

WORKING MEMORY AND INTELLECTUAL DISABILITIES

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Relationships between working memory, expressive vocabulary and arithmetical reasoning in children with and without intellectual disabilities

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Abstract

This experiment examined the relationships between working memory and two measures of achievement, namely expressive vocabulary and arithmetical reasoning, in children with and without intellectual disabilities (ID). For 11-12-year-old children with intellectual disabilities, memory measures tapping the central executive were the most important predictors of both expressive vocabulary and arithmetical reasoning, with phonological memory making a small additional contribution to expressive vocabulary. For mainstream 11-12-year-old children, phonological memory was the best predictor of expressive vocabulary, whereas, arithmetical reasoning ability was predicted by visual memory and to a lesser extent phonological memory. The third group of children, 7-8-year-old mainstream children, had been matched on mental age with the intellectual disability group. For these children the most important predictor of expressive vocabulary was phonological memory, with a small additional contribution from visual memory. Arithmetical reasoning was best predicted by memory measures tapping the central executive with an additional contribution from phonological memory. These results suggest that different working memory resources are used by children of varying ages and ability levels to carry out at least some cognitive tasks.

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This study addresses the relationships between different aspects of working memory performance and two cognitive abilities, expressive vocabulary and arithmetical reasoning, in school age children with mild to moderate intellectual disabilities (ID). Prevalence rates of intellectual disabilities in U.S. samples of school age children have been reported at as high as 20.3 per thousand (Larson, Lakin, Anderson, Kwak, Lee & Anderson, 2001), indicating a real need to study these children in depth.

“Working memory” refers to the “active”, current information that must be kept in mind to carry out everyday tasks, and underpins many key skills such as reading, vocabulary development and mathematics. Despite recent acknowledgements that the working memory model (Baddeley, 1986) may be underspecified, particularly with respect to one component, the central executive, the model still holds a “central place in cognitive psychology” (Andrade, 2001, page 282) because of its theoretical simplicity, relative specificity compared to general resource models, and range of applications (Andrade, 2001). The working memory model (Baddeley, 1986) is divided into three main components. A “central executive” provides the overall control and management function and incorporates more complex keeping track of information. Examples include reading (one must keep the gist of each sentence in mind whilst reading and processing the next sentence) and mental arithmetic (in performing calculations, the numbers must be kept in mind as well as interim and final results). These tasks call for a combination of online processing and storage of the information to be processed and, therefore, require “complex” working memory.

Experimental tasks to measure central executive capacity have grown out of Daneman and Carpenter’s (1980) original reading and listening span tasks, used to obtain measures of concurrent storage and processing (see also Siegel & Ryan, 1989, and

Leather & Henry, 1994). These tasks involve making relatively simple decisions about individual items, such as whether a sentence is true or false (this is the processing component); then recalling some key information from each individual item, such as the final word in each sentence (this is the storage component). Similar tasks in different domains have also been developed. All of these tasks involve making decisions about a series of items (e.g. a series of “counts” – counting span; judgements about which item of three is slightly different from the others – odd one out span; simple arithmetical questions – sums or operation span) and subsequently recalling the product or location of the items (Henry & MacLean, 2002; Hitch & McAuley, 1991; Hitch, Towse & Hutton, 2001; Russell, Jarrold & Henry, 1996). It must be noted that central executive “working memory” tasks are a “subset” of the more broadly defined central executive measures commonly used in neuropsychological contexts (e.g. Wisconsin Card Sorting Task, Trail Making Task etc.).

Two types of slave systems provide for rote recall of phonological information (the “phonological loop”) and visual and spatial information (the “visuo-spatial sketch pad”) respectively in the working memory model. Experimental tasks which measure the phonological loop are those requiring serial recall of phonological information (e.g. words, nonwords, digits). Tasks which measure the visuo-spatial sketch pad require recall of visual and/or spatial information (e.g. patterns, locations). A fourth component of the working memory model has recently been added (Baddeley, 2000), the “episodic” buffer, which is hypothesised to act as a temporary storage system using a multimodal code. This system integrates information from the slave systems with information from long-term memory.

