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Association Between Attention, Working Memory and Addition Performance
in Preschool and Early-school Children

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Abstract

Addition is a very important ability for children's academic achievement. This study examined the associations between attention, working memory, and simple addition in preschool and early-school children. A sample of 30 K3 and 22 Grade one students were recruited and their performance on sustained attention, and verbal and visuospatial working memory tests were measured. Preschool children were also asked to perform single-digit addition, while early-school children were required to perform both single-digit and double-digit additions. Pearson's correlation coefficients were computed between sustained attention and addition, and between working memory and addition in preschool and early-school children separately due to their attention and working memory are at different developmental stages. Results showed that there were no significant correlations between sustained attention and addition or between working memory and addition in early-school group. However, the correlations between verbal working memory and single-digit addition with a sum greater than ten, and between sustained attention and single-digit addition with a sum greater than ten were found to be significant in the preschool group. Since sustained attention was also found to be significantly correlated with verbal working memory in preschool children, a partial correlation on single-digit addition with a sum greater than ten was performed. The findings of this study suggested that only verbal working memory was partially correlated with single-digit addition with sum greater than ten in preschool children after controlling the effect of sustained attention.

Association Between Attention, Working Memory and Addition Performance in Preschool and Early-school Children

Mathematics is an essential skill in daily life transactions. It is also important for academic achievement (Sam & Ernest, 1997), as it sets the foundation for learning other subjects through improving our logical thinking and problem solving abilities, which predicts later reading and science achievement. (Claessens & Engel, 2013; O'Donoghue, 2002; The Hong Kong Education Bureau, 2017). Mathematics is a broad discipline including a wide range of skills varying from number sense or counting to calculus. Among these skills, addition is found to be a basic yet crucial skill in predicting mathematical learning and problem solving performance (Hiebert, et al., 1996; Nunes, Bryant, Barros, & Sylva 2012; Raghubar & Barnes, 2016). Despite the mathematics-related factors, such as number knowledge, that affect addition performance, other cognitive factors namely working memory (Espy et al., 2004; Gathercole & Pickering, 2000; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; McLean & Hitch, 1999) and attention (Carpenter & Moser, 1984; Resnick, 1989) were proven to be important contributors to our success in addition.

Working Memory

Working memory (WM) is a tripartite system which is responsible for simultaneous retaining and processing of information (Baddeley & Hitch, 1974). WM consists of the central executive component (CE), a domain-general system which coordinates and allocates attentional resources to the two domain-specific slave components. Phonological loop, one of the slave components, consists of a phonological store to temporarily hold and rehearse verbal information. They are known as verbal short-term memory (VSTM) and verbal working memory (VWM) respectively. Similarly, visuospatial sketchpad is for maintaining

and processing non-verbal and spatial materials. They are known as visuospatial short-term memory (VSSTM) and visuospatial working memory (VSWM) respectively (Baddeley & Hitch, 1974; Baddeley, 1986; Baddeley, 1996). WM is not a fixed ability, its capacity increases with age (Cowan, Aubuchon, Gilchrist, Ricker, & Sauls, 2011). Besides, research found that there is a change of the use of verbal strategies to encode visual information when children get older. For example, a study found that children aged below five mainly relied on their VSWM to encode visual materials, while ten-year-old children used verbal strategies to describe the details of the visual materials in order to memorize the information in verbal form (Hitch, Halliday, Schaafstal, & Schraagen, 1988). In other words, older children rely less on VSSTM and VSWM when information was presented in visuospatial modality.

