Subcomponents of visuospatial working memory: Investigating the importance of order in sequential recall and its relationship with mathematics performance

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Visuospatial working memory (VSWM) is responsible for storing and manipulating visual and spatial information. Its predictive relationship with mathematics performance in children is well known, especially in younger children. Research has so far not investigated the role of order during recall in sequential tasks, following its subdivision into simultaneous and sequential VSWM. This paper investigates this, in order to determine its predictive power in predicting likely mathematics performance. Children (n=204) performed a battery of WM tasks, including those drawing on both visuospatial and phonological WM, followed by a standardised mathematics test. The data showed significant differences in the number of items recalled in each task, as well as significant correlations between many of the variables. Measuring did not correlate with simultaneous VSWM or block recall, nor did shape correlate significantly with block recall. The results will be further analysed to investigate more intricate relationships present within the data.

Keywords: visuospatial; verbal; working memory; mathematics performance

Introduction

Academic achievement is a subject which gathers increasing attention worldwide, however, the performance of children in mathematics in England comes under particular scrutiny. From statistics published by the Department for Education in 2017, 37.8% of all pupils in state-funded secondary schools, including hospital schools and alternative provision, did not achieve a grade A*-C or 9-4 in GCSE mathematics or an equivalent (Department for Education, 2017). Statistics such as these highlight the need for further research into the underlying factors that contribute to underachievement in mathematics at the school level. Current research is concerned with understanding the intricacies of the relationship between visuospatial working memory (VSWM) and mathematics in young children. By focusing on early influences of this relationship, it is hoped that impact will be long-term, taking a preventative approach rather than restorative. There is, however, a gap in current understanding regarding the influence of order during the recall phase of tasks, on information recalled and its relation to mathematics.

The theoretical foundations of understanding working memory are based on the multi-component model, proposed by Baddeley and Hitch (1974). It is proposed that one component of working memory is specifically responsible for the storage and manipulation of visual and spatial information; the visuospatial sketchpad. Typically, the literature suggests that VSWM is strongly linked to mathematical ability in young children (Holmes & Adams, 2006; Ashkenazi et al., 2013), hence selecting 7-8 year olds as participants in this study as research suggests age-related differences in contribution of VSWM to mathematics (Holmes, Adams & Hamilton, 2008). Whilst previous work has sought to subdivide the influence of simultaneous and sequential VSWM (Mammarella et al., 2017), all sequential measures have relied on replication of a specific order sequence during the recall phase. Such measures have been used alongside simultaneous tasks to determine the influence of simultaneous or sequential VSWM, however, to date, none have investigated the influence of the need for order during the recall phase. It is, therefore, logical to bridge this gap between previously used simultaneous and sequential tasks. As a result, the current study has three main aims: 1) to assess whether simultaneous or sequential presentation affects the amount of information recalled, 2) to identify whether the need for order during the recall phase of the task influences the amount of information recalled, and 3) to consider how the method of presentation and need for order in recall relates to performance on maths measures.

Method

204 (113 females) 7-8 year old children, from a range of demographic backgrounds, completed a battery of visuospatial (simultaneous, sequential without order, and block recall) and verbal (counting recall, digit recall, and backward digit recall) working memory measures before also completing a standardised mathematics test. Standardised working memory measures were administered as per the instructions provided with the Working Memory Test Battery for Children (WMTB-C), with derived measures following the same structure and administration procedure, aside from presentation using a Windows laptop. In each instance, the mathematics test (Access Mathematics Test) was administered in paper form. All children were tested individually, by a single researcher, in a quiet area of their school. Measures were administered in a randomised order, however, the size of the grids used in the derived measures of VSWM were administered in a fixed order (3x3 then 4x3, and 4x3 then 4x4, for sequential and simultaneous, respectively). A correlational design was used throughout.

For this stage of analysis, a repeated measures Analysis of Variance (ANOVA) was conducted in the first instance, using VSWM measures as within subjects factors. Following this, correlational analyses were carried out including VSWM composite measures (composite scores for the number of items recalled for simultaneous and sequential no order measures were created by summing raw scores for individual tests respectively) and mathematical component scores. Finally, a series of hierarchical regression analyses were conducted. SPSS was used for all analysis at this stage.

Results

Initially, an ANOVA demonstrated significant differences were present between all VSWM tasks regarding the number of items recalled. The mean for each task can be seen on the bar chart, below.

