazza, M., Mechelli, A., Price, C. J., & Butterworth, B. (2006). Exact and approximate judgements of visual and auditory numerosity: An fMRI study. *Brain Research, 1106*, 177-188.

Shallice, T., McLeod, P., & Lewis, K. (1985). Isolating Cognitive Modules with the Dual-Task Paradigm: Are Speech Perception and Production Separate Processes? *The Quarterly Journal of Experimental Psychology, 37A*, 507-532.

Stanescu-Cosson, R., Pinel, P., van de Moortele, P. F., Le Bihan, D., Cohen, L., & Dehaene, S. (2000). Understanding dissociations in dyscalculia: A brain imaging study of the impact of number size on the cerebral networks for exact and approximate calculation. *Brain, 123*, 2240-2255.

Yagoubi, R. E., Lemaire, P., & Besson, M. (2003). Different brain mechanisms mediate two strategies in arithmetic: evidence from Event-Related brain Potentials. *Neuropsychologia, 41*, 855-862.

Zago, L., Petit, L., Turbelin, M.-R., Anderson, F., Vigneau, M., & Tzourio-Mazoyer, N. (2008). How verbal and spatial manipulation networks contribute to calculation: An fMRI study. *Neuropsychologia, 46*, 2403-2414.

Zhou, X. L., Chen, C. S., Dong, Q., Zhang, H. C., Zhou, R. L., Zhao, H., Chen, C. H., Qiao, S. B., Jiang, T., & Guo, Y. (2006). Event-related potentials of single-digit addition, subtraction, and multiplication. *Neuropsychologia, 44*, 2500-2507.

Zhou, X. L., Chen, C. S., Zang, Y. F., Dong, Q., Chen, C. H., Qiao, S. B., & Gong, Q. Y. (2007). Dissociated brain organization for single-digit addition and multiplication. *NeuroImage, 35*, 871-880.