Importance of working memory in addition. WM has been identified with central importance in addition performance among both preschool children (Espy et al., 2004) and school-aged children (Swanson, 2011). The amount of cognitive resources available for retaining and retrieving answers from previous steps in calculation may be limited by WM, which affects the accuracy of calculation (Barrouillet & Lépine, 2005). For example, when adding 37 to 45, one will add 7 and 5 first and get a sum of 12, the “1” in the sum 12 will be retained in mind. Then one will add 3 to 4, the “1” will be carried over in order to get the total (Berg, 2008; Brainerd, 1983; Nunes et al., 2012). Research also found that children used different strategies including finger counting and long-term memory retrieval in addition (Geary, Hoard, Nugent, & Bailey, 2012; Paul & Reeve, 2016; Raghubar, Barnes, & Hecht, 2010). There is a shift of strategies across development in solving addition problems from object counting, to finger counting and verbal counting, then to long-term memory retrieval (Carpenter & Moser, 1984; Geray et al., 2004; Siegler & Shrager, 1984). WM performance was found to be related with frequency and accuracy of use of addition strategies (Barrouillet & Lépine, 2005; Geary et al., 2004).

Importance of VWM and VSWM in addition. Both VWM and VSWM are found to be related to addition performance in preschool and early-school children (Logie, Gilhooly, & Wynn, 1994; McLean & Hitch, 1999). A study investigated the relationships between VWM, VSWM and mathematics achievement in preschool and early-school children showed that mathematics achievement of preschool children had a close association with VSWM, while that of early school children was closely related to their VWM (Rasmussen & Bisanz, 2005). Although both WM are correlated to addition performance, previous studies in adults found that VWM and VSWM play different roles in different types of addition problems that vary in number of digits and whether it involves carrying. In single-digit addition, there is no significant difference between the role of VWM and VSWM as the sum can be obtained directly by finger counting or memory retrieval (Hecht, 2002). In multi-digit addition, VWM was used to retain problem information (Fürst & Hitch, 2000) and interim results through verbal rehearsal (Heathcote, 1994), while VSWM was related to number alignment (Trbovich & Lefevre, 2003) and the use of counting strategies when performing multi-digit addition (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Hubber, Gilmore, & Cragg, 2014). For addition with carrying, VWM has been found to have a role in storing information of the number to be carried in addition problems regardless of the number of digits involved (Fürst & Hitch, 2000; Noël, Désert, Aubrun, & Seron, 2001). Besides, Kyttälä and Lehto (2008) found that VSWM was involved in accuracy when solving addition problems with carrying.

Attention

Another cognitive factor that affects addition is attention. Attention is defined as the ability to focus on goal-relevant stimuli and ignore distractors at the same time (Lavie, Hirst, De Fockert, & Viding, 2004). Sustained and selective attention are found rapidly developing in preschool and early-school children and they set the foundation for the development of

other types of attention namely shifting and divided attention (Hanania & Smith, 2010).

Selective attention is the ability to search for a particular stimulus and filter out distracting information (Evans & Preston, 2011) and was proven to be rapidly developing in children aged four to seven (Jones, Moore, Amitay, Eccles, & Jacquelynne, 2015). Sustained attention, which is defined as the ability to maintain focus on a particular task over an extended time period (Betts, McKay, Maruff, & Anderson, 2006), rapidly develops in preschool and early-school children, but its development slows down after middle childhood (Betts et al., 2006; Klenberg, Korkman, & Lahti-Nuuttila, 2001; Loher & Roebbers, 2013).

Importance of sustained attention on addition. Correlational studies found that sustained attention was positively correlated with mathematics performance in which single-digit addition was involved among both preschool and school-aged children (Anobile, Stievano, & Burr, 2013, Steele, Karmiloff-Smith, Cornish, & Scerif, 2012). Researchers suggested that sustained attention was required in maintaining focus during alignment of digits when performing multi-digit addition (Bull, Espy, & Wiebe, 2008; Klahr, Langley, & Neches, 1987). In contrast, recent researches have proven that selective attention had no significant correlation with mathematics performance in school-aged children. Metallidou, Malegiannaki, Eleni, and Kiosseoglou (2016) found an insignificant correlation between selective attention and mathematics performance in Grade two to six children, which was consistent with the insignificant correlation between selective attention and calculation accuracy found by Commodari and Di Blasi (2014). It suggested that sustained attention plays a more important role in mathematics learning. Unfortunately, limited comprehensive research focused on the importance of sustained attention on specific types of addition (with or without carrying), in either preschool or early-school children. Therefore, sustained attention has been chosen to be the focus of this study.