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Research arising from Baddeley's (1986) model has indicated that working memory capacity is related to performance in reading, vocabulary development and arithmetical skill in adults and children without intellectual disabilities. Specifically, a number of measures of phonological loop storage, such as nonword repetition, digit span, nonword span and recognition span, have been shown to relate to vocabulary knowledge and ability to learn previously unfamiliar words (e.g. Adams, Bourke & Willis, 1999; Gathercole & Baddeley, 1989; 1990; Gathercole & Pickering, 1999; Gathercole, Service, Hitch, Adams & Martin, 1999; Michas & Henry, 1994) and weakly to reading comprehension and word recognition (e.g. Shankweiler, Liberman, Mark, Fowler & Fischer, 1979; Swanson, 1994). There is also some evidence for a small relationship between performance on mathematical tasks and phonological loop storage (Fürst & Hitch, 2000; Heathcote, 1994; Lehto, 1995; Logie & Baddeley, 1987; Logie, Gilhooly & Wynn, 1994), and also broader measures of phonological processing (Swanson & Sachse-Lee, 2001). Visual and spatial working memory have been implicated in level of arithmetic skill and performance of mental addition problems (Heathcote, 1994; McLean & Hitch, 1999; Reuhkala, 2001 – although Bull, Johnston and Roy (1999) found no evidence that 7-year-olds classified as poor in mathematical ability showed weaker spatial working memory).

Measures of complex working memory, or central executive-loaded working memory, according to Baddeley's model, relate, in varying degrees, to reading development and mathematical ability in children (Bull & Scerif, 2001; Hitch & McAuley, 1991; Hitch et al., 2001; Leather & Henry, 1994; Lehto, 1995; Passolunghi & Siegel, 2001; Siegel & Ryan, 1989; Swanson, 1994; Swanson & Sachse-Lee, 2001; Wilson & Swanson, 2001 – although see Reuhkala, 2001 for contrary evidence with respect to

mathematical skills). In adults with ID, measures of working memory have been shown to relate to various academic skills including reading and arithmetic (Numminen, Service, Ahonen, Korhonen, Tolvanen, Patja & Ruoppila et al., 2000).

Research of this type, looking at relationships between working memory and cognitive skills, is rare in children with ID. Gathercole and Pickering (2000) provided evidence that children with low attainment at school (age 6 to 7 years) in standardised National Tests of literacy and arithmetic showed deficits on three measures of central executive function, according to Baddeley's working memory model, and visuo-spatial short-term memory. They argued that central executive capacity plays an important role in the learning of complex cognitive skills. However, these children were in mainstream schools and were not classified as having intellectual disabilities. Another relevant strand of evidence is that the pattern of working memory performance in children with ID differs from that of typically developing children. Henry and MacLean (2002) found that some measures of working memory span in children with ID were at mental age appropriate levels, some were below and some were above. Therefore, the relationships between working memory skills and cognitive outcome measures may be different in children with and without ID.

This study presents data examining relationships between two cognitive abilities, namely expressive vocabulary and arithmetical reasoning, and measures of working memory in children with intellectual disabilities, comparing them to typically developing children matched for mental and chronological age. The purpose of the work is to examine whether children with ID may use working memory resources differently when carrying out cognitive tasks, in comparison with typically

developing peers of comparable mental age (MA) and chronological age (CA). We focus on expressive vocabulary (ability to provide word definitions) and not receptive vocabulary (ability to comprehend word meanings). Although much of the previous research reporting links between vocabulary knowledge and phonological memory has used measures of receptive vocabulary (e.g. Gathercole & Baddeley, 1989), the relationship has also been found using measures of expressive vocabulary (Gathercole, et al., 1999). Defining words requires the child to formulate and express a definition containing some distinctive and salient characteristics of the concept. The data reported here represent further analysis of the data collected by Henry and MacLean (2002) in a study of working memory in children with and without intellectual disabilities.

