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Working memory and educational achievement in children with intellectual disabilities

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Working memory and educational achievement in children with intellectual disabilities

Abstract

Background. There is little previous research examining whether measures of working memory are related to educational achievement in children with intellectual disabilities (ID).

Method. A battery of working memory and achievement measures was administered to 11- to 12-year-old children with ID; younger typically-developing children of comparable mental age were also assessed.

Results. The working memory measures that assessed phonological short-term memory (PSTM) accounted for the most variance in reading and spelling in children with ID, whereas the working memory measures that assessed central executive-loaded working memory (CELWM) accounted for the most variance in number skills. These relationships were broadly similar among typically-developing children.

Conclusions. Compensatory strategies for weak PSTM may help to improve reading and spelling skills in children with ID, whereas reducing CELWM loads may be more helpful in aiding their number skills.

Working memory and educational achievement

The working memory model (Baddeley, 2007) has been very influential amongst researchers examining working memory impairments in children with intellectual disabilities (ID) and developmental disorders (e.g. Alloway & Gathercole, 2006; Henry & Maclean, 2002; Jarrold, Baddeley & Hewes, 2000). This model comprises four components: a phonological loop to hold and maintain speech-based information; a visuospatial sketchpad to hold and maintain visuospatial and possibly kinaesthetic information; a central executive to provide overall attentional control of the working memory system; and an episodic buffer, which contributes modality free storage as well as links to long-term semantic and language knowledge (Baddeley & Hitch, 1974; Baddeley, 2000; 2007).

There is evidence that the functional organisation of the working memory system corresponds to the proposed components of the working memory model in typically developing children from six years and possibly younger (Alloway, Gathercole, Willis & Adams, 2004; Gathercole, Pickering, Ambridge & Wearing, 2004a). One of the clearest distinctions appears to be that between more passive forms of short-term memory *storage* (e.g. via the phonological loop or visuospatial sketchpad) and working memory measures with an explicit *executive* load, which requires both processing and storage (Bayliss, Jarrold, Gunn & Baddeley, 2003; Swanson, 2008). For children with ID, the evidence is sparser, but the structure of working memory appears to be similar, at least in terms of the three original components of working memory: the phonological loop; the visuospatial sketchpad; and the central executive (Henry, 2001). However, visuospatial tasks may be more strongly linked with central executive processing in adults with ID (Numminen, Service, Ahonen, Korhonen, Tolvanen, Patja et al. 2000), and individuals with ID may rely more on stored knowledge from long-term memory (Numinnen, Service & Ruoppila, 2002) or central executive skills (Bayliss, Jarrold, Baddeley & Leigh, 2005) to support working memory performance.

The purpose of the current study was to examine whether measures of working memory are related to educational achievement in children with ID. There is extensive evidence that working memory measures are important predictors of educational achievement in TD children (Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005; Bayliss, Jarrold, Gunn & Baddeley, 2003; Bayliss et al, 2005; Berg, 2008; Bull & Scerif, 2001; Bull, Espy & Wiebe, 2008; Gathercole & Pickering, 2000; Gathercole, Pickering, Knight & Stegmann, 2004b; Hitch, Towse & Hutton, 2001; Leather & Henry, 1994; St. Clair-Thompson & Gathercole, 2006).

In particular, phonological short-term memory (PSTM) and phonological processing have been reported to show relationships with reading, spelling and, in some cases, arithmetic in TD children (Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005; Berg, 2008; Bull et al., 2008; Fuchs, Fuchs, Compton, Powell, Seethaler, Capizzi et al., 2006; Hecht, Torgesen, Wagner & Rashotte, 2001; Leather & Henry, 1994; Swanson, 2008; Wagner & Torgesen, 1987). However, these relationships may be indirect or vary with development/type of problem in the case of arithmetic (Lee, Ng, Ng & Lim, 2004; Rasmussen & Bisanz, 2005; see also Durand, Hulme, Larkin & Snowling, 2005, for contrary evidence). Central executive-loaded working memory (CELWM) has been shown to relate to reading, spelling and arithmetic (Bull & Scerif, 2001; Gathercole et al., 2004b; Geary et al., 2004; Hitch, Towse & Hutton, 2001; Imbo & Vandierendonck, 2007; Imbo, Vandierendonck & De Rammelaere, 2007; Leather & Henry, 1994; Lee et al., 2004; St. Clair-Thompson & Gathercole, 2006; Swanson, 2008); although not all studies have reported the relationships with arithmetic (e.g. Fuchs et al., 2006). Finally, visuospatial short-term memory (VSSTM) is not generally found to be related to reading and spelling progress in TD children, but has been linked to early number skills (Bull et al., 2008; Krajewski & Schneider, 2009; Rasmussen & Bisanz, 2005).

