Working memory performance in children with and without learning disabilities

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Acknowledgements:
This research was funded in part by the Wellcome Trust, grant number 042860.
We would like to thank the children and teachers from the following schools who kindly took part in this project: Garratt Park School; Southfields Community College; Lilian Baylis School, Highshore School, Headington Middle School and Sandhills
Community Primary School. Thanks are also due to Cayne Smith, Michelle Wysling
and Katherine English for their work with the children.
Abstract

Performance on seven working memory span tasks was examined in children with learning disabilities (LD) aged 11-12 years. They were compared with typically developing children of the same chronological age (CA) and the same mental age (MA). Limited evidence was available to support a “difference” position whereby the LD group obtained lower scores than both the CA and MA groups (word span only). Some evidence was found for the “developmental” position whereby the LD group performed at the same level as the MA group, but more poorly than the CA group (digit span, reverse digit span, odd one out span - a visuo-spatial complex span task). Finally, some evidence supported a “difference” account whereby children in the LD group performed better than the MA group, although still not as well as the CA group (spatial span, pattern span, listening span - a verbal complex memory span task). Results were interpreted with reference to the role of strategies in working memory performance.
Research on memory development in children with learning disabilities often describes memory deficits including poor short- and long-term memory, difficulties with encoding, poor use of retrieval cues and poor use of memory strategies such as rehearsal (e.g. Borkowski, Peck & Damberg, 1991; Bray & Turner, 1986; Belmont, 1978; Detterman, 1979; Ellis, 1978; Weiss, Weisz & Bromfield; 1986). The current study examined short-term storage and processing in children with learning disabilities, using the working memory model (Baddeley, 1986) as a theoretical framework. Children with learning disabilities were compared with children matched for mental and chronological age on several measures of working memory span. Our key question was whether or not working memory performance kept pace with mental age.

Two theoretical approaches to cognitive processing in children with learning disabilities are the “developmental” and “difference” or “defect” models. The “developmental” position (Zigler, 1969; Zigler & Balla, 1982) characterises the behaviour of those with learning disabilities, not due to acquired brain injury, as inherently similar to those without learning disabilities. Underlying cognitive processes are the same as those in typically developing children, only slower to develop, and reaching asymptotic levels at an earlier stage. As Weiss, Weisz and Bromfield (1986) noted, this position assumes that children with learning disabilities go through the same stages as typically developing children (the “similar sequence hypothesis”), and that their cognitive structures are the same (the “similar structure hypothesis”). This model predicts that if groups of children with and without learning disabilities are matched on current level of acquired intellectual performance (i.e. mental age), performance on cognitive tasks should not differ between the groups.
The “difference” or “defect” position regards the behaviour of those with learning disabilities as different from those without learning disabilities. Usually, some kind of structural deficit (e.g. weaker stimulus trace, Ellis, 1963) or process deficit (e.g. rehearsal, Belmont, 1978; Ellis, 1970) is hypothesised. Ellis (1969) described individuals with learning disabilities as having “defective behaviour when compared to others of similar chronological age” (Ellis, 1969, p. 558, italics original). Milgram (1973) regarded those with learning disabilities as demonstrating an “equal-MA deficit”. Even when matched to younger children for mental age, those with learning disabilities performed more poorly on tasks requiring verbal mediation (verbal input, output or organisation). Both of these authors can be described as holding a “difference” position, although they disagree as to whether the appropriate comparison group is matched for CA or MA. A less conventional “difference” position was taken by Kohlberg (1968) who argued that children with learning disabilities were richer in “general experience” than younger children with the same mental age. This extra experience was argued to confer an advantage in performance over younger children matched for mental age.

Weiss et al. (1986) examined these positions by reporting a meta-analysis of studies on information processing tasks, including several studies of memory performance. All utilised the mental age matched comparison group. Weiss et al. (1986) concluded that children with learning disabilities did have deficits in memory performance, supporting the conventional “difference” position. However, there was considerable heterogeneity in the results for different types of memory tasks, with some studies finding support for the other two models. In focussing on the mental age match design, Weiss et al. (1986) were testing between the Milgram (1973) or Kohlberg (1968) “difference” account and the Zigler (1969) “developmental”
approach. Although Zigler (1969) described Ellis’ position as a difference account with respect to mental age matched comparison groups, Ellis has always used CA comparison groups (e.g. Ellis, 1969; Ellis & Cavalier, 1982; Ellis, Deacon & Wooldridge, 1985).

