The Role of Components of Working Memory and Age in Predicting Mathematical Performance in Primary School Children

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Abstract

Adequate performance in mathematics is crucial not only during an individual's time in education but continues to be important throughout the course of their life. In order to detect potential later difficulties in mathematics, understanding mechanisms behind mathematical performance is key. Working memory is strongly suggested to be one of these contributing factors, yet it is not clear if all components of working memory are involved, and/or to what extent each component plays in this working memory-mathematical performance relationship. In addition to this, findings are also inconclusive on the role that age may have in this predictive association. Accordingly, this study aimed to explore the predictive role of the components of working memory (the executive functions inhibition, shifting and updating, the visuospatial sketchpad and the phonological loop) in mathematical performance, as well as how age may act as a moderating factor. The study tested primary school children from one international school and three Dutch schools in The Netherlands, and components of working memory were measured by various tests, including work-recall backwards and word-recall forwards, through the computer program e-prime. In variation to previous findings, the results illustrated that all components of working memory, except that of the visuospatial sketchpad, were non-significant in predicting mathematical performance. Moreover, age did not prove to be a moderating factor in this relationship for any of the working memory components. The non-significant results are suggested to be due to a result of a multitude of reasons, such as variations in the sample, with it involving students from one international school and three Dutch schools, and hence second language of students - particularly in the international school - may have compromised test performance.

Working Memory and Age in Predicting Mathematical Performance

Mathematical performance is required for many daily activities that children partake in throughout their school years, and for the rest of their lives. It is therefore crucial to understand the mechanisms behind this performance as well as the predictive indicators of performance. Researchers suggest that working memory and its executive functions (inhibition, shifting and updating) play a key role in the development of mathematical skills (Bull, Espy & Wiebe, 2008; Geary, 2011; Swanson & Kim, 2007). However, it is unclear which working memory components contribute to mathematical performance, as well as whether or not there are age-related changes. Hence, the aim of this study is to explore this working memory-mathematical performance relationship through the different components of working memory, as well as if age plays a moderating role in this.

Baddeley's Model of Working Memory

Baddeley's model of working memory helps to clarify the general framework of working memory, which describes a central executive system that interacts with two subsystems: the speech-based phonological loop and the visuospatial sketchpad (Baddeley &Hitch, 1974; Baddeley & Logie, 1999). The phonological loop temporarily stores verbal information and items are maintained in the phonological store via the process of articulation. The visuospatial sketchpad stores visuospatial information for brief moments and is involved in generating and manipulating mental images. The central executive's role in the cognitive system is to coordinate activity and to devote its resources to augmenting the amount of resources that the two subsystems can hold (Baddeley & Hitch, 1974; Baddeley & Logie, 1999). The central executive is made up of the executive function sub-components of: updating, shifting and inhibition. Updating involves monitoring incoming information and revising the current contents of the working memory by modifying it to more recent and relevant information. Shifting includes shifting attention and cognitive control between tasks while overcoming interference from previous stimuli. Finally, inhibition involves purposefully suppressing and overriding dominant responses while ignoring extraneous information (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000).

Working Memory and Mathematical Performance

Regarding mathematical performance, there are inconsistencies in its reported relationships with the central executive system and its subsystems, and even if the components of working memory are involved at all. Seemingly consistent is that the central executive tends to play a larger role in more complex and unfamiliar tasks, and its importance lessens when task performance becomes more long-term and automatic (Geary, 2011). Yet, there are also various findings regarding the significance of the components of working memory in predicting mathematical performance. For instance, one study with pre-schoolers found that inhibitory control proved to be the key aspect of working memory employed (Blair & Razza, 2007). Then, in a meta-analysis the strongest correlations with mathematical performance proved to be: verbal updating, followed by the visuospatial sketchpad and then visuospatial updating (Friso-van den Bos, Van der Ven, Kroesbergen & Van Luit, 2013). Different again are components not playing a role in this relationship, for instance in a study where both visuospatial and verbal memory were found to predict performance on mathematical tests in the tested 7-year-olds, but then solely visuospatial memory played a predictive role in the tested group of 8-year-olds (Alloway & Passolunghi, 2011). To gain clarity on this, the current research explores each component of working memory (the three central executive functions, phonological loop and visuospatial sketchpad) in if they each predict mathematical performance.

