Do coordinate measures of visual working memory predict verbal and non-verbal intelligence in children aged 7–13 years?

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The associations between visual working memory and intelligence have been extensively investigated in adults and children, in particular with the focus of smaller coordinate changes in visual arrays. Research has suggested that the association between coordinate measures of working memory of intelligence is non-existent within an adult context. However, more recent developmental research has suggested a contrast in a younger sample. In a novel use of a change detection protocol, using 90 children aged 7–13 years, the current research aimed to clarify the relationship between a coordinate measure of visual working memory and both verbal and non-verbal intelligence. It was found that the coordinate measure of visual working memory performance was a significant predictor of both verbal and non-verbal intelligence, in particular the 5% changes within the coordinate arrays. Results are discussed in terms of the future use of such visual working memory tasks with a particular emphasis of the use of 5% visual array changes.

Keywords: change detection, coordinate measures, intelligence, verbal intelligence, working memory

Visual working memory capacity can be defined in several ways ranging from the simple storage of objects within memory slots (Luck & Vogel, 1997) to the storage of all items in an array with the use of a dynamically distributed resource shared equally between these items (Bays, Catalao, & Hussain, 2009). These perspectives have been applied to both adults (Awh, Barton, & Vogel, 2007; Scolari, Vogel, & Awh, 2008) and children up to the age of 10 years old (Gathercole & Pickering, 2000; Riggs, McTaggart, Simpson, & Freeman, 2006) using measures that can assess both large and small changes in visual arrays.

Working memory capacity measures have also been shown to have strong links to intelligence, including scholastic achievement scores (Cowan, Fristoe, Elliott, Brunner, & Scott Saults, 2006) and fluid intelligence tasks (Fukuda, Vogel, Mayr, & Awh, 2010). Carpenter, Just and Shell (1990) suggested that both types of measures contain similar visual processing mechanisms, giving reasons for such positive correlations between the tasks, while Kyllonen and Christal (1990) suggested that processing speed underlies the relationship between working memory and intelligence. Engle, Laughlin, Tuholski, & Conway, 1999) suggested that the relationship may be down to the ability to hold information in memory without being disrupted from interference and distractions of other information.

Developmental work from Cowan et al. (2006) suggested that the links between working memory and intelligence measures are apparent in childhood and this is primarily due to the development of the scope of attention (amount of information held) within memory. Links were made between a child's scope of attention and scholastic achievement scores. For example, a child with a larger scope of attention had the ability to store more items within memory, causing a greater prospect for storing intelligence measure details. Within this research, the visual working memory task used was based upon that of Luck and Vogel (1997; 2013) who assessed the more categorical properties of visual working memory whereby a person can identify large changes in visual arrays.

More recent research (e.g., Burnett Heyes, Zokaei, van der Staaij, Bays, & Hussain, 2012) suggested that the links between working memory and intelligence still exist today, however, a consideration should be made regarding they type of visual working memory task used.

Burnett Heyes et al. (2012) used a child sample and found contrasting results, identifying a significant relationship between visual working memory capacity and measures of intelligence. Within this research, a coordinate visual working memory task was used, which assessed the smaller changes in a visual array, like the precise rotation of a bar. Burnett Heyes et al. (2012) used CAT-3 performances to create full scale IQ scores as the intelligence measure. The combination of both verbal and non-verbal abilities in this statistic, however, compromised the identification of the relationship between the coordinate measures of capacity with verbal and with non-verbal intelligence measures and this now leaves further scope for investigation within the current study.

The current study will aim to identify the clear relationship between coordinate visual working memory measures and the separated verbal and non-verbal intelligence measures. Fukuda et al. (2010) had presented no links between coordinate measures of visual working memory and intelligence in adults, suggesting that this link may only be present within a developing sample.

Due to the unclear nature of the types of intelligence visual working memory may link to, the current investigation aims to explore this and discover if a coordinate visual working memory task can have links to intelligence in a developmental sample. Of particular interest, the aim is to clarify these distinct relationships with both verbal and non-verbal intelligence, using regression methods to show how visual working memory can contribute to the development of intelligence. Current researchers will aim to use a task created in the work of Jenkins (2016) which utilised a change detection paradigm, designed to assess working memory in terms of 5–20% changes in shape size. This task was seen as a coordinate measure as it measured the fine details that could be stored within visual working memory.

Burnett Heyes et al. (2012) found significant relationship between the full scale IQ measure and their coordinate visual working memory task. Therefore, the current research aims to build upon this and identify the direction of these relationships with the use of regression methods. Hence, it is predicted that the coordinate working memory task will have the ability to predict both verbal and non-verbal intelligence in the development sample.