These studies, for the most part, concentrated on individual measures of memory performance ranging from iconic storage to long-term memory. The focus here was on short-term storage and processing. The working memory model (Baddeley & Hitch, 1974; Baddeley, 1986) provides a clear theoretical framework for looking at temporary storage and processing of information and has become the dominant theoretical account in recent years. Working memory is divided into a central executive or attentional control system plus two “slave” storage systems for the temporary retention of information. One storage system, the phonological loop, is for phonological material and the other, the visuo-spatial sketch pad is for visual and spatial information. These two sub-systems are limited in capacity to a few items and decay is very rapid. Items can be maintained in each system for short periods of time by using modality specific rehearsal mechanisms. Evidence for rehearsal derives from studies showing that engaging in concurrent visual or spatial activity disrupts short-term visuo-spatial storage (Brooks, 1967, Byrne, 1974) and engaging in concurrent speech (e.g. “the, the, the”…) disrupts phonological short-term storage (Baddeley, Lewis & Vallar, 1984; Murray, 1968).

In children without learning disabilities, the working memory model has received much attention in the last two decades, accounting for many of the experimental findings very successfully (see Gathercole, 1998; and Henry & Millar, 1993 for reviews). There have been fewer working memory studies examining children with learning disabilities. One exception to this is a detailed series of
experiments by Hulme and Mackenzie (1992). They looked at children with moderate to severe learning disabilities (I.Q. levels between 20 and 50) and concentrated on the phonological loop system. They found lower digit and word spans compared to children matched for mental age. Memory span scores also increased at a much slower rate over five years for the children with learning disabilities compared to the mental age matched children. This study, therefore, provided evidence for the difference position. Russell, Jarrold and Henry (1996) also found evidence for the difference position using memory span for words and several measures of complex span (memory span tasks requiring concurrent storage and processing).

However, there are studies using mental age match designs that have supported the developmental position. Jarrold and Baddeley (1997) found no differences between children with moderate learning disabilities and typically developing children matched for mental age on digit span and Corsi span (memory for spatial locations). The same result was found by Vicari, Carlesimo and Caltagirone (1995) using both forwards and backwards measures of recall. Jarrold, Baddeley and Hewes (2000) failed to find differences between children with moderate learning disabilities and typically developing children matched for mental age on a word span task. There are several other studies that have used working memory tasks, although not explicitly mentioning the working memory model. Some have supported the difference position, reporting deficits for children with learning disabilities compared to mental aged matched groups in auditory digit span (Marcell and Weeks, 1988; Marinossosn, 1974), memory span for abstract pictures (Marinossosn, 1974) and memory span for meaningful pictures (Burack & Zigler, 1990). Others have supported the developmental position (e.g. Brown, 1974, found deficits in forwards and backwards digit span).
What can we make of this research? Little agreement exists as to whether working memory performance keeps pace with mental age or not, offering no clear support for either the development or difference accounts. There are several features of the research that may account for the disagreements. The assessments of intellectual disability varied considerably from study to study. Many used measures of receptive vocabulary to estimate I.Q. and this may provide a somewhat unbalanced picture of general ability. Some studies used school records or the most recent ability test that had been administered. Considerable inconsistency could result from these techniques. The most reliable method is to use the same standardised assessment of ability for all participants, including the controls, but this is rarely done. In addition, none of the reviewed studies used a wide range of working memory tasks in the same study. It is possible that working memory performance in children with learning disabilities varies depending upon the type of memory task. Some aspects of working memory may be relatively better than others. In fact, the arguments developed by Milgram (1973) would lead to the prediction that MA-LD differences in performance would occur for verbal memory tasks but not for non-verbal memory tasks. Ellis et al. (1985), in adults with learning disabilities, has found that pictures are stored better than letters in a Brown-Peterson task.

One study that has used a range of working measures (Gathercole & Pickering, in press) found a number of differences between children with and without special educational needs. These included differences on phonological short-term memory tasks using nonwords, visuo-spatial tasks involving recalling the position and order of a sequence of black squares and recalling routes through mazes, and central executive measures (reverse digit span and listening span). Despite the breadth of this study, we
do not know exactly what levels of learning disability the children had and a mental age matched comparison group was not included.