Mathematical Learning in Hong Kong

Children in HK learn mathematics at an earlier age than their peers in developed countries. Information shows that in the United States (The Government of the United States of America, 2015), preschool children begin to learn to solve addition problems within ten, and children in the United Kingdom (The Government of the United Kingdom, 2014) only start learning addition in Grade one. In HK, although the guideline from the Education Bureau stated that preschool children should only learn counting and number sequencing but not addition (Education Bureau, 2006), most of the HK preschool children have already learned simple addition either through formal education in nursery/kindergarten or taught by parents informally. Among older children, four-digit addition is taught in Grade four in both the US and the UK, however it has been already taught in Grade three in HK (Education Bureau, 2002; The Government of the United Kingdom, 2014; The Government of the United States of America, 2015). These show that HK children start to learn simple and advanced addition earlier than their peers in other developed countries (Browne & Wong, 2017; Education Bureau, 2006).

A recent study investigated teachers' expectations on students' mathematics abilities in HK and the UK. The authors reported that some HK nursery teachers expect children as young as two-year-old to be able to solve single-digit addition with a sum within ten. In addition, all teachers in HK would expect five-year-old to six-year-old children are able to solve single-digit addition with a sum greater than ten, while only about 43% of the teachers in UK would expect their same aged students are able to do the same level of addition (Browne & Wong, 2017). These findings show that not only children in HK learn mathematics earlier than their peers in other countries, but also teachers in HK have a "higher" expectations on their young students' mathematics abilities than their counterparts in other nations.

The Present Study

Both WM and attention mentioned above are important for addition performance, and children in HK start to learn addition at a very young age. Therefore, it is of interest to investigate the associations between WM, attention and addition performance in a sample of young children who are in a stage of rapid development of both attention and working memory in this study. Based on the difference in (1) addition learning between HK and Western children, (2) developmental stage and (3) education level, we divided the children into two groups (i.e., the Preschool group (K3 children) and the Early-school group (Grade one children)).

There were two major objectives in the present study, they were as followed:

1. We investigated the associations between working memory (i.e. VSTM, VSSTM, VWM and VSWM) and addition (i.e. single-digit and double-digit) performance in Preschool and Early-school children. We hypothesized that there were significant positive correlations between both VSWM and VWM and double-digit addition with carrying in Early-school group, and between VSWM and single-digit addition with a sum greater than ten in Preschool group.
2. We investigated the associations between attention (i.e. sustained attention) and addition (i.e. single-digit and double-digit) performance in Preschool and Early-school children. We hypothesized that there were significant positive correlations between sustained attention and single-digit addition in Early-school and Preschool groups, and between sustained attention and double-digit addition in Early-school group.

Methods

Participants

52 children (26 boys and 26 girls) studying in different local mainstream schools were

recruited through convenience sampling. Participants were included in this study based on three selection criteria: (a) children attending K3 and Grade one; (b) children receiving mainstream education in HK since kindergarten and; (c) children with basic addition skills. Children with special educational needs, for example autism, were excluded. Parental consent was obtained prior to data collection. This study has obtained the ethics approval from the Human Subjects Ethics Review Panel of the Hong Kong Polytechnic University.

Procedures

All participants were assessed individually by two undergraduate students who received training on tests administration. All testing was conducted in a quiet room at the Hong Kong Polytechnic University. Parents were asked to complete a consent form and a questionnaire to collect their demographic data before testing on their child. Child had to follow the same sequence to complete tasks on measuring attention, addition performance, and lastly WM. Short breaks were provided in-between sessions if needed. All measures were administered in a single session which lasted for approximately two to two-and-a-half hours.

Measures

Working memory. The Automated Working Memory Assessment (AWMA, Alloway, 2007) is a standardized computerized tool to assess WM performance of children. Standard score of each subtest are generated by the computerized program. In this study, two subtests were chosen to assess each type of working memory, therefore, a total of eight subtests were conducted to measure children's WM. Digit recall and non-word digit recall were conducted to assess children's VSTM while counting recall and backward digit recall were conducted to assess VWM. VSSTM was assessed by dot matrix and block recall and VSWM was measured by odd-one-out and spatial recall. All verbal English subtests were being translated

to Cantonese by the tester during administration. All the subtests show a steady increase in difficulty.