Role of Age in Working Memory and Mathematical Performance

Various studies exploring the role of age and mathematical performance conclude that younger children rely greater on their visuospatial sketchpad for learning and applying new mathematical skills and once these skills have been learned, older children tend to rely more on their phonological loop (Andersson & Lyxell, 2007; De Smedt, Janssen, Bouwens, Verschaffel, Boets & Ghesquière, 2009; Van der Ven, Van der Maas, Straatemeier & Jansen, 2013). With regards to this relationship of a decrease of one's usage of visuospatial working memory when performing mathematical tasks as one grows older, there are suggested to be three explanations for this dependence (Van der Van et al, 2013). Firstly, in line with development, younger children seem to employ more visuospatial representations and strategies of the mathematical tasks at hand - such as having a number line and using their fingers to count -, while the answers of older children grow to be more verbally memorised. Secondly, novelty may explain this shift, as it is suggested that visuospatial working memory is used by individuals of all ages when encountering novelty problems, and once the tasks become more familiar they become verbally memorised. Thirdly, mathematical domain specificity may explain this relationship, where the usage of visuospatial working memory with mathematics is dependent upon the mathematical domain.

There is also evidence that even between executive functions, that age plays a moderating role. Generally, inhibition appears to be more employed by younger children than older. This is suggested to be due to perhaps inhibition developing earlier than other working memory components, or because younger children may be more susceptible to distractions in their environment, hence the demand for the emergence of inhibition (Huizinga & van der Molen, 2007; Senn, Espy, & Kaufmann, 2004).

Overall, despite the various perspectives, the problem still comes down to the same notion of understanding the relationship between working memory and mathematical achievement, as well as what role age may play as a moderator. Some studies yield the conclusion that age does act as a moderator while others conclude that is does not, or perhaps that novelty is the moderating factor instead (Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; Van der Van et al., 2013). There is also further discrepancy in that different working memory components may be increasingly or decreasingly important with age, and thus further clarification on this topic is required.

Current Study

Due to the discrepancies in findings – as mentioned above -, further investigation is important, particularly as a better understanding of the roles that working memory and age play in predicting mathematical performance may aid in preventing or ameliorating potential long-lasting problems in mathematics. For instance, through perhaps interventions involving the training of working memory if its components prove to play a significant role. This leads to the final research question that explores: to what extent do the components of working memory (central executive functions of inhibition, shifting and updating, visuospatial sketchpad and phonological loop) predict mathematical performance in primary school children, and does age account for differences in this relationship? Firstly, this research explores the components of working memory separately, so if 1) the three central executive functions, 2) the visuospatial sketchpad and 3) the phonological loop predict mathematical performance in primary school children. Despite discrepancies, generally prior research concludes that these components all play a predicting role in this relationship (Bull, Espy & Wiebe, 2008; Geary, 2011; Swanson & Kim, 2007). Hence, it is hypothesised that there will be an association between each of these working memory components and mathematical performance through a unique explained variance. As for the latter aspect of the research question, regarding the moderating role that age may play, it is further hypothesised that age will be a moderating factor in the relationship between components of working memory and mathematical performance in primary school children (see. Figure 1). This is based on the results of most studies that conclude there is a moderating role, most typically in that visuospatial working memory is more greatly employed at a younger age, and verbal working memory more in later stages (Andersson & Lyxell, 2007; De Smedt, Janssen, Bouwens, Verschaffel, Boets & Ghesquière, 2009; Van der Ven, Van der Maas, Straatemeier & Jansen, 2013).