METHODOLOGY

Design

This study used a non-factorial design, with predictor variables of age and the coordinate visual working memory measure (separated into 5%, 10%, 15% an 20% changes). The criterion variables were the verbal intelligence measure and non-verbal intelligence measure. Age was presented as the control variable.

Design

Overall, 90 children age 7–13 years took part in the investigation. Three schools within the North East of England and one school from the South of England participated. In total, 27 Year 8 children took part (12 males, 15 females). They had a mean age of 12.74 (SD = .45). A total of 33 Year 6 children took part (13 males, 20 females). They had a mean age of 10.09 (SD = .29). A total of 30 Year 3 children took part (14 males, 16 females). They had a mean age of 7.13 (SD = .35). In the current paper, the Year 8 children are labelled as the 12–13 year olds group; the Year 6 children as the 10–11 year old group; and, the Year 3 children as the 7–8 year old group.

Materials

Coordinate task

The coordinate visual working memory task assessed small size changes in visual arrays, using 5%, 10%, 15% and 20% size changes. The encoding array consisted of 1 shape which was presented as either a green triangle, blue square or a red circle, in one of 8 possible circular positions in the array. This array measured 120mm x 120mm. Areas of the shapes measured at 20mm^2. In the retrieval array, a single shape was presented in the centre of the screen, with participants being required to make a bigger/smaller judgement. The shapes could differ at being 5%, 10%, 15% or 20% bigger or smaller, with each percentage change being equally presented at retrieval.

For the coordinate task, 20 trials were presented for array size 1. Within this task, 5 trials were presented for the 5% changes; 5 trials for the 10% changes; 6 trials for the 15% changes; and, 4 trials for the 20% changes. Overall, 50% of the shapes were presented as 'bigger', and 50% of the shapes were presented as 'smaller'. None of the retrieval arrays were the same size as the encoding arrays.

In the current protocol, participants had to decide if the retrieval shape was bigger or smaller. If the shape was identified as bigger, then the 'm' key on the keyboard was pressed (Refer to Figure 1).

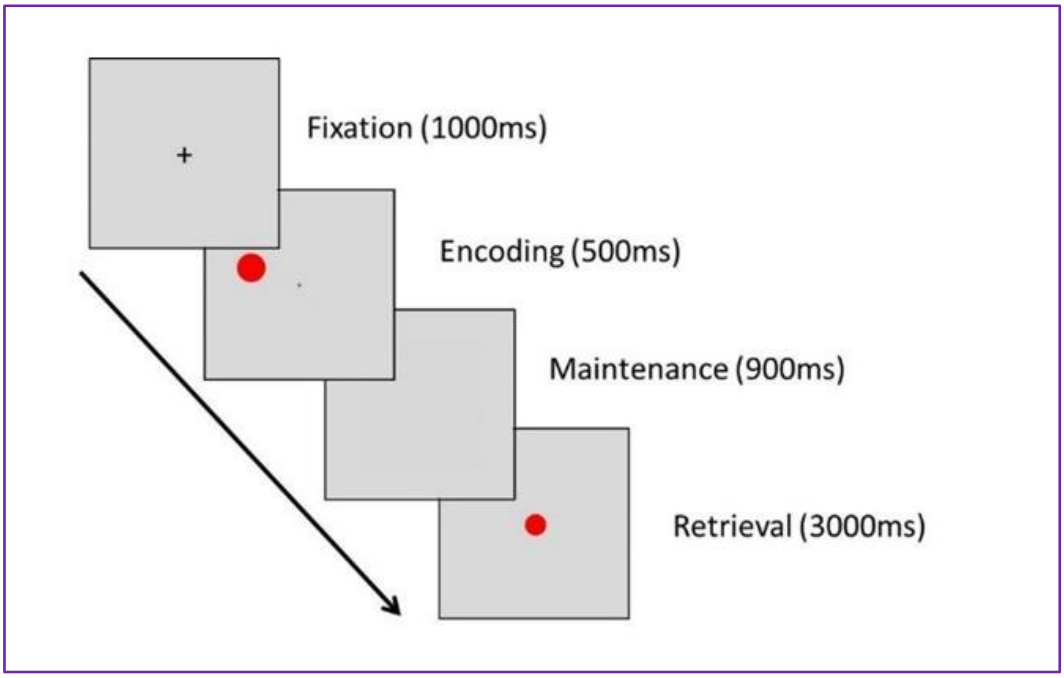

Figure 1: An example of one trial for the Coordinate Change Detection Task containing array size 1.