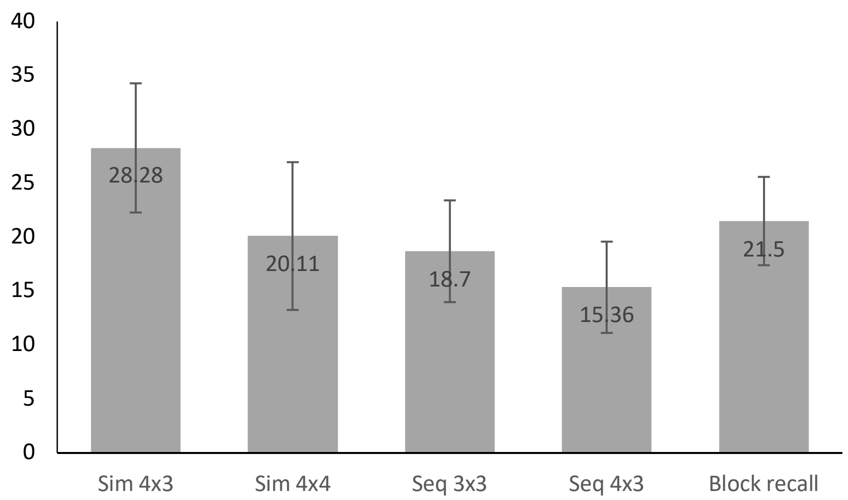

Figure 1. Figure 1 shows the mean number of items recalled for of the VSWM tasks administered. Error bars represent the standard deviation for each measure.

Higher numbers of items recalled during the block recall task (mean=21.5) than the sequential task with no order (mean=18.7 and 15.36) presents an unexpected result, however, there are a number of possible explanations for this. Perhaps the most likely is the clarity of the task instructions for such young children to comprehend, followed by the possibility that block recall may require less mental manipulation due to the direct repetition nature of the task. The highest scores can be seen for the simultaneous 4x3 task (mean=28.28), however, this result is not consistent for the 4x4 variation of the task (mean=20.11), in which the average number of items recalled was lower than that for block recall (mean=21.5). This result may reflect the maximum grid size (4x3) that children of this age are able to cope with, hence the drop in score for the larger (4x4) grid.

Following this, correlation analyses were run to assess the relationship between each of the VSWM measures and each of the components of mathematics as measured by the AMT.

Table 1. Table 1 shows the correlations between the VSWM measures and mathematics subscales of the AMT.

	Using and applying mathematics	Counting and understanding number	Knowing and using number facts	Calculating	Understanding shape	Measuring	Handling data
Composite sim	0.333**	0.296**	0.429**	0.286**	0.271**	0.135	0.288**
Composite seq	0.247**	0.228**	0.313**	0.244**	0.144*	0.197**	0.235**
Block recall	0.269**	0.138*	0.232**	0.172*	0.012	0.048	0.165*

*p<0.005, **p<0.001

From Table 1, it is evident that simultaneous VSWM correlates significantly, but weakly, with all mathematics measures with the exception of measuring. A similar pattern can be seen for block recall, however, here understanding shape also does not correlate significantly. Interestingly, sequential VSWM correlates significantly with all components of mathematics, suggesting it is related to overall mathematical development.

A series of regressions demonstrated the importance of simultaneous VSWM in the prediction of mathematics performance, both for mathematics as a whole, and for each individual component of mathematics, with R^2 values ranging from 10% to 21.2%. Notably, simultaneous VSWM did not make a significant contribution when predicting measuring. Rather, this component was significantly predicted by sequential VSWM.

Discussion and Current Conclusions

At this stage, VSWM appears to be the strongest predictor of the measures used, however, only accounts for up to 21.2% of the variance of mathematical performance. The predictive strength of VSWM, in terms of variance accounted for, appears to vary depending on the component of mathematics in question, ranging from 10% for calculating to 20% for knowing and using number facts.

There are some limitations inherent in this study that it will be necessary to address in future work. Regarding the measures used, verbal measures involved the use of number words, which could feasibly have altered the predictive relationship between verbal working memory and mathematics performance. This is of particular significance in an age group in which one would expect dramatic developmental changes. However, the use of such measures is in line with previous work suggesting a component of working memory responsible for numerical information (as reviewed by Raghubar, Barnes & Hecht, 2010), hence the results generated are not entirely unexpected. Continuing on from this, the study concerned only a narrow age group of typically developing children. As such, it is not possible to examine any longitudinal changes relating to age, or to highlight any differences between typical and atypical populations.

The findings from this study have important implications in educational research. An understanding of the elements of working memory that support mathematics development is fundamental for educators aiming to improve children's mathematical attainment. Research is currently trying to exploit this relationship to generate working memory training programmes (e.g., Alloway, 2012; Holmes & Gathercole, 2014). However, at present, randomised controlled trials have not identified evidence of transfer of effects onto academic tasks (e.g., Dunning, Holmes & Gathercole, 2013), though evidence is mixed (see Morrison & Chein, 2011 for a review of this literature). It would be of great benefit to educators to understand the predictive nature of working memory for individual components of mathematics as this would enable educators to highlight potential areas of vulnerability in their students.

Further ongoing investigation is required in order to fully understand the meaning of the data. The data will be modelled in order to highlight the most salient relationships between variables, and to identify the unique variance accounted for by each aspect of working memory. The R program (R Core Team, 2018) with the "lavaan" library (Rosseel, 2012) will be used. Model fit will be assessed using various indexes according to the criteria suggested by Hu and Bentler (1995 in Hoyle, 1995). We will consider the chi-square (χ^2), comparative fit index (*CFI*), non-normed fit index (*NNFI*), standardized root mean square residual (*SRMR*), and root mean square error of approximation (*RMSEA*). Following confirmatory factor analysis (CFA), we will conduct variance partitioning in order to further understand the contributions of each measure to mathematics.

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