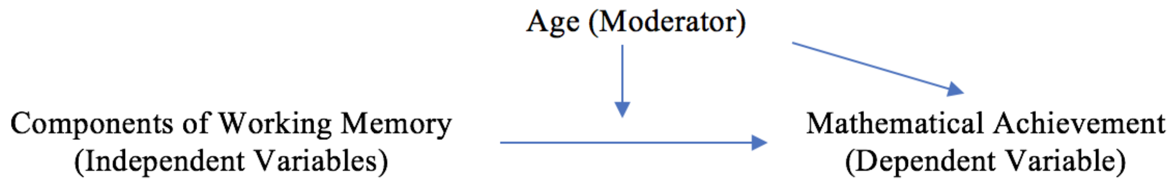

Figure 1. The Moderating Role of Age in Current Study

Method

Participants

The research involved primary students from four different schools (three Dutch schools and one international school) in The Netherlands. Furthermore, Cito scores of the Dutch students and progress test in maths scores (PTM) of the international students were requested from the schools in order to gain insight into the children's academic performance. One school was contacted per thesis student, in order to determine if they would be willing to cooperate in our research, and once the school confirmed, the children's parents were sent letters in order to allow their child to participate. On top of this, an ethical committee approved this research prior to the testing taking place. Per Dutch school, 30 children were tested, and 16 from the international school, all from grades 3-6. The mean age of the students was 8.04 years (*SD* = 1.13), and there was a 50:50 split in the total 98 boys and girls.

Procedure

The students were tested with several tasks that were executed on a laptop with the computer program e-prime, each of which are discussed in detail below. Along with these tests, the children also completed number-line tasks, and their patterning skills were investigated, yet these results were not required in this research paper. Each child was tested individually in a quiet room in two sessions of 25 minutes. They were given general praise throughout the tasks.

Measuring Instruments

Dot-Matrix. The dot-matrix is from the Automated Working Memory Assessment (AWMA), and in this study was used as a measure for the visuospatial sketchpad of participants (Alloway, 2007). The procedure includes the child observing a 4x4 grid on the screen, and there is a cross in one of the squares. The child must locate this cross and remember its location once it disappears. With every correct answer, one point is awarded, and following four correct trials they move to the next level, in which the series length increases by one. If the child succeeds in each level, they proceed until a series length of 5 crosses is obtained. In the case of a child incorrectly answering 3 trials within one level, the game will terminate. In order to measure the scores, the total number of correctly answered trials was used. The AWMA is described as having a good internal reliability and adequate psychometric properties for the use of a diagnostic tool (Alloway, 2007; Alloway, Tracy, Gathercole, Susan, Kirkwood, Hannah, Elliott, & Julian, 2008).

Odd-One-Out. The odd-one-out task was also taken from the AWMA (Alloway, 2007). This task was used to measure the central executive subcomponent of ‘updating’, along with the Word Recall Backwards test. In this test, 3 shapes appear on the computer screen and the child must point out the shape that differs from the other two. After the shapes have disappeared, the child must also recall the location of the shape that was the odd one out. The scoring as well as the rules for progressing to each level are the same as those of the dot-matrix.

Word Recall Backwards. Again, the word recall backwards was taken from the AWMA (Alloway, 2007). As stated above, this test was used along with the odd one out test to measure the central executive subcomponent of ‘updating’. This test includes a child listening to lists of at least 2 words and having to verbally repeat them in reverse order. To score, each correctly repeated list is rewarded a point, and progressing through each level is the same as that of the dot-matrix.

Word Recall Forwards. The word recall forwards task was taken from the AWMA too and was employed to measure how the phonological loop functions (Alloway, 2007). Similarly to the word recall backwards, the child must listen to words and repeat them, but has to rehearse them in the same order that they hear them. The scoring and progress through the levels is identical to than in the dot-matrix.

Flanker Inhibition. The flanker inhibition task was established by Eriksen and Eriksen (1974). This was employed to measure the functioning of the central executive subcomponent of ‘inhibition’. The test included there being a fish on the screen that either faced left or right, and the child was instructed to press the allocated letter on the keyboard depending on the direction of this fish (z=left, m=right). Inhibition was tested when there was more than one fish on the screen, and the child had to only indicate the direction that the fish in the centre was facing. The scores of the child are calculated by subtracting the reaction time of congruent answers (fish in the same direction) from the reaction time of incongruent answers (fish in different directions). The 1974 study concluded that response times were significantly greater in the incongruent conditions than the congruent conditions, with good test-retest reliability and internal consistency (Eriksen & Eriksen, 1974).