Working memory and educational achievement

There is relatively little research on the relationships between working memory and educational achievement in children with ID. Some researchers have found evidence for links between CELWM and achievement in mathematics in children with ID (Alloway & Temple, 2007; Henry & MacLean, 2003). Similarly, Numminen, Service, Ahonen, Korhonen, Tolvanen, Patja et al. (2000) found a range of relationships between academic skills and working memory in *adults* with ID (CELWM was related to reading, writing and mathematics; PSTM was related to reading and writing; and VSSTM was related to mathematics). However, two studies failed to find correlations between working memory measures and reading and/or spelling in children with ID (Alloway & Temple, 2007; Bayliss et al., 2005; although the former study used participants with a wide range of abilities, IQ 55-115, mean 80). Other researchers have reported that the ability to rehearse verbally in PSTM is linked to success in learning to read, offering some suggestion that PSTM may be relevant to literacy in children with ID (Connors, Atwell, Rosenquist & Sligh, 2001).

Exploring the relationships between working memory and academic achievement in children with ID remains a pressing question for at least three reasons. Firstly, there is very little relevant research in samples of children with clearly defined ID. Secondly, children with ID have known difficulties with working memory, even when compared to TD children of similar *mental age* level, particularly in the area of PSTM (e.g. Bayliss et al., 2005; Hasselhorn & Mähler, 2007; Henry, 2001; Henry & MacLean, 2002; Hulme & Mackenzie, 1992; Russell, Jarrold & Henry, 1996; Van der Molen, Van Luit, Jongmans & Van der Molen, 2007). These working memory difficulties are likely to impact negatively on their academic achievement (Mähler & Schuchardt, 2009). Finally, specifying the contributions of different types of working memory skills to academic achievement can provide a basis for treatment and intervention programmes.

Therefore, the current study included measures assessing the three original components of working memory (PSTM, VSSTM, CELWM), together with a range of achievement measures (reading, spelling, number skills), in order to determine which aspects of working memory were most important for each academic skill. It was predicted that PSTM and CELWM would be related to reading and spelling in children with ID, given the extensive literature documenting these relationships in the TD population, although this prediction was somewhat speculative given some previous negative findings (e.g. Bayliss et al., 2005). We also predicted, based on the limited amount of research in ID populations, that CELWM would be related to number skills. Finally, we speculated that PSTM and VSSTM may also be related to number skills, following from the findings in TD populations (Geary, Hoard, Byrd-Craven, Nugent & Numtee, 2007).

Method

Participants

The final sample included 35 children with mild to moderate ID (mean IQ = 57) of non-specific aetiology, recruited via Educational Psychologists from special schools (n=7) or mainstream schools with specialist provision (n=28) in the north of England. The criteria for inclusion were: (a) a chronological age of 11-13 years; (2) an IQ between 39-75; (3) a mental age between 60-120 months [13 children were excluded based on IQ scores above 75 or continued absence during testing]; and (4) no specific developmental disorder identified. The final 32 children in the TD group (mean IQ = 101) were drawn from mainstream schools and the criteria for inclusion were: (1) no history of learning problems; (2) a chronological age of 6-8 years; (3) a mental age between 60-120 months; and (4) an IQ of 80 or above (range 83-126) [5 children were excluded as mental age exceeded 120 months]. Table 1 gives mean scores for both samples on all study variables. The selection criteria were successful in matching the samples for mental age (ID group: 91months; TD group: 92 months), although there was slightly more variability in the TD sample. Data for three children with

ID and one TD child had three missing values in each case; these were replaced with the mean for the overall sample, a conservative strategy unlikely to enhance group differences.