In the current study, both mental and chronological age matched control groups were employed to give clear evidence as to the strengths and weaknesses of working memory in children with learning disabilities. The mental age match comparison allowed us to examine whether working memory in children with learning disabilities was at a level commensurate with respect to their current level of cognitive development. Although MA is an imperfect measure of intellectual ability, it does give an indication of the current level of intellectual functioning that is independent of memory. Our measure of MA specifically avoided using any memory measures. The chronological age match comparison allowed us to assess whether all aspects of working memory were poorer in children with learning disabilities, using the benchmark favoured by Ellis (1969; Ellis & Cavalier, 1982).

The same standardised test of ability (British Ability Scales II – verbal reasoning scale and non-verbal reasoning scale) was used with all participants to ensure that learning disability was clearly defined and measured, and to ensure that the control groups were properly matched. Working memory was evaluated using a wide range of memory span tasks to assess the phonological loop, the visuo-spatial sketch pad and the central executive. The tasks were taken from previous literature as being reliable measures of each component of working memory. For example, the capacity of the phonological loop is typically assessed using materials that can be stored phonologically, usually words, nonsense words or digits. Here, the phonological memory span tasks were digit span and word span. Temporary visual and spatial storage, the domain of the visuo-spatial sketch pad, were assessed separately using memory span for nonsense pictures (nonsense pictures were used to
reduce the likelihood of them being labelling and remembered as words) and memory span for spatial positions (based on the Corsi span task).

Simple short-term storage of visuo-spatial or phonological materials can be contrasted with span tasks that require some form of processing together with recall of the results of that processing (e.g. Daneman & Carpenter, 1980). The processing requirement calls for central executive resources on top of short-term storage. Span tasks of this nature can be referred to as “complex” span tasks or central executive-loaded span tasks. One complex span task requiring phonological processing and storage (listening span – derived from Leather & Henry, 1994) was included as well as one requiring visual and spatial processing and storage (odd one out span – derived from Hitch & McAuley, 1991). Listening span requires the child to state whether a sentence is true or false, and then retain the last word of that sentence while subsequent sentences are presented and processed. Odd one out span requires the child to choose one of three nonsense pictures that is different from the other two and retain its spatial position while subsequent odd one out decisions are made. A third central executive-loaded span task was reverse digit span. This task requires that a list of numbers be retained and reversed before recall, calling upon central executive resources to manipulate the information (e.g. Lehto, 1996). Overall, the current battery of working memory tasks was similar to that used by Gathercole and Pickering (in press) except that the focus here was purely on span measures to facilitate comparisons between the different working memory components.

Method

Participants
Participants were 139 children with and without learning disabilities. The CA group (chronological age match group) included 45 children aged 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 LD group (learning disabilities 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 learning disabilities (mean General Conceptual Ability 57.2, s.d. 11.7, range 40-79). This range encompassed borderline, mild and moderate learning disabilities as described in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV). The MA (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 11 to 12-year-old children came from two mainstream inner city schools in South London and one mainstream middle school in Oxford. Some of the children with learning disabilities came from the two South London mainstream schools (n=9) and the remainder came from two special schools for children with learning disabilities also in South London. The 7 to 8-year-old children came from a mainstream primary school in Oxfordshire. It was not possible to match exactly for gender in each of our subgroups, particularly in the LD group. There were 15 boys and 30 girls in the CA group, 42 boys and 11 girls in the LD group and 21 boys and 20 girls in the MA group. All children were tested individually in their schools. Table 1 gives full details of the sample. There was a slight mental age
advantage for the MA group (7 years 10 months as opposed to 7 years 5 months in the LD group). A one-way analysis of variance on mental age scores showed a main effect of group overall, $F(2,136) = 294.2, p < .001$, as expected. Post hoc Scheffe tests (alpha level 5%) indicated that the CA group had significantly higher mental ages than the LD group ($p < .001$) and the MA group ($p < .001$). However, the LD and MA groups did not differ significantly.

Table 1 about here

For two children with moderate LD, there was missing data for some span tasks: digit span, pattern span and reverse digits for one child; and listening span and odd one out span for another. In the former case, the child did not want to participate in the final session, in the latter case, the child did not want to attempt the two complex span tasks (this probably means he was unable to manage them). There was also missing data for two children in the average ability control group: pattern span, spatial span and odd man out span for both of them. This was because one child was excluded from school and another moved away during the testing period.