Method

Participants

Participants were 139 children with and without intellectual disabilities (ID). The CA group (chronological age match group) included 45 children of age 11-12 years (mean age 12 years 1 month, s.d. 4.5 months, range 11 years 4 months to 12 years 11 months). They were of average intellectual ability as assessed by the British Ability Scales II, Elliott, 1996, (mean General Conceptual Ability 103.8, s.d. 9.3, range 84 to 123). The ID group included 53 children who were mainly 11-12 years old (mean age 11 years 11 months, s.d. 5.5 months, range 11 years 2 months to 13 years 6 months). They had intellectual disabilities (mean General Conceptual Ability 57.2, s.d. 11.7, range 40-79). This range encompassed borderline, mild and moderate intellectual disabilities as described in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV). The MA group (mental age matched

group) included 41 children aged 7 to 8 years (mean age 7 years 11 months, s.d. 5.5 months, range 7 years 0 months to 8 years 11 months). These children were of average ability (mean General Conceptual Ability 101.0, s.d. 12.3, range 82 to 136).

The average ability CA children came from two mainstream inner city schools in South London and one mainstream middle school in Oxford. Some of the children with intellectual disabilities came from the two South London mainstream schools (n=9) and the remainder came from two special schools for children with intellectual disabilities also in South London. The MA children came from a mainstream primary school in Oxfordshire. All children were tested individually in their schools.

Ethical approval for the study was obtained from the institutions at which it was carried out and informed written consent was obtained from parents prior to participation.

Procedure and Materials

Our outcome measures of expressive vocabulary and arithmetical reasoning were taken from the BAS II tests (we used BAS “ability” scores which are like raw scores in that they are not age corrected). “Word definitions” required the child to define a series of increasingly difficult words and we will refer to this as “expressive vocabulary”. “Quantitative reasoning”, which we will call “arithmetical reasoning”, required the child to solve arithmetical problems presented in a series of three dominoes. A relationship between each side of the domino must be deduced (e.g. every right-hand side contains 2 more than every left-hand side) by examining two filled-in dominoes, then used to solve the final domino which contains a blank right-

hand side. Easier items are presented using black dots (like dice) or simple symbols (e.g. crosses), moderate difficulty items are presented as whole numbers and the most difficult items require two operations to get from the left-hand number in the domino to the right-hand number (e.g. multiply by 2 and subtract 1).

The memory span tasks were as follows. Two measures of phonological memory were used, word and digit span, and we used combined scores in the analyses to obtain a somewhat broader overall measure. For word span, the child was required to recall a series of one-syllable words in order orally. The words were presented by the experimenter at a rate of one per second and were drawn from a pool of eight high frequency words (cake, sheep, frog, bus, clown, kite, drum, boot). Children were presented with lists of increasing length beginning with a list length of two words. There were three trials at each list length. As long as the participant passed two trials at any particular list length, they went on to the next list length. Memory span was the longest list at which two correct responses were given, plus one half-point credit if one list out of three was correctly recalled at the next (longer) list length. For digit span, the Experimenter presented lists of digits verbally at a rate of one per second. Recall was oral and the child had to recall items in order. The test began with a list length of two items and continued with successively longer lists, always with two trials for each list length. Testing ceased when both lists at a particular list length were incorrect. Span was the longest list length correctly recalled. It must be noted that both word span and digit span are measures of phonological memory that are, to some extent, influenced by stored semantic knowledge (e.g. the person's knowledge of word meanings).

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There were also two measures of visuo-spatial span, again combined for the purposes of analysis, again to obtain a somewhat broader measure of visuo-spatial storage. For spatial span, the child was presented with an array of 9 black-and-white drawings of cubes on a white background. The cubes were drawn in perspective with one side shaded and were randomly arranged on the background. The experimenter pointed to a series of cubes and the child was asked to point to the same cubes in the same order immediately afterwards. List lengths began at 2 for all children and progressed up to 8. There were two trials at each list length. In order to proceed to the next list length, one out of the two trials at least had to be reported accurately. Spatial span was scored as the longest list length correctly recalled at least once. Testing ceased if the participant failed to recall a list length on either of the two trials. For pattern span, lists of nonsense pictures were presented to the child. Pictures were presented in an array from left to right and were black-on-white line drawings. After viewing each array for five seconds, a second array was presented in which the nonsense drawings were presented in a different order. The child was asked to point to the nonsense pictures in the order in which they appeared on the first array. Testing began with two lists of two nonsense pictures. Successively longer lists were presented, always with two trials at each list length, and testing ceased when both lists at a particular list length were incorrect. Span score was the longest list length correctly recalled.