Flanker Shifting. The flanker shifting task is part of the same flanker task established by Eriksen and Eriksen (1974), and is based on the principles of the Dimensional Change Card Sorting Test (Zelazo, 2006). This task was employed in the research as a measure for the functioning of the central executive subcomponent of 'shifting'. This task followed on from that of the flanker inhibition one described, but now the child has to switch their response strategy. When a picture of food appears on the screen, the child must respond according to the direction of the fish in the middle, while when grass appears on the screen, the child must rather respond to the direction that the flanking fish are facing. To calculate the scores, the number of correctly sorted shifting items was used.

Mathematical Performance. Mathematical performance was measured by using end-of-year mathematical scores of the children. For the students from the Dutch schools, this included using their ability scores (vaardigheidsscores) from their Cito tests. These were standardised so that children in each grade had an average score of 0. As for the students from the international school, their mathematical achievement was measured by their PTM scores. Because these scores are already standardised, these scores were rather scaled down to the standardised ability scores by dividing each score by 15 and subtracting the grade average from these scores. The reliability of the Dutch Cito scores is said to be between 0.86-0.95 (Hop, Janssen, & Engelen, 2016; Jolink, Tomesen, Hilte, Weekers, & Engelen, 2015). As for the PTM, this has been standardised on around 35,000 pupils, and is hence described to be reliable and accurate (Progress Test Series, n.d.).

Data Analysis

This study employed a cross-sectional design, where the task results per student were compared to their mathematical performance. Analysis involved employing a multiple regression for exploring the measures of the components of working memory and their roles in predicting mathematical performance. Furthermore, to explore the moderating role of age in these relationships, a moderation analysis was conducted. Some data was missing at random for instance if a child was sick, or they could not complete all tests in the 25 minute sessions, of which explains the differences in the degrees of freedom between models.

Results

Descriptive statistics of the test scores measures (independent variables), the standard mathematical performance score (dependent variable) and age (moderator) are reported in Table 1. All measures were approximately normally distributed, except those of Flanker

Inhibition, which reflected a positive skew and high kurtosis. In order to normalise this measure, outliers were filtered out by calculating the interquartile range (IQR) of the Flanker Inhibition scores, using a step of 1.5*IQR and removing those scores above the 3rd quartile and below the 1st quartile. This removed the skewness and kurtosis, the number of cases left was 86 (from 97). Other assumptions were also checked, for instance autocorrelation and multicollinearity, and these assumptions were met. Table 2 displays the correlations between measures. It should be noted that in this correlation and onwards analysis, Flanker inhibition scores have been reversed, as this was the only measure with scores in the opposite direction as the rest. As the maximum score for Flanker Inhibition is indicated as being 2221.08, the reversed score was the students' score subtracted from this maximum score. As the correlation table displays, none of the measures were significantly correlated with Flanker inhibition. In addition, standardised mathematics scores were not significantly correlated with Word recall backward and Flanker shifting, Word recall backward was not significantly correlated with Flanker shifting, age was not significantly correlated with Flanker Inhibition nor standardised mathematics scores, and Word recall forward was not significantly correlated with dot-matrix. Apart from these, all other correlations were significantly correlated.

Table 1.
Descriptive Statistics of Age, Working Memory and Mathematical Performance Measures

Variable	*N*	Mean	*SD*	Min	Max	Skewness	Kurtosis
Age	98	8.04	1.13	6	10	-.16	-1.00
Dot-Matrix	98	16.56	3.48	5	24	-.40	.17
Odd-One-Out	97	13.99	3.38	5	20	-.08	-.09
Word Recall Fwd	93	15.95	2.61	10	22	.02	-.67
Word Recall Bwd	93	7.05	2.36	2	13	.31	-.30
Flanker Shifting	97	15.20	3.49	6	19	-.86	-.42
Flanker Inhibition	97	149.05	389.18	-924.83	2221.08	2.26	9.86
Standardised Math Score	98	<.001	.06	-2.23	2.01	.04	-.69