Full written consent from the schools at which this research took place and the parents of each participant was obtained. Written consent was also obtained from each child taking part in the study using a specially worded information sheet and consent form, phrased in clear straightforward language. Ethical permission for the research project was obtained from the London South Bank University Research Ethics Committee.

Procedure

Children were tested in their schools over three sessions of 30-45 minutes. Session 1 included two tasks from the British Ability Scales II (BAS II, Elliott, Smith & McCullouch, 1996), a UK-normed measure of intelligence, which includes verbal reasoning, non-verbal reasoning and spatial reasoning scales. Two sub-tests were administered, one from the non-verbal reasoning scale (Matrices) and one from the verbal reasoning scale (Verbal Similarities), which gave an estimate of IQ (known as General Conceptual Ability, GCA). Mental age was calculated according to relevant tables in the manual, which provide average mental age levels for differing levels of performance. Session 2 included Single Word Reading and Spelling Skills from the BAS II, and four memory span tasks (digit, spatial, word, pattern). Session 3 included Number Skills from the BAS II and the remainder of the memory span tasks (picture, listening, odd one out). Assessments of reading and spelling focused on very simple decoding or spelling of single words. The assessment of number skills required children to identify numbers and perform simple numerical calculations. Although the test moves on to more complex mathematical questions, the present sample did not reach this level.

Working Memory Measures

Word and digit span. These are both conventional measures used to assess PSTM (e.g. Alloway & Temple, 2007; Bayliss et al., 2005; Henry, 2001; Mähler & Schuchardt, 2009) and were presented as serial order span tasks. The Experimenter read out lists of one-syllable, familiar words (clown, bus, owl, kite, ring, frog, drum, sheep, cake) or digits, at a rate of one per second, and the child was asked to repeat the list in the same serial order. For these, and all of the following span measures (except pattern span), there were three trials per list length, to a maximum list length of 7. List lengths increased incrementally, provided at least two of the three trials were completely correct. Memory scores represented the number of trials that were completely correct, as this measure is regarded as more reliable and sensitive than span (Ferguson, Bowey & Tilley, 2002) and the data were better distributed.

Picture span. The recall of nameable pictures is likely to assess PSTM in children over the age of five years, because children recode the pictures as verbal items (Conrad, 1971; Palmer, 2000). However, before making this assumption, relationships between picture span and the more conventional PSTM measures, word and digit span, were evaluated. Correlations suggested that picture span was indeed closely related to word and digit span, and was not related to the visuospatial span measures. Therefore, it was concluded that picture span constituted a measure of PSTM. In the current task, line drawings (on 10x16cm white cards) of each word from the word span task were shown to children at a rate of one per second. Children were asked to point to the pictures in the correct serial order on a response sheet containing all nine pictures (differently ordered on each trial).

Spatial span. In general, measures of VSSTM should reflect both visual (static) and spatial (dynamic) recall, because these two elements are believed to be functionally separable in VSSTM (Darling, Della Sala & Logie, 2007; Logie & Pearson, 1997). Spatial span is a commonly used measure of spatial or dynamic memory span (e.g. Bayliss et al., 2005; Mähler & Schuchardt, 2009). In the current version of the task, the Experimenter pointed to a series of line drawings of cubes represented on a 30x20cm white card, at a rate of one per second. Children were asked to point to the cubes in the correct serial order.