The measure of central executive-loaded working memory span was based on three tasks. In listening span, participants heard short sentences that could either be true or false (e.g. “children go to school” or “grass grows in the house”). Sentences were presented in groups of one to four and the child was asked to listen to each sentence,

say whether it was true or false and then recall the last word from each of the sentences. All children began by hearing just one sentence, saying whether it was true or false, and then recalling the last word. Once the child had passed three trials with one sentence (i.e. a list length of one), two sentences were presented and the child attempted to recall two sentence-final words. Three trials were administered at each list length. Testing continued to longer list lengths (i.e. lists of three and then four sentences), provided the participant recalled the sentence-final words correctly on at least two of the trials. Listening span was the longest list length at which two trials were passed, plus an extra half-point credit if one list at the next list length was correctly recalled. Sentence-final words could be recalled in any order on this task.

Odd-one-out span involved showing children a “response” sheet with two elongated rectangular blank boxes drawn on it, one above the other. Each box was divided into three sections from left to right (see Figure 1). The child was then presented with a card containing three similar looking figures in a row from left to right. The card was the same size as the blank boxes on the response sheet and was placed just above the top blank box. It was pointed out that each figure corresponded to one section in the blank box. Figures were black-on-white line drawings of various shapes and symbols. On each card, two of the figures were identical, with the third differing slightly from the other two (see Figure 2 for two examples). The child was asked to point to the figure that was different from the others – i.e. the odd one out. The Experimenter then placed her finger on the section in the blank box corresponding to the position of the odd one out and said, “the odd one out goes here, in this space – try to remember where it goes because I am taking the card away”. The card was removed and a

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second card with three figures on it was placed just above the second, lower blank box. Again, the child was asked to point to the odd one out and the Experimenter demonstrated that the new odd one out belonged in the corresponding section of the lower blank box. The card was removed and the child was asked to try to recall the positions of the upper and lower odd one out pictures by pointing to the appropriate sections on the response sheet.

This first trial was to demonstrate the task and two further practice trials using list lengths of two items were administered. However, there was one change to the procedure in subsequent trials. The blank boxes were covered up during presentation of the cards with figures on them. This was to prevent children using their fingers to mark the spatial positions of the odd ones out. Provided the child passed the two practice trials, the next list length was administered (three cards). A new response sheet with three rectangular blank boxes (upper, middle and lower) was presented and the child was told that this time three cards would be presented. List lengths increased to 5 cards, with new response cards containing 4 and then 5 rectangular blank boxes, and testing continued provided the child obtained at least two out of three trials correct at any particular list length. Odd one out span was the longest list length at which two trials were passed, plus an extra half-point credit if one trial at the next, higher, list length was correct.

Figures 1 and 2 about here

The final measure was reverse digit span. This was identical to the digit span test, except that recall was in reverse order. One practice trial was administered to check that the child understood the instructions. Span was the longest list length correctly recalled and testing ceased when both lists at a particular list length were incorrect.

Results

The scores on digit and word span were summed to create a phonological memory measure. Similarly the scores on pattern and spatial spans were summed to create a visuo-spatial memory measure. Finally scores on the two complex memory measures (listening span and odd-one-out span) and reverse digit span were summed to create a central executive-loaded measure. Mean scores on these variables (which were all normally distributed) are shown in Table 1. A detailed breakdown of group differences on each of the memory span measures is given in Henry and MacLean (2002). Here we focus only on the relationships between the working memory measures and the outcome measures.

Table 1 about here

Correlations between memory measures and outcome measures

Table 2 shows the correlations between the outcome measures and the working memory measures. For the CA group, phonological memory was significantly correlated with both outcome measures, expressive vocabulary and arithmetical reasoning. Visuo-spatial memory was significantly correlated with arithmetical

reasoning and the central executive-loaded measure was not significantly correlated with either outcome measure. The pattern of correlations for both the ID and the MA groups showed all three memory measures being significantly correlated with each of the outcome measures.