Note. Fwd = Forward. Bwd = Backward

Table 2.
Correlations between Age, Working Memory and Mathematical Performance Measures

	1	2	3	4	5	6	7	8
1. Age	1							
2. Dotmatrix	.46**	1						
3. Odd-One-Out	.52**	.58**	1					
4. Word Recall Fwd	.23*	.19	.34**	1				
5. Word Recall Bwd	.43**	.30**	.36**	.16	1			
6. Flanker Inhibition	-.02	.09	-.08	-.05	.07	1		
7. Flanker Shifting	.40**	.28**	.32**	.18	.22	-.01	1	
8. Standardised Math Score	-.01	.33**	.26*	.26*	.19	.02	.20	1

Note. Fwd = Forward. Bwd = Backward. $*p < .05$; $**p < .01$.

Because the test scores of the independent variables that would represent the central executive did not all load onto one factor, the subcomponents shifting, inhibition and updating were explored separately in predicting mathematical performance. Thus, only the scores of Word recall backwards and Odd-One-Out were combined by adding them together to represent the subcomponent of Updating, as these scores did load onto a single factor, with each additional factor having an eigenvalue smaller than 1. Table 3 displays the summaries of the multiple regression models 1 and 2, with the former including age and the latter excluding it. Table 4 presents the multiple regression statistics of the measures in these two models in predicting mathematical performance. It can be seen in model 1, with age included, that age as well as the scores from the dot-matrix and flanker shifting are statistically significant in predicting mathematical performance. Yet, when age was removed in model 2, solely the dot-matrix score significantly predicted mathematical performance and no longer the flanker shifting scores.

Table 3.

Multiple Regression Model Summary for Variables Predicting Mathematical Performance

Model	R^2	*F*	*df1*	*df2*	*p*
1 (With Age)	.26	4.41	6	74	<.001
2 (No Age)	.18	3.12	5	75	.01

Table 4.

Multiple Regression Statistics for Variables Predicting Mathematical Performance

Model		*B*	*SE (B)*	*β*	*t*	*p*
1	Age	-.33	.11	-.39	-2.98	.01
	Dot-Matrix	.09	.04	.33	2.61	.01
	Word Recall Fwd	.07	.04	.19	1.81	.08
	Flanker Shifting	.07	.03	.24	2.14	.04
	Flanker Inhibition	.00	<.01	-.05	-.50	.62
	Updating	.06	.06	.16	1.13	.26
2	Dot-Matrix	.07	.04	.27	2.02	.05*
	Word Recall Fwd	.07	.04	.19	1.62	.11
	Flanker Shifting	.05	.03	.15	1.37	.18
	Flanker Inhibition	.00	.01	-.05	-.45	.66
	Updating	<.01	.06	<.01	.02	.99

Note. Fwd = Forward *=,047

In order to explore if age acted as a moderator in any of these relationships, all predictor variables were centered and moderation analysis for each interaction was run. Table 5 displays the findings of this moderation analysis for each predictor variable, with age as the moderator. As seen, in every second model where the interaction measure with age was included in the analysis, the increases in variance explained were not statistically significant.

Table 5.

Moderation Analysis with Age in Predicting Mathematical Performance

Model	*Predictors*	*B*	*SE(B)*	R^2 *Change*	*F Change*	*df1*	*df2*	*Sig F. Change*
1.1				.146	8.136	2	95	.001
	Age	-.17	.09					
	Dot-Matrix	.12	.03					
1.2				.010	1.114	1	94	.294
	Age	-.18	.09					
	Dot-Matrix	.12	.03					
	Age x DM	-.03	.03					
2.1				.063	3.035	2	90	.053
	Age	-.03	.09					
	WRF	.09	.04					
2.2				.000	.028	1	89	.867
	Age	-.03	.09					
	WRF	.09	.04					
	Age x WRF	.01	.04					
3.1				.043	2.121	2	94	.126
	Age	-.06	.10					
	F Shift	.06	.03					
3.2				.000	.026	1	93	.873
	Age	-.06	.01					
	F Shift	.06	.03					
	Age x F Shift	-.01	.03					
4.1				.001	.029	2	94	.971
	Age	.02	.09					
	F Inhibit	<.01	.00					
4.2				.014	1.311	1	93	.255
	Age	.05	.09					
	F Inhibit	.00	.00					