Pattern span. The static visual component of VSSTM is most often assessed using memory for patterns of squares in matrices (e.g. Mähler & Schuchardt, 2009). The current version of this test was similar to the Visual Patterns Test (Della Sala, Gray, Baddeley & Wilson, 1997), but was developed to include equal numbers of symmetrical and non-symmetrical grids. Square or rectangular grids (matrices) were presented (2x2; 2x3; 3x3; 3x4; 4x4; 4x5), with a number of interior squares highlighted in red (ranging from 1 to 7). Each grid was shown for three seconds, and was replaced with an empty grid on which the child was asked to indicate the previously filled squares. Each span level (2-6) contained six trials, half of which were presented on square grids, the other half of which were presented on rectangular grids (i.e. for a span of two items, there were three trials using the 2x2 grid and three trials using the 2x3 grid; for a span of three items there were three trials using the 2x3 grid and three trials using the 3x3 grid, etc.). There were also three trials at span length one with a 2x2 grid; and three trials with a 4x5 grid at span length 7 (total possible trials 36). Span length increased incrementally unless fewer than four trials out of six were completely correct.

Listening span. This measure is often used to assess CELWM in the verbal domain, as it requires concurrent processing of sentences and storage of individual words (Leather & Henry, 1994; Siegel & Ryan, 1989). The current version of this task was taken from an earlier study of children with ID (Henry, 2001). The experimenter read out a series of short sentences (four to six words) and the child judge whether each was true or false (e.g. I wear lipstick on my NOSE). Following this, the child was asked to remember that final word from each sentence in correct serial order.

Odd one out span. In order to assess CELWM in the non-verbal domain, odd one out span was developed to require concurrent visual and spatial processing and storage (e.g. Henry, 1991; Russell, Jarrold & Henry, 1996). The current version of this task was taken from Henry (2001). The Experimenter showed the child one or more examples of three simple nonsense diagrams presented on horizontally orientated 20x10cm cards one at a time, and asked him/her to point to the one that was slightly different from the other two in each case. Following this, the child was asked to point to the spatial location of each 'odd one out' on a set of blank response cards (each approx. 20x10cm; the number of blank response cards corresponded to the number presented initially).

For digit, word, picture and spatial span, lists began with two items; for pattern, listening and odd one out span, lists began with one item.

Results

Data were normally distributed for all variables, without excessive skewness or kurtosis; slight kurtosis for spatial span (trials correct, z = 2.18) in the ID group was within acceptable limits (Field, 2005).

Group Differences

Table 1 includes mean scores for each study variable for both groups, together with significance tests (independent samples *t*-tests) on group differences (ID vs TD). Effect sizes are included, expressed as r, whereby r = .10 represents a small effect, r = .30 a medium effect and r = .50 a large effect (Field, 2005). Chronological age and IQ differed between the groups as expected, but there were no significant group differences for mental age. Although school achievement did not differ significantly between the groups, there was a small numerical advantage in reading and spelling for TD children (r =.15 in each case). All three measures of PSTM (word, digit, picture span) showed significant group differences in favour of the TD group that were of at least medium effect size. VSSTM (spatial, picture span) and CELWM (listening, odd one out span) did not differ significantly between the groups.

Table 1 about here

Correlations between study variables.

Table 2 illustrates the correlations between study variables, including mental age, for both groups. An alpha value of $p < .01$ was used.

Performance on *number skills* was significantly related to picture span and listening span in both groups. Performance on *spelling* and *reading* was significantly related to word and digit span in the ID group; and to all three measures of PSTM in the TD group (spelling performance was additionally related to listening span).

In addition: (1) There were orderly relationships in both groups between measures hypothesised to assess the same components of working memory: (a) all measures of PSTM (word, digit, picture span) related to each other (suggesting that picture span did, indeed, assess PSTM), but not to the VSSTM measures (spatial and pattern span), which were themselves related; and (b) odd one out and listening span (CELWM) were related, although this just missed a significance in the ID group (*r* = .40). (2) Simple span measures (“component skills”) contributed to performance on CELWM measures. In the ID group, digit span related to listening span; and pattern span related to odd one out span. In the TD group, digit and picture span both related to listening span, and picture and pattern span both related to odd one out span. (3) Reading and spelling were strongly related in both groups (*r*s = .92/.94), but their relationships with number skills were lower (*r*s .40 - .49). (4) Mental age was positively related to educational achievement in both groups, but the relationships took different forms: for ID children, mental age related to number skills; for TD children, mental age related to reading and spelling.