Table 2 about here

In order to see which memory measures were the best predictors of expressive vocabulary and arithmetical reasoning, a series of stepwise regressions were carried out separately for each of the three groups. Scores on expressive vocabulary and arithmetical reasoning were the dependent measures, and the three memory measures were the independent variables and age. All three independent variables were entered as a block in the regressions. Age made no significant contribution to any of the regressions, and in each regression with excluded variables, the beta values for the excluded variables were low. Tables 3 and 4 show the R square values, R square Change (proportion of the variance in the dependent variable accounted for by each variable in the equation) of those variables contributing significantly to the regression.

Expressive vocabulary

For the CA group, the regression equation was $expressive\ vocabulary = 88.41 + 3.56(phonological\ memory)$. Only phonological memory accounted for a significant proportion (16%) of the variance in expressive vocabulary. For the ID group, the regression equation was $expressive\ vocabulary = 23.41 + 3.27(central\ executive-$

loaded memory) + 3.00(*phonological memory*). The central executive-loaded measure accounted for the largest proportion of the variance (30%), with phonological memory accounting for a significant further 6% of the variance. For the MA group the regression equation was $expressive\ vocabulary = 19.33 + 3.87(\textit{phonological\ memory}) + 4.37(\textit{visuo-spatial\ memory})$. Phonological memory was the strongest predictor of expressive vocabulary (22%) with visuo-spatial memory accounting for a significant further 10% of the variance (see Table 3).

Table 3 about here

Arithmetical reasoning

In the case of arithmetical reasoning, the strongest predictor of performance in the CA group was visuo-spatial memory (24.5%), with phonological memory contributing a further 7% of the variance ($arithmetical\ reasoning = 49.57 + 4.04(\textit{visuo-spatial\ memory}) + 2.77(\textit{phonological\ memory})$). For the ID group, only one measure made a significant contribution, namely the central executive measure which accounted for 31% of the variance ($arithmetical\ reasoning = 32.36 + 5.15(\textit{central\ executive-loaded\ memory})$). In the MA group, the central executive-loaded measure accounted for 41% of the variance, with an additional contribution from phonological memory of 15% of the variance ($arithmetical\ reasoning = -6.57 + 5.86(\textit{central\ executive-loaded\ memory}) + 5.90(\textit{phonological\ memory})$) See Table 4.

Table 4 about here.

Discussion

The working memory measures accounted for between 16 and 56% of the variance in expressive vocabulary and arithmetical reasoning, indicating that they were modest to good predictors of performance. Of particular interest were the patterns of relationships between the working memory measures and the cognitive measures in each of our study groups.

The results for the CA group were easily interpretable in terms of previous research. For expressive vocabulary, the only significant predictor of performance was phonological memory, and this ties in well with research demonstrating that measures of phonological short-term memory are related to vocabulary knowledge and the ability to learn previously unknown words (e.g. Baddeley, Gathercole & Papagno, 1998; Gathercole & Baddeley, 1989; Gathercole, Hitch, Service & Martin, 1997; Gathercole et al., 1999; Michas & Henry, 1994). Although we are not in a position to comment on the direction of causality, and there is some debate about this issue (e.g. Snowling, Chiat & Hulme, 1991), nevertheless, the absence of any relationships with visuo-spatial or central executive-loaded memory does suggest a degree of specificity in the relationship between expressive vocabulary and phonological memory.

Similarly, the fact that the key predictor of arithmetical reasoning was visuo-spatial memory, with a minor contribution from phonological memory, fits well with the published literature (e.g. Bryant, MacLean, Bradley & Crossland, 1989; Fürst & Hitch, 2000; Heathcote, 1994; Logie & Baddeley, 1987; Logie, Gilhooly & Wynn, 1994; McLean & Hitch, 1999; Reuhkala, 2001). Broadly speaking, arithmetical

ability may draw upon visuo-spatial skills, but component skills such as counting during arithmetical tasks or the need for temporary storage during calculations may utilise phonological memory (Logie & Baddeley, 1987; Logie, Gilhooly & Wynn, 1994; MacLean, Bryant & Bradley, 1987). Note, however, that specific mathematical operations such as mental arithmetic may draw on somewhat different working memory resources, depending upon the precise requirements of the task (Fürst & Hitch, 2000).