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

**Procedure and Materials**

Children were given seven memory span tests over two sessions. Some of the children were also participating in a larger study on eyewitness memory (half of the CA group and most of the LD group). All children were assessed using four of the six subtests from the British Ability Scales II (BAS II – Elliott, 1996), namely Word Definitions and Verbal Similarities (comprising the verbal reasoning scale) and
Matrices and Quantitative Reasoning (comprising the non-verbal reasoning scale). General Conceptual Ability (GCA) was pro-rated from these two core scales (we did not administer the third core scale, Spatial Reasoning, as it included a memory test).

For the children with learning disabilities and the MA comparison group, four of the memory span tests were administered in the same session as the BAS II: word span, spatial span, listening span and odd one out span (in that order). Three further span tests were given as part of the Test of Learning and Memory (TOMAL – Reynolds & Bigler, 1994) in another session: digit span, pattern span and reverse digits. Overall, two span tasks assessed phonological short-term memory (digit span and word span), two assessed visuo-spatial short-term memory (spatial span and pattern span) and three assessed “complex” memory span involving central executive resources (listening span, odd one out span and reverse digit span). Within the complex memory span tasks, two were verbal tasks (listening span, reverse digits) and one was a visuo-spatial task (odd one out span). The order of testing was slightly different for the CA control group because of greater constraints imposed by lesson times. These children received the tasks in the same order as the other children, except that pattern span, spatial span and odd man out span were administered separately in a final extra session. Each span task is described below.

*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.

**Spatial span.** This was based on Corsi span. The child was presented with an A4-sized 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.

**Listening span.** This task was based on one used by Leather and Henry (1994). 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. The full span task is given in the Appendix.

*Odd one out span.* This task was loosely based on one used by Hitch and McAuley (1991) and involved remembering the spatial locations of nonsense pictures over trials.

First, children were shown an A4 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 A4 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 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 A4 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 A4 sheet with three 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 A4 sized 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 and extra 0.5 credit if one trial at the next, higher, list length was correct.

Figures 1 and 2 about here

The other three span tasks were based on tests in the Test of Learning and Memory (TOMAL – Reynolds & Bigler, 1994).

*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.

*Pattern span.* This task is called visual sequential memory in the TOMAL. 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.

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

Reliability and validity of the span measures

Each span task consisted of two or three presentations (i.e. trials) at each list
length. In order to assess the reliability of each measure, span scores were calculated
from each set of first presentations (i.e. all trial 1’s), each set of second presentations
(all trial 2’s) and each set of third presentations (all trial 3’s) where three trials were
always administered (listening span and odd one out span). Together with the total
span score, calculated as described in the previous section, there were three or four
estimations of span for each task that could be used to estimate reliability (this method
is similar to that used by Engle, Tuholski, Laughlin and Conway, 1999). The
correlations between each pair of span estimations (i.e between each possible pairing
of the total span, the first, second and third (where available) trial estimations) were
calculated and the average of these correlations provides a measure of task reliability.
The means of the correlations for each span task were as follows: digit span = .76 (range .63 to .84); word span = .79 (range .65 to .86); pattern span = .80 (range .73 to .86); spatial span = .86 (range .75 to .92); listening span = .74 (range .63 to .87); odd one out span = .79 (range .64 to .90); and reverse digit span = .82 (range .72 to .93). These all indicated moderate to good reliability.

Correlations were also carried out between each of the memory span tasks to examine whether span tasks measuring the same working memory components were more strongly related to each other than to span tasks measuring different components. Table 2 gives these correlations. Only significance values better than $p < .01$ (two-tailed) were accepted given the number of correlations carried out. The first thing to note was that every span measure was significantly related to every other span measure, apart from word span and pattern span. Secondly, mental age was strongly related to every span measure: digit span, $r(138) = .65$ $p < .001$; word span, $r(139) = .56$ $p < .001$; pattern span, $r(136) = .59$, $p < .001$; spatial span, $r(137) = .66$, $p < .001$; listening span, $r(138) = .69$ $p < .001$; odd one out span, $r(136) = .50$ $p < .001$; and reverse digit span, $r(135) = .58$ $p < .001$. Clearly, working memory span scores were closely linked to mental age.