For convergent validity, moderate correlation was found between AWMA and other WM assessment battery, such as Word Order ($r = 0.64$). For reliability, a high internal consistency, with Cronbach's α for each subtest ranges from 0.88 to 0.95, was found in all the subtests (Alloway, 2009).

Attention. Test of Everyday Attention for Children, Second Edition (TEA-Ch2; Manly et al., 2016), a standardized clinical battery, was used to assess children's sustained attention. TEA-Ch2 Junior Form version, designed for children aged five to seven, was used in this study. Barking, Hide and Seek Auditory (HSA), Simple Reaction Time (SRT) and Sustained Attention to Response Test (SART) were administered to assess children's sustained attention. Scaled score of each test and a sustained attention index were generated by the computerized program upon completion. TEA-Ch2 Junior Form has acceptable composite reliability for sustained attention index, with mean equals to 100 and one SD equals to 15 (reliability=0.837). Construct validity is strong and the internal consistency is between 0.55 and 0.90 (Manly et al., 2016).

Addition Test. Due to the lack of local standardized assessments to measure addition performance in children in this specific age range, a set of single-digit and double-digit addition questions were prepared by the investigators based on the syllabus for mathematics suggested by the HK Education Bureau and other mathematics exercises widely used locally. After reading the curriculum guideline and the content of the textbooks on the Recommended Textbook List from Education Bureau (2017), we expected K3 children to be able to solve single-digit addition with a sum within ten and Grade one children are capable of solving double-digit addition without carrying. A pilot test was performed on four children (two K3 students and two Grade one students) and it showed that the test designed by the investigators

was able to differentiate the addition performance between two K3 and two Grade one children. Investigation on reliability and validity of the test was not possible due to limitation of resources in the current study. In the addition test, single-digit addition is measured by one-digit-to-one-digit addition and double-digit addition by two-digit-to-two-digit addition.

The Addition Test is a paper-and-pencil test which consists of two sections: single-digit and double-digit addition. All the questions were presented horizontally in an ascending order of difficulty level based on the number of digits and times of carrying involved (Ng, 2012). The test starts with single-digit addition with a sum within ten (e.g. $4+3=7$), proceeding to single-digit addition with a sum greater than ten (e.g. $5+6=11$), then to double-digit addition with or without carrying (see Appendix A). There are four levels of difficulty with eight questions for each level, making a total of 32 questions. Preschool children were required to finish the entire single-digit addition section (i.e. they have to complete 16 questions only in total), while early-school children had to do both sections (i.e. they have to complete 32 questions in total).

Children were given a set of printed test and encouraged to finish it accurately within five minutes to prevent the participants from spending too much time on some questions. If participants indicated any difficulty to continue the test, or gave a wrong answer for three consecutive questions, the test would be discontinued. No calculator was allowed and calculation strategies and use of draft were not restricted but were recorded down by the investigators. Number of questions attempted, correct answers and total time used to complete the tests or the time when a discontinue rule was met were recorded.

Data Analyses

Data were analyzed using the Statistical Package for Social Science version 23 (SPSS). Pearson's correlation coefficients were computed to examine whether sustained attention is

correlated with better performance in addition. Sustained attention was operationalized by sustained attention index in TEA-Ch2. Addition performance was indicated by the results in the addition test. Number of correct answers of single-digit addition with a sum within ten and greater than ten were inputted for analyses separately, so as for double-digit addition.

Pearson's correlation coefficients were computed to examine whether VWM or VSWM contributes to better addition performance. As not all subtests in AWMA were performed, the four WM variables were operationalized by the mean of the standard scores in the two corresponding subtests. Addition performance was operationalized by inputting the Number of correct response.

Two separate sets of Pearson's correlation coefficients were conducted to examine the relationship between WM, sustained attention and addition performance variables for Preschool group ($n=30$) and Early-school group ($n=22$). Significance was set at 0.05. Our findings interpretation was guided by Cohen's (1992) effect size scale (i.e. small effect size is $r = 0.10$; medium effect size is $r = 0.30$; large effect size is $r = 0.50$).