The practical implications of these results are that typically-developing 11-12-year-olds are not depending heavily or solely on central executive-type resources to carry out tasks such as defining words, or solving arithmetical tasks that require the extraction of a rule from given instances and applying this rule to complete a mental arithmetic problem. They are utilising the slave system most relevant to the task, namely the visuo-spatial sketch pad for arithmetic and the phonological loop for expressive vocabulary. Why is there no evidence for a central executive contribution? In carrying out our cognitive tasks, it may be possible to draw upon stored knowledge, for example, stored definitions of words, stored answers to arithmetical problems (e.g. times tables) and stored knowledge about relationships between numbers (e.g. doubling is the equivalent of multiplying by 2). By using stored knowledge maintained in the relevant slave sub-system (phonological loop, visuo-spatial sketch pad), the need for central executive resources to process the problem is reduced. This may well reflect the contribution of the episodic buffer (Baddeley, 2000), acting as the interface between working memory and stored knowledge, although research on this new component of the working memory model is currently in its infancy.

However, this age group were using phonological memory in the arithmetical task to a

minor degree, and this implies that they may be storing some interim results of calculations in a verbal form.

The children with ID did not show the same kind of pattern as their same age mainstream peers, and this implies that they were using different working memory resources to carry out the same cognitive tasks. For both outcome measures, the most significant predictor of performance was the central executive-loaded memory measure. Clearly, carrying out cognitive tasks such as the ones used here (defining words and working out arithmetical relationships) made demands on both processing and storage abilities, similar to those required in carrying out central executive type memory span tasks. Rather than being able to draw upon stored knowledge (e.g. stored definitions of words, number knowledge, memorised material), the children with ID may have to work out solutions to questions from scratch each time. Wilson & Swanson (2001), commenting on children with specific disabilities in mathematics, proposed similarly that they “lacked a general knowledge of arithmetical facts” and that “these deficits in LTM may have placed unnecessary demands on central processing.” (both quotes, page 246).

Hence, defining a word or working out a mathematical relationship may require considerable resources in terms of processing and storage for children with ID. We are not in a position to comment on the relative contributions of processing and storage from the current data, as we do not have separate measures for both of these variables. However, this would be a fruitful area for further research because it would help pinpoint whether it is the processing task itself or the combination of processing

and storage that is most strongly related to performance on the cognitive tasks. The current results are in line with the findings reported by Gathercole and Pickering (2000). They found that children with low attainment showed relationships between measures of central executive function and achievement measures (literacy and mathematics). However, we also found evidence for an additional contribution to expressive vocabulary performance from phonological memory. This parallels the relationship found for the CA group and ties in with the mainstream literature, but, importantly, the role of phonological memory was subsidiary to the role of central executive-loaded memory.

The practical implications of these results for children with ID are that many tasks may be extremely demanding each time they are carried out, because children with ID might possess less stored knowledge or have difficulty in accessing the stored knowledge they do have. Our results cannot distinguish between these two possibilities, although they do suggest that if tasks for children with ID are firmly rooted in well-established knowledge areas, this may increase the chances that they can use stored knowledge to support their performance. Teaching methods that supply more external support to compensate children for lack of stored knowledge (or difficulty accessing it) may be effective (e.g. providing charts of tables for arithmetic, providing more pictures to aid understanding of words) by reducing the central executive load produced by cognitive tasks. However, although these techniques can help in the immediate solution of demanding tasks, they will be less helpful as long-term learning strategies. A complementary approach would be to work to consolidate and build up long-term arithmetical and semantic knowledge in children with ID. Increasing stored knowledge should help to reduce some of the competing demands

made during complex cognitive tasks, thereby reducing the processing load for these children.

The younger mainstream children (MA group) were of the same mental age as the ID group. If children of the same developmental level process cognitive tasks in the same way and use the same working memory resources, one would expect them to show the same patterns of relationships between the memory measures and the outcome measures. For arithmetical reasoning, there was some evidence to support this view. For both the MA and the ID groups, the most important predictor of performance was the central executive-loaded memory measure, suggesting that at earlier developmental levels, arithmetical reasoning is supported by central executive resources. Bull, Johnston and Roy (1999) have also proposed that central executive capacity is most relevant at intermediate stages of arithmetic development – i.e. before long-term representations are automated. However, in the MA group, there was an additional contribution to arithmetical reasoning from phonological memory which was sizeable (15%). This suggests that, like the CA group, children in the MA group used phonological memory to aid performance, possibly for the verbal storage of interim calculations or for counting.