Table 2 about here

Relationships between academic achievement and working memory.

Hierarchical multiple regressions were used to examine the relative contributions of working memory predictor variables to reading, spelling and number skills in each group. The predictions concerned the relative contributions of PSTM, VSSTM and CELWM in explaining variance in the educational achievement measures, therefore, predictor variables reflecting each of these constructs were included in the multiple regressions. A PSTM predictor variable was created by averaging the *z*-scores for word, digit and picture span (note that regressions based on a PSTM variable that averaged just the two traditional measures of PSTM, word and digit span, produced almost identical results). Similarly, the VSSTM predictor variable was the average of the *z*-scores for spatial and pattern span; and the CELWM predictor variable was the average of the *z*-scores for listening and odd one out span. Forced entry was used, whereby all predictors were entered simultaneously, to avoid making assumptions about which working memory variables may be of greatest importance in predicting educational achievement.

Initial analyses included all three predictors, but as VSSTM was not even close to significance in any regression, it was dropped in subsequent analyses as recommended by Field (2005). Mental age was not included in the regressions for three reasons. First, it related more strongly to CELWM than PSTM or VSSTM, and our predictions concerned the *relative* contributions of the three working memory variables, not mental age. Second, we had no specific predictions regarding the contribution of mental age to academic achievement. Third, the sample sizes were not sufficient to support the inclusion of an additional variable (the analyses reported contain at least 15 participants per predictor variable). Note that due to the relatively small sample sizes, these analyses are only able to detect large effects (Field, 2005).

ID group

Table 3a shows the regression for *reading*. The regression model was significant, $F(2, 32) = 8.58$, $p < .01$, accounting for 35% of the variance in reading scores. PSTM was a significant predictor of single word reading, but CELWM was not.

Table 3b shows the regression for *spelling*. The regression model was significant, $F(2, 32) = 7.71$, $p < .01$, accounting for 33% of the variance in spelling scores. PSTM was a significant predictor of single word spelling, but CELWM was not.

Table 3c shows the regression for *number skills.* The regression model was significant, $F(2, 32) = 10.04$, $p < .001$, accounting for 39% of the variance in number skills. CELWM was a significant predictor of performance in number skills, but PSTM missed significance (p =.08).

TD Group.

Table 3a includes the regression for *reading.* The regression model was significant, $F(2, 29) = 10.41$, $p < .001$, accounting for 42% of the variance in reading skill. PSTM was a significant predictor of single word reading, but CELWM was not.

Table 3b includes the regression for *spelling.* The regression model was significant, $F(2, 29) = 11.91$, $p < .001$, accounting for 45% of the variance in spelling skill. PSTM was a significant predictor of single word spelling, but CELWM was not.

Table 3c includes regression for *number skills.* The regression model was significant, $F(2, 29) = 4.78$, $p < .05$, accounting for 25% of the variance in number skills, however, neither of the working memory predictors were able to explain significant amounts of the variance (although CELWM was marginally significant, $p < .07$).

Tables 3a to 3c about here

Discussion

It was predicted that PSTM and CELWM would be related to reading and spelling in children with ID, and that CELWM (and possibly PSTM and VSSTM) would be related to number skills. These predictions were partially supported. For reading and spelling, PSTM was a significant predictor of performance in children with ID. However, CELWM was not significant in either case. For number skills, the only significant predictor of performance in children with ID was CELWM, supporting predictions; but the absence of relationships with PSTM and VSSTM did not support the speculation that these working memory abilities might also be related to number skills.

The current results suggest that PSTM is important in the development of early reading and spelling in children with ID, accounting for about one third of the variance in each of these skills. Good PSTM has long been regarded as implicated in decoding individual words, blending together phonemes and generating appropriate spellings based on accurate and clear phonological representations in TD children (e.g. Shankweiler, Liberman, Mark, Fowler & Fischer, 1979). The present results are also consistent with previous findings in children with ID, that the ability to *refresh* phonological codes in working memory is related to success in learning to read (Connors et al, 2001). In general, the links between PSTM, verbal rehearsal, phonological recoding and academic achievement would be worthy of further study, as these relationships are poorly understood in populations of children with ID.