	Age x F Inhibit	.00	.00					
5.1				.080	3.873	2	89	.024
	Age	-.14	.10					
	Updating	.14	.05					
5.2				.008	.742	1	88	.391
	Age	-.13	.10					
	Updating	.13	.05					
	Age x Updating	.04	.04					

Note. DM = Dot-Matrix. WRF = Word Recall Forward. F Shift = Flanker Shifting. F Inhibit = Flanker Inhibition

Discussion

This study aimed to gain insight into the role of the components of working memory in predicting mathematical performance in primary school children. This is important as previous results on this topic have been inconsistent, particularly with regards to understanding how age may act as a moderator in this. Furthermore, by understanding the predictive role of working memory as well as the moderating role of age, perhaps long-lasting problems in mathematics in one's academic and possibly later career can be prevented.

As for the research questions, the first posed if the central executive predicts mathematical performance in primary school children. From the multiple regression analysis, we can see that the three subcomponents of the central executive (inhibition, shifting and updating) were all non-significant in predicting mathematical performance when age was removed from the analysis, and when included, only that of shifting was significant. Notably, we see a negative relation between age and mathematical performance, which is unexpected as the mathematics tests were already standardised for age. A possible explanation for this may be due to variation in ability per year group and possibly the means per group in the grades with older students were lower as a result of these varying abilities of the students in each grade. As for hypothesis one, this is rejected as the three executive functioning functions were not significant in predicting mathematical performance, regardless of the inclusion of age. This does not support literature that concludes the central executive does predict mathematical performance, as well as growth in this domain (Cragg & Gilmore, 2014;

Koresbergen et al., 2009). Rather, perhaps these findings can be explained by other factors, such as some of the participants attending an international school that employed an English-based mathematics test system of the Progress Test in Mathematics, while the rest attended Dutch schools that used the standard Dutch mathematics tests of Cito. The variations in both the training of mathematical skills and testing of mathematical performance may hence explain this non-significance. This explanation is also suggested in a meta-analysis that found differing correlation coefficients depending on the country of origin (Friso-van den Bos et al., 2013). Alternatively, all three of these subcomponents may not have been independently statistically significant as they show both unity and diversity in their functioning (Miyake & Friedman, 2012).

Research question two explored if the visuospatial sketchpad plays a role in predicting mathematical performance. Dot-matrix was the measure for this component, and as displayed in the multiple regression results when age was both included and excluded, it was still significant in this relationship, thus hypothesis two is accepted. This finding was in line with literature that also found the visuospatial sketchpad to be a predictor in mathematical performance (Geary, 2011; Swanson & Kim, 2007). This may tell us something about the strategy usage that the students employ when their visuospatial sketchpad is engaged in a task, for instance if they used retrieval over counting methods this may have played a role in the significant results (Wu, Meyer, Maeda, Salimpoor, Tomiyama, Geary, & Menon, 2008). However, strategy use in different components of working memory requires further investigation.

The third research question investigated the association between the phonological loop and mathematical performance, which was measured by the word-recall forward test. This component proved not to be significant in predicting mathematical performance, regardless of age being included in the multiple regression analysis. Based on this, the third hypothesis is rejected. Generally, this is not in support of literature exploring this association, apart from a study that illustrated how the phonological loop was predictive of mathematical performance in 7-year-olds but then not predictive in 8-year-olds (Alloway & Passolunghi, 2011). Yet, in their study the non-significance was explained by age, with the older children employing their executive functioning resources more when performing visuospatial tasks over tasks measuring their phonological loop. We see in the following section that age does not explain phenomenon in the current study. While it has also been shown that there is no moderation effect between different types of information recalled (word, non-word or digit recall), and the correlation size with mathematical performance for phonological loop measures, in this study perhaps using word recall did have an effect as a result of second language (Gathercole, Pickering, Ambridge, & Wearing, 2004). For those in the international school, not everyone had English as their first language, and for some in the Dutch schools this was also the case with Dutch not being their first language. Perhaps the listening and verbal repetition aspects of this measure affected the children's' scores and hence impacted the results for this working memory component.