Results

Descriptive Statistics

Table 1 shows the demographics of all participants. Most of the participants has learnt single-digit and double-digit addition and are ranked middle to upper 1/3 in class at school. Table 2 shows the means, standard deviations and range for all the measures. There was no significant difference in the means of VWM, VSWM, and sustained attention between the Preschool and the Early-school groups.

Table 1
Demographics of Participants (N=52)

Variable	<i>n</i>	%
Gender		
Male	26	50
Female	26	50
Education		
Preschool	30	57.7
Early-school	22	42.3
Addition knowledge learnt		
Single-digit	16	30.8
Double-digit	36	69.2
Remedial		
Mathematics	10	19.2
Others	22	42.3
None	20	38.5
Mathematics ranking at school		
Upper 1/3 of the class	17	32.7
Middle 1/3 of the class	32	61.5
Lower 1/3 of the class	3	5.8
Parent's level of education		
Secondary	26	50
University or above	26	50

Note. *N* = frequency; % = valid percent

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Table 2

Mean, Standard Deviation (SD), and Range of Participant's Performance on Years of Education, Verbal and Visuospatial Short-term Memory, Verbal and Visuospatial Working Memory, Sustained Attention and Addition Performance

Preschool Group (n=30)			Early-school Group (n=22)	
Variable	N	Mean (SD), Range	N	Mean (SD), Range
Years of Education	30	3.55 (.648), 2-5	22	4.52 (.626), 4-6
VSTM	30	113.833 (7.584), 92-127.5	22	111.5 (8.246), 96-125
VSSTM	30	116.033 (13.469), 92.0-140.0	22	116.591 (13.749), 88.5-137.5
VWM	30	117.533 (13.938), 88.0-140.5	22	119.318 (16.673), 93.5-145.5
VSWM	30	123.717 (11.069), 93.5-135	22	121.568 (8.973), 98-132
SA	27	119.593 (17.241), 76-145	22	122.455 (15.039), 89-145
SDA				
SDA (sum ≤10)	30	7.200 (1.270), 4-8	22	7.727 (.703), 5-8
SDA (sum >10)	30	5.400 (2.430), 1-8	22	7.5 (1.185), 3-8
DDA				
DDA (WOCA)	--	--	22	7.909 (.294), 7-8
DDA (WCA)	--	--	22	6.455 (2.064), 2-8

Note. VSTM = Verbal Short-term Memory; VWM = Verbal Working Memory; VSSTM = Visuospatial Short-term Memory; VSWM = Visuospatial Working Memory; SA = Sustained Attention; SDA (sum ≤10) = Number of correct answers for single-digit addition with a sum within 10; SDA(sum >10) = Number of correct answers for single-digit addition with a sum greater than 10; DDA (WOCA) = Number of correct answers for double-digit addition without carrying; DDA (WCA) = Number of correct answers for double-digit addition with carrying.

* $p < 0.05$. ** $p < 0.01$.

Correlations between Working Memory and Addition Performance

Pearson's correlation coefficients were computed to examine the correlations between WM and addition performance. Both skewness and kurtosis were insignificant to meet the normality criteria. For Early-school group, no significant correlation was found between both types of WM and double-digit addition with carrying (all $ps > 0.05$) (Table 3). For Preschool group, there was significant correlation found between VWM and single-digit addition with a sum greater than ten ($r = 0.422, p < 0.05$) (Table 4). The effect size was medium (Cohen, 1992). However significant correlation was absent between VSWM and single-digit addition with a sum greater than ten ($r = 0.115, p > 0.05$) (Table 4).

Correlations between Attention and Addition Performance

Pearson's correlation coefficients were computed to examine the correlations between attention and addition performance. Both skewness and kurtosis were insignificant to meet the normality criteria. For Early-school group, there was no significant correlation between sustained attention and double-digit addition (all $ps > 0.05$) (Table 3). For Preschool group, there was significant correlation between sustained attention and single-digit addition with a sum greater than ten ($r = 0.408, p < 0.05$) (Table 4). According to Cohen's (1992) criteria, the correlation indicated was of medium effect size.