In order to provide a more conservative test of the relationships between the span measures, mental age was partialled out in the next set of correlations between the memory span measures. Table 2 gives these correlations in italics. Again, only significance values of better than $p < .01$, two-tailed, were accepted. The two phonological memory tasks (digit span and word span) were significantly related to each other, $r (135) = .30$, $p < .001$, and not to any other span measures. This indicated that the phonological short-term storage measures were distinct from the other span measures and that the two phonological tasks were, at least to some extent, measuring...
the same construct. Spatial span and pattern span were significantly related to each
other, $r(133) = .34, p < .001$, suggesting that our two visuo-spatial tasks were
measuring the same construct. Finally, the three span measures with a central
executive component were related to each other (listening span with odd-one-out
span, $r(133) = .23, p < .01$; listening span with reverse digit span, $r(134) = .26, p <
.01$; and odd-one-out span with reverse digit span, $r(132) = .23, p < .01$), again
implying construct validity. All of the predicted correlations were, therefore,
significant.

However, there were also relationships between odd-one-out span and both of
the simple visuo-spatial span tasks (pattern span, $r(132) = .25, p < .01$; and spatial
span ($r(133) = .25, p < .01$). This was probably because all three tasks involved the
processing of visual and spatial information. Listening span and spatial span were
unexpectedly related ($r(133) = .38, p < .001$). It is possible that the children were
using a spatial strategy to help them in the listening span task. Alternatively spatial
span may not be exclusively a “simple” measure of short-term visuo-spatial storage as
it related significantly to two of the central executive-loaded span measures.

To summarise, all of the tasks within the same working memory domain
related to each other, providing evidence of construct validity. However, there was
some cross-over with respect to the visuo-spatial and complex span measures
indicating some relationships between these two domains of working memory.

Table 2 about here

Memory span data

Mean memory spans for each group and for each span task are given in Table
3. The data were subjected to a multivariate analysis of variance with group as one
between subjects factor (LD, CA, MA) and gender (male, female) as the other. Each
of the span tasks were entered as dependent variables. The effect of group was highly
significant overall, Pillai’s Trace = .79, F(14, 248) = 11.57, p < .001, and was also
significant for every span measure separately [F’s (2,129), p < .001 in each case – F-
values were as follows: digit span (26.5); word span (19.4); pattern span (27.3);
spatial span (46.3); listening span (45.1); odd-one-out span (15.7); and reverse digit
span (31.0)]. There was no main effect of gender and no interaction between gender
and group. Only one span task showed a main effect of gender (digit span, F(1, 129)
= 4.40, p < .05, - females had slightly higher spans that males overall) and in no case
was the interaction between group and gender significant.

Post hoc Scheffe tests with an alpha of p < .05 were used to examine the
nature of the group differences in memory span. The “developmental” model
predicted that span scores should keep pace with mental age (i.e. LD = MA < CA)
whereas the “difference” models predicted that span scores would either fall behind
mental age or exceed it.

Scores on digit span, reverse digit span and odd-one-out span supported the
“developmental” model. In each case, children with learning disabilities did not differ
significantly from the matched MA group, but both of these groups obtained
significantly lower scores than the CA group. Word span scores supported the
conventional “difference” model. Here, the children with learning disabilities
obtained significantly lower span scores than the matched MA group, who in turn
obtained significantly lower scores than the CA group. The two visuo-spatial short-
term storage tasks (pattern span and spatial span) and listening span produced a
pattern consistent with the unconventional “difference” position (Kohlberg, 1968).
For these tasks, children with learning disabilities obtained significantly higher scores than the MA matched group, but significantly lower scores than the CA group.

Therefore, our results supported each of the three models in part, and underlined the very strong relationships between mental age and all of the measures of memory span.

Table 3 about here

Discussion

Using a range of working memory span tasks, we assessed phonological short-term storage (the phonological loop), visuo-spatial short-term storage (the visuo-spatial sketch pad) and short-term storage with concurrent processing demands (the central executive) in 11- to 12-year-old children with learning disabilities. They were compared with groups of typically developing children matched for chronological age (CA) and mental age (MA) in order to examine whether working memory was closely related to current developmental level or mental age (the “developmental” position), current chronological age, or neither (the “difference position”). Performance might exceed mental age (the unconventional “difference” position, Kohlberg, 1968) or performance might not reach the mental age level (the “defect” or conventional “difference” position).