It must be noted that relationships between working memory and reading/spelling in children with ID had not been found in two previous studies (Alloway & Temple, 2007; Bayliss et al., 2005), and it is not clear how to explain the differences in results. Alloway and Temple (2007) used a combined assessment of reading, spelling and comprehension (Wechsler Objective Reading Dimensions, WORD), whereas the current assessments required only single word reading and spelling, and did not include reading comprehension. Bayliss et al (2005) also incorporated a reading comprehension measure (judging whether sentences were true or not) as well as a lexical decision task (to assess decoding and word recognition) in their study. It is possible, therefore, that the increased complexity of the reading measures used in the earlier studies, in contrast to the very *simple* measures of single word reading and spelling used here, could account for the differences between results.

Contrary to predictions, CELWM was not a significant predictor of either reading or spelling in children with ID (or, indeed, in TD children). There are at least two possible explanations for the lack of relationships between CELWM and achievement in reading and spelling. Firstly, as already noted, the current study employed simple assessments of single word reading/spelling, and it might be that only more complex and demanding tasks such as sentence reading, comprehension and spelling during free writing require substantial CELWM resources. Secondly, measures of PSTM may relate to academic achievement in children with ID (and younger TD children such as those tested here), because PSTM is a very pure estimate of general working memory *capacity* in children who do not use memory strategies such as verbal rehearsal (Cowan, 2005). In fact, rehearsal deficits have often been noted in individuals with ID (Belmont & Butterfield, 1971; Hasselhorn & Mähler, 2007; Hulme & Mackenzie, 1992; Russell et al., 1996); and verbal rehearsal develops only gradually in TD children (e.g. Henry & Millar, 1993). Therefore, in samples where rehearsal is more prevalent, CELWM may become a more important predictor of reading and spelling than PSTM.

For those ID children with significant PSTM delays, measures can be taken to reduce memory demands (see Gathercole, Lamont & Alloway, 2006). These include using memory aids/supports (personal boards on desks with key information or visual reminders); reducing verbal demands (very short simple subject-verb-object sentences); and managing processing loads in classroom tasks (for example, in a writing task reduce vocabulary demands, shorten lengths of sentences, and provide a clear task structure to reduce executive demands). Our results suggest that mean scores of around *three items or less* (across the three PSTM tasks used here) would be cause for concern (of the 8 ID children in this category, 5 were largely unable to read or spell, 1 was weak, and 2 were making reasonable or good progress; one further child with a slightly higher span, 3.5, obtained scores of nearly zero on reading and spelling; no children with spans higher than 3.5 obtained markedly low scores on reading and spelling).

With respect to number skills, the only significant working memory predictor to relate to the performance of children with ID was CELWM, supporting previous findings in the literature (Alloway & Temple, 2007; Henry & MacLean, 2003). Thus, for children with ID, numerical operations seem to be dependent on CELWM, i.e. they require the ability to concurrently process and store relevant information. It is notable that although the current study and previous work employed similar measures of CELWM, each study included a *different* assessment of numerical ability (Alloway & Temple used the Wechsler Objective Numerical Dimensions (WOND), which assesses numerical operations and mathematical reasoning; Henry & MacLean used Quantitative Reasoning from the British Ability Scales 2, which assesses arithmetical problem solving; the current study evaluated simple number recognition and mathematical operations). This is interesting, particularly as there is evidence that the contribution of CELWM to arithmetic performance *varies* depending on task demands in TD children (Imbo & Vandierendonck, 2007). Given this, and the fact that, in the current study, the relationship between CELWM and number skills failed to reach significance in TD children, it might be concluded that CELWM is a more reliable and consistent predictor of mathematics in children with ID than it is in TD children.