The final research question explored the role of age as a moderating factor in the working memory-mathematical performance relationship. From the results of the moderation analysis, it was seen that age was not a significant moderating factor between any of the working memory components and mathematical performance, and hence the fourth hypothesis is rejected. This is not in line with literature that suggests in general that younger children - due to knowing less about mathematical symbols and operations - would employ more working memory resources than older children who may be less engaged due to this information being stored in their long-term memory (Peng, Namkung, Barnes, & Sun, 2016). More specifically, age was not seen to be a moderating factor for any of the components of working memory, while literature suggests particularly between the visuospatial sketchpad and the phonological loop, that the former is more employed by younger students and the latter by older students when it comes to predicting mathematical performance (De Smedt et al., 2009). As this is not in line with literature, any of the following limitations with this study may explain why age did not act as a moderator.

Another possible limiting factor may have been due to the inclusion of one international school and three Dutch schools. As discussed, this could have affected the results in a number of ways, including the fact that the working memory tests were conducted in English rather than Dutch in the international school, and that the mathematical performance measures varied between these two types of schools. On top of this, having either Dutch or English as a second language may have affected the results. Related to this, it is known that other individual and school-based factors such as socio-economic status and school size play a role in one's mathematical achievement, next to components of working memory, and perhaps the combination of the one International and three Dutch schools emphasised the impacts of these factors (Kiliç, Çene & Demir, 2012). Due to a small sample size of international students in this study a comparison was not possible, but this issue could be addressed in future research by comparing this working memory-mathematical performance relationship of students at international schools versus Dutch schools in The Netherlands.

A further limitation was that although the Dutch Cito test is a national curriculum test and is a composite measure of mathematical performance, the PTM from the international school, is neither a national curriculum test, nor a composite measure and rather focuses on mathematical ability. For this reason, ability scores from the Cito test were used as a measure for the students in the Dutch schools as they were more comparable to the PTM ability measure. Yet, the test type that is shown to have the highest correlations with working memory are rather national curriculum tests and composite measures, possibly due to (just like the different components of working memory) requiring a variety of operations and updating sets of information (Best, Miller & Naglieri, 2011; Raghubar, Barnes & Hecht, 2010). Based on this, and in addition to the previous recommendation for future research, a comparison between Dutch and international students may be accurate when mathematical performance is measured by national curriculum tests in both cases, rather than being domain specific.

On the other hand, strengths of this study include that despite the variation in language, care was taken in the translation of all tests from the Dutch versions, and instructions between administrators were ensured to be identical. Furthermore, for the recordings of the word recall forwards and word recall backwards tests, it was ensured that a native speaker of English and Dutch recorded these, respectively. Regarding the investigation of the potential moderating factor of age, a strength of this study was that there was a large age-range of 6-10 year olds who participated.

Overall, this study did not find the components of working memory to play a predictive role in students' mathematical performance scores, aside from that of the visuospatial sketchpad. Moreover, age did not prove to act as a moderator in this working memory-mathematical performance relationship, for any of the working memory components. The mainly non-significant findings of this research could be explained by a multitude of reasons, ranging from a cross-over in the functioning of the central executive subcomponents to potential variations in language comprehension and mathematics teaching methodology and test designs between the students from the international and Dutch schools. Further research is still required to gain an understanding into exactly what role each component of working memory plays in predicting mathematical performance, as well as how factors such as age, educational background, test type and language may affect this relationship. In conclusion, this study illustrates how there are many more factors that may affect mathematical performance, other than working memory, and especially in a more globalising world, effects of a national versus international education are also important to explore.

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