Partial Correlation between Working Memory, Attention and Addition Performance

Since there was significant correlation found between VWM and addition performance and between attention and addition performance in the Preschool group, partial correlation coefficient was computed to examine the correlation between VWM and performance in single-digit addition with a sum greater than ten in Preschool Group only, when controlling the effect of sustained attention, and vice versa. After controlling the effect

of sustained attention, significant correlation was found between VWM and addition performance ($r = 0.492, p < 0.05$) (Table 5). However, no significant correlation was found between sustained attention and addition performance after controlling the effect of VWM ($r = 0.067, p > 0.05$) (Table 6).

Table 3

Correlations Among Verbal and Visuospatial Short-term Memory, Verbal and Visuospatial Working Memory, Sustained Attention and Addition Performance of Early-school Group

Variable	1	2	3	4	5	6	7	8	9
1. VSTM	--								
2. VSSTM	.413	--							
3. VWM	.437*	.583**	--						
4. VSWM	.117	.497*	.414	--					
5. SA	.161	.330	.447*	.003	--				
6. SDA (sum ≤10)	.193	-.007	-.067	-.072	-.060	--			
7. SDA (sum >10)	.253	-.152	.134	.274	-.334	.000	--		
8. DDA (WOCA)	.245	-.398	.171	-.043	-.216	-.126	.683**	--	
9. DDA (WCA)	.197	-.251	.011	.086	-.291	.188	.389	.542**	--

Note. VSTM = Verbal Short-term Memory; VWM = Verbal Working Memory; VSSTM = Visuospatial Short-term Memory; VSWM = Visuospatial Working Memory; SA = Sustained Attention; SDA (sum ≤10) = Number of correct answers for single-digit addition with a sum within 10; SDA (sum >10) = Number of correct answers for single-digit addition with a sum greater than 10; DDA (WOCA) = Number of correct answers for double-digit addition without carrying; DDA (WCA) = Number of correct answers for double-digit addition with carrying.

* $p < 0.05$. ** $p < 0.01$.

Table 4

Correlations Among Verbal and Visuospatial Short-term Memory, Verbal and Visuospatial Working, Sustained Attention and Addition Performance of Preschool Group

Variable	1	2	3	4	5	6	7
1. VSTM	--						
2. VSSTM	.245	--					
3. VWM	.082	.577**	--				
4. VSWM	.411*	.603**	.624**	--			
5. SA	.326	.608**	.605**	.573**	--		
6. SDA (sum ≤10)	-.097	.225	.280	-.056	.183	--	
7. SDA (sum >10)	-.036	.305	.422*	.115	.408*	.465**	--

Note. VSTM = Verbal Short-term Memory; VWM = Verbal Working Memory; VSSTM = Visuospatial Short-term Memory; VSWM = Visuospatial Working Memory; SA = Sustained Attention; SDA (sum ≤10) = Number of correct answers for single-digit addition with a sum within 10; SDA (sum >10) = Number of correct answers for single-digit addition with a sum greater than 10.

* $p < 0.05$. ** $p < 0.01$.

Table 5

Correlation Among Verbal Working and Addition Performance of Preschool Group with Controlling for Sustained Attention

Variable	1	2
1. VWM	--	
2. SDA (sum >10)	.492*	--

Note. VWM = Verbal Working Memory; SDA (sum >10) = Number of correct answers for single-digit addition with a sum greater than 10.

* $p < 0.05$.

Table 6

Correlation Among Sustained Attention and Addition Performance of Preschool Group with Controlling for Verbal Working Memory

Variable	1	2
1. SA	--	
2. SDA (sum >10)	.067	--

Note. SA = Sustained Attention; SDA (sum >10) = Number of correct answers for single-digit addition with a sum greater than 10.

* $p < 0.05$.

Discussion

In the present study, we examined the associations between WM, attention and addition performance in preschool and early-school children. Our findings showed that sustained attention and VWM were associated with better addition performance in Preschool group.