The practical implication of the link between CELWM and number skills, is that reducing CELWM demands may be of particular help for children with ID when they are carrying out mathematical tasks. Henry and MacLean (2003) suggested that one way of reducing processing demands is to improve stored knowledge about numbers and arithmetical facts. In terms of the working memory model (Baddeley, 2000), long-term memory knowledge is accessed and integrated via the episodic buffer, thus contributing positively to performance on tasks that demand executive input. Greater depth of numerical knowledge should provide higher levels of support and, therefore, reduce the demands on central processing.

Relationships between VSSTM and academic achievement were absent in children with ID (and TD children). Although VSSTM has been found to contribute to arithmetical performance in younger TD children (Bull et al., 2008; Krajewski & Schneider, 2009; Rasmussen & Bisanz, 2005), the nature and sophistication of the arithmetical task may be a key factor. For example, Krajewski & Schneider (2009) reported that VSSTM was related to quantity-number competencies at age 6, but not mathematical school achievement at age 8. It may be, therefore, that only the very simplest aspects of the development of mathematical understanding are related to VSSTM.

Overall, relationships between academic achievement and working memory were similar in the ID and TD groups. For TD children, PSTM was the only significant predictor of reading and spelling; the same result as found for the ID group. With respect to number skills, no individual working memory predictors were significant in the TD group, but the predictor that came closest to significance was CELWM, the same variable that accounted for variance in the ID group. These results are compatible with recent findings in typical children, whereby residual variance in CELWM predicted mathematics achievement, and residual variance in PSTM predicted single word reading (Swanson, 2008). The current results suggest that the development of working memory, and its relationship to academic achievement, may not differ markedly in ID and TD populations. However, one limitation of this study was the relatively small sample size. Generalisations must be made cautiously, and larger sample sizes would offer more power to detect a greater range of smaller effects. Similarly, one reviewer noted that taking a working memory perspective led to a particular choice of working memory measures, which may have contributed to the findings. However, there is considerable evidence that *independent* memory systems support short-term memory storage (like the current PSTM) and simultaneous processing and storage abilities (like the current CELWM), in research that tests between one-and two factor models without assuming a particular theoretical framework (e.g. Swanson, 2008).

Finally, the structure of working memory appeared similar in children with ID compared to TD controls, with orderly relationships between span measures hypothesised to assess the same components of working memory. These findings suggest that the mechanisms responsible for performance in different areas of working memory may be similar in TD children and those with ID. However, children with ID still showed a mental age level deficit in *all three* measures of PSTM, but not in VSSTM or CELWM. The deficit in PSTM in children with ID is perhaps the most consistent finding in this area (e.g. Bayliss et al., 2005; Henry & MacLean, 2002; Hulme and Mackenzie, 1992; Russell et al., 1996; although see Connors, Carr & Willis, 1998; Jarrold & Baddeley, 1997). Henry and MacLean (2002) suggested that weaknesses in the utilisation of memory strategies (e.g. verbal rehearsal) may account for PSTM difficulties, but further research is necessary to rule out other explanations such as capacity limitations in the phonological store (Jarrold, Baddeley & Hughes, 2000), speech rate or scanning time impairments (Cowan, Nugent, Elliott, Ponomarev & Saults, 1999), or difficulties with redintegration of words at the point of recall (Hulme, Roodenrys, Schweikert, Brown, Martin & Stuart, 1997; Turner, Henry & Smith, 2000; Turner, Henry, Smith & Brown, 2004; Schweickert, 1993).

Summary. PSTM was a significant predictor of single word reading and spelling in children with ID; whereas CELWM was a significant predictor of number skills. These relationships were broadly similar in typically-developing children of the same mental age, suggesting that the structure of working memory and its relationship to academic achievement does not differ markedly in these two groups of children.

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Table 1. Mean performance (SD in brackets) of children with ID and mental age controls (TD) on all study variables. Differences between groups are significant where noted. Number skills, spelling and reading are given as raw scores.