Children with learning disabilities always obtained lower working memory span scores than the CA group. However, their performance relative to the MA control group, varied depending upon the span task. For three span tasks, children with learning disabilities performed significantly better than the MA group, although not as well as the CA group (these included pattern span, spatial span and listening
span), supporting the “unconventional difference” position. For one span task (word span), the more conventional “difference” model was supported as children with learning disabilities obtained lower scores than the MA group, who in turn obtained lower scores than the CA group. For the remaining three span tasks, children with LD obtained the same scores as children matched for mental age (digit span, reverse digit span and odd one out span), with both of these groups being outperformed by the CA group, supporting the “developmental” model.

What do these results imply? Looking at the comparisons between the MA and LD groups, scores on both measures of simple visuo-spatial short-term storage were better in the children with learning disabilities than the typically developing MA matched children. This suggests that some aspect of general experience was improving these children’s performance over and above intellectual ability. It may be premature to speculate that children with learning disabilities have a relative advantage on simple visuo-spatial working memory tasks, but there is some previous evidence for this. Milgram (1973) reviewed a large number of studies and concluded that children with learning disabilities showed a verbal developmental lag. Ellis et al. (1985) found that adults with learning disabilities showed poorer recall for pictures than letters in a Brown-Peterson task. Finally, Martin, West, Cull and Adams (2000) found that adults with mild learning disabilities were poorest on the verbal memory subtests from the Rivermead Behavioural Memory Test and best on the visual memory subtests. However, it must be noted that performance on our “complex” odd one out span task was equal in the MA and LD groups, so if there is a relative LD advantage on visuo-spatial span tasks, this is restricted to “simple” span tasks.
Children with learning disabilities performed below their mental age level on word span. One might speculate that children with learning disabilities performed poorly on word span because they were not using verbal rehearsal. Several authors have proposed that rehearsal deficits can explain the poor verbal short-term memory performance found in children with learning disabilities (Belmont, 1978; Brown, 1974; Ellis, 1970). Also, using a working memory framework, Hulme & Mackenzie (1992) and Jarrold et al., (2000) found no evidence of word length effects (indicative of verbal rehearsal or at least some form of phonological coding) in children with moderate to severe LD (although small word length effects were found by Russell et al. (1996) in a similar sample). Typically developing children show evidence of using some form of verbalisation strategy with auditory presentation from the age of seven years (Henry, 1991; Henry, Turner, Smith & Leather, 2000), so our MA group may well have begun to use a verbal rehearsal strategy to improve their performance on word span.

If lack of verbal rehearsal can explain the poor word span performance of children with learning disabilities, this leaves the question of why the LD group performed as well as the MA group on digit span and reverse digit span. A speculative explanation could be that digits are overlearned items with higher levels of familiarity than even the high frequency words that were used here. Recent work has implicated a long-term memory component in phonological memory span (Hulme, Maughan & Brown, 1991; Hulme, Roodenrys, Brown & Mercer, 1995), possibly mediated by “redintegration” – a process of assembling items to be recalled that is aided by long-term knowledge (Hulme, Roodenrys, Schweickert, Brown, Martin and Stuart, 1997; Turner et al., 2000). For a child using verbal rehearsal, the small familiarity difference between words and digits might be less significant compared to the larger
advantage of using verbal rehearsal. For the non-rehearsing child with LD however, the familiarity difference might favour digits much more substantially. Looking at the means (Table 3), there was very little difference between digit span and word span for the MA group (in fact, a slight numerical advantage for word span), whereas digit spans were just over half an item higher than word spans in the LD group. To be fair, there was just as large an advantage to digit span in the CA group, so it may be that for these older and more fluent rehearsers, the familiarity advantage returns.

We have attempted to explain the performance of children with learning disabilities on the two simple phonological span tasks with reference to the role of verbal rehearsal. How can we explain their relatively better performance compared to the MA group on listening span? This was a surprising result as we might have expected that complex verbal tasks would cause difficulty for children with learning disabilities. The explanation for this may also reside in strategy use. For listening span, it is probably difficult to use rehearsal strategies, particularly for novice rehearsers such as 7- or 8-year-olds. Rehearsing existing words whilst processing the next sentence is a complicated operation and perhaps beyond the capabilities of both our LD and MA groups (although it might be more manageable for the CA group). Hence, it could be argued that neither the LD nor the MA groups were using rehearsal strategies for this complex verbal task. Without the effects of strategy use, the LD group may have achieved higher scores because of increased levels of general familiarity with the items or more practice carrying out joint remembering and processing tasks in school work.