Intelligence measures

Wechsler's Abbreviated Scale of Intelligence, 2nd Edition (WASI-II, 2011) was chosen as the intelligence measure since it involves both verbal and non-verbal subsets. Two subsets of WAIS were chosen (vocabulary and matrix pattern) instead of all fours subsets as this reduced administration time to approximately 15 minutes. Raw scores and z-scores were used from this measure. Within the WASI-II, the verbal subscale consisted of a 'vocabulary' tasks whereby participants had to name abstract and more concrete words and images presented to them in a book. Within non-verbal scale, a 'matrix patterns' task was completed where participants had to complete a set of patterns created from different shapes and real life objects.

Procedures

Ethical approval was obtained from Northumbria University ethics committee, where the research was conducted. Testing took place in a quiet room inside of each school. Before each task, the researcher explained this procedure to the child using a PowerPoint presentation and made sure the instructions were understood. The first task to be completed was the coordinate visual working memory task. An encoding array, consisting of one shape, was presented for 500 milliseconds followed by a maintenance interval image (900 milliseconds) which contained only a central cross. A retrieval array was then presented for 3,000 milliseconds, consisting of only one central shape, and participants had to identify whether the shape presented at retrieval had changed in size to become bigger or smaller.

The second task consisted of intelligence measure subsets, name the vocabulary and matrix subsets of WAIS. All tasks were counterbalanced to avoid fatigue and order effects, and each testing session lasted approximately 30 minutes per child.

RESULTS

All scores were transformed into z-scores using the formula $z = (x - \mu)/\sigma$, where 'x' was the raw score; 'μ' was the sample; and, 'σ' was the sample standard deviation (See Table 1). Participants had one z-score for the coordinate visual working memory task, verbal intelligence measure and the non-verbal intelligence measure.

Table 1
Means and Standard Deviations of Raw Scores and Converted Z-scores for All Memory and Intelligence Measures

Scores	12–13 Year Olds	10–11 Year Olds	7–8 Year Olds
Coordinate Raw	16.55 (2.65)	16.24 (2.53)	14.26 (2.97)
Matrix Raw Score	18.11 (3.33)	17.09 (2.62)	13.30 (1.82)
Vocabulary Raw	30.71 (3.64)	28.69 (2.51)	17.26 (2.84)
Coordinate Z-score	.305 (.92)	.196 (.88)	−.491 (1.03)
Matrix Z-score	.595 (1.00)	.288 (.79)	−8521 (.55)
Vocabulary Z-score	.789 (.55)	.485 (.38)	−1.244 (.43)
Coordinate 5%	.19 (.87)	.01 (1.01)	−.17 (.98)
Coordinate 10%	.24 (.92)	.01(1.07)	−.23 (.95)
Coordinate 15%	.16 (.90)	.31(.72)	−.49 (1.16)
Coordinate 20%	.30 (1.01)	.20 (.91)	−.50 (.91)

Correlations

Bivariate correlations were conducted on the standardised z-scores between the coordinate visual working memory task, vocabulary task score and matrix task score. The use of partial correlations allowed the current results to control for any effects of age. When age was not controlled for, all correlations were positive and were highly significant (all p's <. 05). When controlling for age, a significant positive correlation, as presented in Table 2, was found between the coordinate visual working memory task and the matrix task (r = .357, p = .001).

Table 2
Correlations Between Z-Scores, Controlling for Age of the Child Below the Diagonal

Tasks	1	2	3
Matrix task		.587**	.472***
Vocabulary task	.205		.279**
Coordinate task	.357***	.009	

*$p < .05$, **$p < .01$, *$p < .001$

Regression analyses

In previous research from Jenkins (2016), the importance of different percentage changes was highlighted, with the suggestion of differences between smaller 5–10% changes, and larger 15–20% changes. As this piece of research is using the coordinate visual working memory task from Jenkins (2016), regression analyses on the coordinate task were conducted separating the data for the 5%, 10%, 15% and 20% changes.

Two hierarchical regressions were conducted on the standardised z-scores to identify whether the 5%, 10%, 15%, and 20% size changes in the coordinate visual working memory task could predict intelligence (vocabulary task score, matrix task score) beyond age. Refer to Table 3 for all regression statistics.

The first regression utilised the matrix task score as the outcome to see if this could be predicted by all percentage change types beyond age.

With this regression, model two was found to be significant $F(5, 89) = 13.883$, $p < .001$, Adjusted $R^2 = .420$, with both age and the coordinate change detection task being found to predict full scale IQ. It has been revealed that 42% of the variance within the model can be accounted by the age and the different percentage changes. A closer inspection of the beta values suggests that only the 5% change was a significant predictor to the model ($\beta = .169$, $p = .011$), indicating a positive relationship between the 5% changes from the coordinate between the 5% changes from the coordinate visual working memory task and the matrix task score. All other percentage changes did not significantly predict the matrix task score.