Early-school Group

In Early-school group, the absence of significant correlations between WM and all types of addition (Berg, 2008; McKenzie, Bull, & Gray, 2003; Rasmussen & Bisanz, 2005; De Smedt et al., 2009), and between sustained attention and all types of addition (Anobile et al., 2013; Fuchs et al., 2006) was inconsistent with previous findings. This suggests that the sample size of the Early-school group may be too small, resulting in a low power to show significance.

Moreover, the demands of working memory and sustained attention were believed to be reduced by the relatively low level of difficulty of self-derived addition test and the strategies used by early-school children. As observed, most of the early-school children used strategies learnt in school, for example drafting and marking down the digit to be carried.

75% of early-school children were observed to have used drafting, while 67% marked down the digit to be carried. This reduced the cognitive demand required in addition (Imbo & Vandierendonck, 2007), leading to small positive correlations observed between VWM, and double-digit with carrying, and between VSWM and double-digit with carrying, and between sustained attention and double-digit addition with carrying. Our observation of strategies used in Early-school group was not completely in line with the research by McKenzie et al. (2003), which proved that Grade two children in the UK relied more on visual strategies. In contrast, our Early-school group used more advanced strategies, which are usually taught in early school in HK. This shows an overall advancement in use of strategies in Early-school group comparing to previous studies.

Preschool Group

Working memory and addition performance. Our findings showed significant correlations between VWM and single-digit addition with a sum greater than ten in Preschool group. They are consistent with previous research that suggested a significant role of VWM in learning addition among both preschool and early-school children (Logie et al., 1994; McLean & Hitch, 1999), which found that phonological loop is a mediator in solving addition problems with a sum greater than 10 (Noël et al., 2001). Furthermore, numbers need to be read and interpreted as verbal materials through subvocal articulation in solving mathematics problems (Aiken, 1971; Logie et al., 1994). Children tend to rely on VSWM to solve novel addition problems and rely more on VWM when they become more familiar with addition problems. This explains why VWM instead of VSWM was significantly correlated with single-digit addition performance in preschool children.

Calculation of single-digit addition with a sum within ten is more automatized in preschool children compared to that of single-digit addition with a sum greater than ten (Van

de Weijer-Bergsma, Kroesbergen, & Van Lui, 2015). Therefore, they rely on long-term memory retrieval when solving single-digit addition with a sum within ten under an automatic process (Imbo, Vandierendonck, & Rammelaere, 2007; Siegler & Shrager, 1984). Conversely, single-digit addition with a sum greater than ten is more complicated (Ng, 2012) and it is not automatized in preschool children. This explains the significant correlation between VWM and single-digit addition with a sum greater than ten. Therefore, objective 1 was partially supported.

We found that Preschool group relied more on VWM instead of VSWM, which contradicted previous studies that showed preschool children rely more on VSWM when performing single-digit addition (Hitch et al., 1988; McKenzie et al., 2003; Rasmussen & Bisanz, 2005), and early-school children rely more on VWM to perform addition (Berg, 2008; De Smedt et al., 2009). Our findings and previous research showed differences in the presentation of questions and design of addition test in terms of range of sum and numbers involved, which may lead to variations in results (Van de Weijer-Bergsma et al., 2015). Therefore, our findings suggested an overall advancement in WM development in HK. This may help to explain the better overall mathematics performance of school-aged children in Asia cities like HK than in western developed countries (Leung 2006; Wei & Dzung, 2014).

Sustained attention and addition performance. Our findings showed significant correlation between sustained attention and single-digit addition with a sum greater than ten in Preschool group. Objective 2 is partially supported. Previous studies have also showed the precursory role of sustained attention in preschool children in learning mathematics, including addition calculation (Steele et al., 2012). However, no significant correlation was found between sustained attention and single-digit addition with a sum within ten in Preschool group. One possible explanation is the time required for completing the task. Calculations involving more steps require longer time to complete, therefore so, one needs to

maintain attention longer in calculations with multiple procedures. Addition with a sum greater than ten, which involves more steps, demands a higher level of sustained attention as it was required to monitor multiple steps calculation (Geary et al., 2004). Conversely, addition with a sum within ten requires lower level of sustained attention, explaining the insignificant correlation between sustained attention and addition with a sum within ten in Preschool group.