Measure	*ID (SD)*	*TD (SD)*	*t-value (1,65)*	*Prob.*	*r*
Chron. Age	12:6 (6.6m)	7:5 (8.5m)	32.68	.000	.97
GCA (IQ)	56.6 (10.9)	100.7 (12.6)	15.40	.000	.89
Mental Age	7:7 (11.5m)	7:8 (15.3m)	.24	n.s.	.03
Number skills[1]	10.68 (4.87)	11.06 (4.32)	.343	n.s.	.04
Spelling[1]	20.24 (13.58)	24.09 (11.17)	1.26	n.s.	.15
Reading[1]	32.86 (24.03)	39.44 (20.05)	1.21	n.s.	.15
Word trials	7.79 (2.23)	9.09 (2.10)	2.46	.017	.29
Digit trials	9.37 (2.15)	11.84 (3.07)	3.85	.000	.43
Picture trials	5.12 (1.97)	6.63 (2.27)	2.92	.005	.34
Spatial trials	8.71 (2.23)	8.75 (1.88)	0.08	n.s.	.01
Pattern trials	19.26 (4.13)	18.41 (3.46)	0.92	n.s.	.11
Listening trials	4.05 (1.89)	4.29 (1.46)	0.59	n.s.	.07
Odd one out trials	7.36 (1.97)	7.96 (2.19)	1.19	n.s.	.15

[1] Raw scores for reading, spelling and number skills are given to facilitate group comparisons.

Table 2. Correlations between study variables. Data for the ID sample are shown above the diagonal; data for the TD sample are shown below the diagonal.

Variables	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
1 MA	-	.59**	.32	.35	.29	.29	.39	.36	.54*	.65**	.40
2 Number	.38	-	.40	.40	.36	.29	.51*	.16	.38	.58**	.37
3 Spelling	.63**	.49*	-	.92**	.58**	.49*	.35	.05	.06	.23	.07
4 Reading	.67**	.47*	.94**	-	.60**	.47*	.41	.19	.08	.28	.17
5 Word	.49*	.15	.55*	.55*	-	.67**	.52*	.17	.06	.36	.06
6 Digit	.48*	.33	.59**	.49*	.71**	-	.44*	.25	.24	.54*	.18
7 Picture	.44	.51*	.54*	.61**	.52*	.51*	-	.22	.27	.34	.24
8 Spatial	.42	.27	.18	.23	.05	.16	.18	-	.59**	.29	.39
9 Pattern	.30	.17	.18	.16	.23	.36	.41	.48*	-	.33	.53*
10 Listening	.48*	.52*	.49*	.38	.43	.59**	.51*	.27	.43	-	.40
11 Odd one out	.34	.33	.44	.41	.44	.45	.50*	.36	.59**	.55*	-

$p < .01$ *

$p < .001$ **

Table 3a: Regressions predicting reading performance for children with ID (upper rows) and TD children (lower rows in italics).

Predictor	**B**	**SE B**	**β**	**t**
PSTM	16.60	4.51	.576	3.68*
CELWM	0.95	4.50	.033	0.21
PSTM	*14.36*	*4.41*	*.608*	*3.26**
CELWM	*1.30*	*4.26*	*.057*	*0.31*

Table 3b: Regressions predicting spelling performance for children with ID (upper rows) and TD children (lower rows in italics)

Predictor	**B**	**SE B**	**β**	**t**
PSTM	9.68	2.59	.595	3.73*
CELWM	-1.10	2.59	-.067	-0.42
PSTM	*7.16*	*2.39*	*.544*	*3.00**
CELWM	*2.22*	*2.30*	*.175*	*0.97*

*$p < .01$.

Table 3c: Regressions predicting number skills performance for children with ID (upper rows) and TD children (lower rows in italics)

Predictor	**B**	**SE B**	**β**	**t**
PSTM	1.61	0.89	.276	1.82#
CELWM	2.65	0.89	.454	2.99*
PSTM	*0.66*	*1.08*	*.130*	*0.63*
CELWM	*1.98*	*1.04*	*.403*	*1.90#*

#*p* < .10, **p* < .01.