The second regression utilised the vocabulary score as the outcome to see if this could be predicted by all percentage change types beyond age.

Similar to the previous regression, model two was found to be significant $F(5, 89) = 44.828$, $p < .001$, Adjusted $R^2 = .711$, with both age and the coordinate change detection task being found to predict full scale IQ. It has been revealed that 71.1% of the variance within the model can be accounted by the age and the different percentage changes. A closer inspection of the beta values suggested that only the 5% change was a significant predictor to the model ($\beta = -.155$, $p = .017$), indicating a negative relationship between the 5% changes in the coordinate visual working memory task and the vocabulary task score. All other percentage changes did not significantly predict the vocabulary task score.

Table 3
Regression Statistics for the Three Coordinate Percentage Change Models

Model	*T*	*β*	*R*
Regression 1 (Model 2), Regressed upon non-verbal IQ			.452
Age	5.74***	.499	
5% change	2.611*	.235	
10% change	.054	.005	
15% change	1.707	.162	
20% change	.303	.030	
Regression 2 (Model 2), Regressed upon verbal IQ			.727
Age	13.428**	.822	
5% change	−2.436*	−.155	
10% change	.192	.013	
15% change	1.650	.110	
20% change	.271	.019	

*$p < .05$, **$p < .01$, *$p < .001$

DISCUSSION

The current investigation aimed to discover if a coordinate visual working memory task could be found to predict verbal and non-verbal intelligence in children aged 7–13 years, building upon the findings of Burnett Heyes et al. (2012). Regression analyses were conducted upon the coordinate change detection task, in particular for the separate percentage changes. These analyses indicated that the 5% changes could predict the verbal and non-verbal ability beyond age, supporting the prediction provided in the report. The relationship between the coordinate visual working memory task and the non-verbal intelligence measure was seen as a positive relationship, indicating that as the visual working memory score increased then do did the non-verbal intelligence score. In contrast, a negative relationship was found between the coordinate visual working memory measure and the verbal measure.

Research from Burnett Heyes et al. (2012) highlighted the importance of coordinate measure in relation to intelligence measures, using a combined IQ score measure. Results from the current investigation do offer some support to the finding of Burnett Heyes et al. (2012) with the coordinate change detection task having the ability to predict intelligence, specifically the smaller 5% changes being able to predict both verbal and non-verbal intelligence. This suggests that the relationship between working memory capacity and intelligence are not solely due to the number of items stored (e.g., suggestions of discrete slot accounts and as previously indicated by Fukuda et al., 2010). The age of the child and the ability to store finite detailed representations within memory also need to be considered and these could be very different within each investigation of working memory and intelligence.

To investigate whether processing speed (Kyllonen & Christal, 1990) or working memory capacity (Engle et al., 1999) can influence these intelligence predictions, further research would need to be conducted to specifically focus upon the amount of time it takes for participants to process information. This could ideally be done with the use of multiple array sizes to specifically focus upon the storage mechanisms within memory to show how visual working memory capacity could be linked to intelligence in terms of how many times were required to be stored.

A consideration must be made to the creation of the coordinate task used. Researchers aimed to use a task that assesses coordinate changes in visual arrays. However, upon further review, it appears that the larger percentage changes (15–20%) could also be seen as more categorical changes. To fully consider the coordinate change detection task as a coordinate procedure, it may be advisable in the future to create a similar task using only changes which range between 5% and 10% to avoid any misconception of array type. The task had been successfully used with an adult population to show the presence of verbal or semantic information use through both categorical and coordinate change detection procedures (Jenkins, 2016).

However, one issue with adding in other different shape types would be the potential use feature binding within the coordinate paradigm. Feature binding has been extensively investigated with researchers such as Brown and Brockmole (2010), and Wheeler and Treisman (2002), therefore pilot investigations would need to be conducted before implementing any increase in coordinate array sizes with children to ensure that errors with binding would be reduced. Similar tasks have been used by Bae and Flombaum (2013) using an adult sample, therefore it might be interesting to create a child version of this protocol.

CONCLUSION

The current study can conclude that there are links between visual working memory capacity and intelligence in children aged 7–13 years, with particular emphasis on the relationships between smaller array changes than the larger ones. Results now leave scope for further investigation regarding the encoding of multiple coordinate items within an array to discover if these relationships are still apparent with multiple encoding items.

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