After controlling the effect of sustained attention, VWM was found to be significantly partially correlated with single-digit addition with a sum greater than ten in preschool children. We believed that the effect of sustained attention was masked by the strong correlation between sustained attention and WM ($r = 0.605$). WM and sustained attention were found to be closely related (Burns, Nettelbeck, & McPherson, 2009; Tillman, Bohlin, Sörensen, & Lundervold, 2009). CE of WM is responsible for allocating attentional resources (Baddeley & Hitch, 1974). Sustained attention and WM also shared functions in monitoring and integrating information (Barkley, 1997; Burns et al., 2009).

Limitations

Regarding the study design, the small sample size, especially in Early-school group, contributed to insufficient power to detect any significance. Second, other potential factors affecting addition performance, such as intelligence and processing speed, are also not being controlled in our study due to time and resources limitation.

Considering the design of our self-derived addition test, which is based on the curriculum of preschool and early-school children in HK, it lacks the sensitivity to differentiate addition performance of early-school children. Most of the early-school children could answer all addition questions with correct answers, leading to a ceiling effect. Such performance among children in Early-school group may result in a narrow range of data, thus

insignificant correlations between WM, sustained attention, and any specific types of addition were yielded. As reflected by the demographic statistics, most of the early-school children attend extra mathematics tutorial classes beyond school time. The use of strategies, which reduces cognitive demand, lead to difficulties in identifying the actual correlation between measured variables and addition performance. Besides, numbers are verbal materials, therefore visual presentation of our addition test may not be the best way to assess two WM aspects.

Conclusion

The present study suggested that VWM is related to addition performance in preschool children while no significant correlation was found in early-school children. The correlation between sustained attention and addition performance in preschool children is believed to be masked by the correlation between VWM and sustained attention. It is suggested that future study should involve a larger sample size together with control of other potential factors. A more comprehensive addition test should be employed. First, level of difficulty and numbers of questions should be adjusted to make sure that the test can differentiate the addition performance in both preschool and early-school children. Second, it is suggested to either restrict the use of strategies during test, or divide the sample into two groups to examine the effect of strategies usage on addition. Lastly, the presentation methods should be consistent with modalities of WM to be examined for a clearer picture of possible relationship between WM and addition of different presentation.

Appendix A.

A Sample Questions Set of the Addition Test

姓名: _____

請於時限 5 分鐘內盡可能快速及準確地計算下列各題。

- 1) $1 + 2 =$ _____
- 2) $7 + 1 =$ _____
- 3) $3 + 2 =$ _____
- 4) $4 + 4 =$ _____
- 5) $1 + 4 =$ _____
- 6) $4 + 3 =$ _____
- 7) $3 + 6 =$ _____
- 8) $2 + 4 =$ _____
- 9) $3 + 8 =$ _____
- 10) $9 + 9 =$ _____
- 11) $5 + 5 =$ _____
- 12) $8 + 7 =$ _____
- 13) $4 + 7 =$ _____
- 14) $9 + 8 =$ _____
- 15) $6 + 9 =$ _____
- 16) $5 + 6 =$ _____
- 17) $12 + 25 =$ _____
- 18) $47 + 32 =$ _____
- 19) $58 + 41 =$ _____
- 20) $80 + 13 =$ _____
- 21) $22 + 34 =$ _____
- 22) $31 + 56 =$ _____
- 23) $65 + 22 =$ _____
- 24) $72 + 26 =$ _____
- 25) $26 + 49 =$ _____
- 26) $39 + 38 =$ _____
- 27) $66 + 15 =$ _____
- 28) $73 + 18 =$ _____
- 29) $18 + 35 =$ _____
- 30) $27 + 28 =$ _____
- 31) $54 + 26 =$ _____
- 32) $73 + 18 =$ _____

算草欄

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