The patterns of relationships between the working memory measures and expressive vocabulary, on the other hand, were less similar in the MA and ID groups. Whereas the central executive measure had been the key predictor for those with ID (with phonological memory as an additional contributor), in the MA group, the most significant predictor was phonological memory (as it had been in the CA group). This

ties in well with previous literature on the relationships between phonological memory and vocabulary acquisition as already mentioned. There was also a surprising additional contribution from visuo-spatial memory. It is possible that children in the MA group were using some kind of visualisation strategy when defining words or referring to well-known pictures of particular words to aid performance.

Therefore, although children in the MA group were of the same ability level as those in the ID group, the inter-relationships between the cognitive tasks and the working memory measures were not identical. This implies that the children with ID were using somewhat different working memory resources to support performance, particularly in the word definition task, than typically developing children who were matched for mental age but differed in both I.Q. and chronological age. In terms of our original question – to what extent do children with ID use the same working memory resources in carrying out these cognitive tasks as children matched for CA and MA – the answer would appear to be, firstly, that children with ID did not resemble their mainstream CA peers. However, they showed some similarities with the MA group. Similar patterns of relationships between the working memory measures and performance in the arithmetical reasoning task were found in both the ID and MA groups, although the relationships were different with respect to performance on the expressive vocabulary task.

In summary, relationships between working memory measures and two cognitive tasks, expressive vocabulary and arithmetical reasoning, were different in children

with ID and groups of children matched for chronological age and mental age. In particular, children with ID showed the largest relationships between the central executive-loaded working memory and the cognitive tasks. Children matched for mental age (to the ID group) showed relationships between central executive-loaded working memory and the arithmetical reasoning task only, whereas, the CA group showed no relationship between either of the cognitive tasks and central executive-loaded working memory. These results suggest that children with ID carry out at least some cognitive tasks using different working memory resources than both same age mainstream peers and mental age matched peers. Future research exploring this issue in more detail and looking at other cognitive tasks, together with the potential education implications would be of great value.

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Table 1 Mean scores on the working memory measures

Group	Working memory measure (summed scores)	Mean	S.D.
CA	Phonological memory	10.56	1.45
	Visuo-spatial memory	10.44	1.79
	Central executive-loaded memory	11.09	2.23
ID	Phonological memory	8.05	1.37
	Visuo-spatial memory	8.17	1.85
	Central executive-loaded memory	8.17	1.99
MA	Phonological memory	8.61	1.47
	Visuo-spatial memory	6.29	1.10
	Central executive-loaded memory	6.89	1.71

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Table 2 Correlations between outcome measures and working memory measures

Group	Outcome measures		
	Memory measures	Expressive Vocabulary	Arithmetical Reasoning
CA	Phonological memory	.40**	.29*
	Visuo-spatial memory	-.04	.49**
	Central executive loaded memory	-.05	.20
ID	Phonological memory	.47**	.35*
	Visuo-spatial memory	.44**	.52**
	Central executive loaded memory	.55**	.56**
MA	Phonological memory	.47**	.60**
	Visuo-spatial memory	.43**	.40**
	Central executive loaded memory	.44**	.64**

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Table 3 Stepwise regression results for Expressive Vocabulary

Group	Working memory measures contributing to regression	Regression statistics		
		R ²	R ² change	Sig.
CA	Phonological memory	.160	.160	.008
ID	Central executive-loaded memory	.302	.302	.000
	Phonological memory	.365	.063	.034
MA	Phonological memory	.224	.224	.002
	Visuo-spatial memory	.319	.095	.027

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Table 4 Stepwise regression results for Arithmetical Reasoning

Group	Working memory measures contributing to regression	Regression statistics		
		R ²	R ² change	Sig.
CA	Visuo-spatial memory	.244	.244	.001
	Phonological memory	.314	.070	.050
ID	Central executive-loaded memory	.312	.312	.000
MA	Central executive-loaded memory	.410	.410	.000
	Phonological memory	.561	.150	.001

Figure 1 Boxes for odd one out span

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Figure 2 Example shapes for odd one out span