These arguments lead to an account of working memory performance in children with learning disabilities that ties in with all three of the models presented.
What we might call “baseline” working memory performance, without regard to improvements that can be brought about by using rehearsal strategies, is better in children with learning disabilities than in typically developing children of equal mental age. This is in accord with an unconventional “difference” position whereby the increased age of our LD group gives them an advantage on many tasks where general experience can aid performance. In tasks where strategies can be used to enhance performance, children with learning disabilities might begin to show either equal performance or a relative disadvantage compared to children matched for mental age. This would reflect the extent to which the typically developing children are using effective remembering strategies whereas the children with learning disabilities are not. In our phonological span tasks, for example, we have suggested that rehearsal may have been used by the mental age matched group but not the LD group. Therefore, once rehearsal strategies are added to the equation, we begin to see evidence for the “developmental” or conventional “difference” models. Although evidence may apparently support difference models, we would argue that there need not be any underlying differences in the cognitive structures used for remembering tasks. The differences could reside in the processes used, namely strategic processes such as verbal rehearsal. Differences could also reside in the levels of familiarity with tasks or task items which impact on long-term memory “back-up” for short-term memory tasks (e.g. redintegration), and these differences may favour the older learning disabled child over the younger MA matched child.

Of course, these are only speculations and they require further testing. There is evidence that typically developing children use some form verbal rehearsal or phonological coding strategy from around the age of 7 years (e.g. Henry, Turner, Smith & Leather, 2000) and that children with learning disabilities do not (e.g. Jarrold
et al., 2000), but this needs to be tested in the same experiment. Previous studies have included participants with mental ages of 4 to 5 years (e.g. Jarrold et al., 2000) and the MA matched groups would, therefore, not be expected to use rehearsal at this age. It is important to include LD groups with mental ages higher than 7 to 8 years to test for the possibility that rehearsal develops relatively later in these children.

We also need to look in more detail at the relative advantage on simple visuo-spatial span tasks that children with learning disabilities had in our study. If the LD over MA advantage were replicated, this could have important implications for teaching methods for children with learning disabilities, supporting the use of visual and spatial materials rather than the more typical verbally based methods. The visual and spatial tasks also need to be carefully examined to ensure that children really are not using memory strategies to enhance recall. We also need to examine why children with LD did not show a relative advantage on the complex visuo-spatial task (odd one out span). We cannot simply conclude that central executive-loaded span tasks are more difficult for children with LD, because they performed at above mental age levels on the other complex task, listening span. Finally, other explanations for variations in performance in different working memory tasks must be considered such as differences in motivation for different tasks, history of failure with particular tasks and novelty/practice tradeoffs (i.e. all children take some time to develop the means of performing tasks, and more exposure to a task is likely to result better performance). This latter point might be relevant for digit span which is a commonly used task in tests of intelligence and likely to have been encountered before by children with a history of learning disabilities.
The correlations between the span tasks were all significant, but this was largely accounted for by mental age (correlations between span measures and mental age ranged between .50 and .69). Memory span performance on all tasks was strongly linked to current level of intellectual functioning as measured by mental age. With the effects of mental age partialled out, we obtained slightly mixed evidence for modality specific associations between the span tasks. For phonological short-term memory the two span tasks, word and digit span, were related to each other but not to other tasks. Pickering, Gathercole and Peaker (1998) also found no relationships between phonological and visuo-spatial short-term span performance. However this was not the case for the short-term visuo-spatial tasks and the span tasks with a central executive loading in our study. Whilst we found the predicted relationships between spatial and pattern span and between the three central executive-loaded span measures, there were additional relationships between odd-one-out span and both of the short-term visuo-spatial span tasks, and between spatial span and listening span. We speculate that spatial span may be more than a simple measure of visuo-spatial short-term storage, as it related to two of our central executive-loaded span tasks. It is also possible that some children used a spatial strategy during the listening span task. The odd-one-out span task may have related to the spatial and pattern span tasks because the complex task encompasses many of the skills tapped by the simple tasks (e.g. analysing nonsense figures, recalling the locations of items).

To conclude, this study has provided evidence that children with learning disabilities have areas of relative weakness and strength in working memory performance. Although they were consistently poorer than children matched for chronological age on all span tasks, performance exceeded that of mental age matched controls on visuo-spatial short-term storage (pattern span and spatial span) and
phonological storage plus processing (listening span). A clear area of weakness for
the children with learning disabilities was in word span, and this could have
implications for the acquisition of other cognitive skills such as vocabulary (e.g.
Gathercole & Baddeley, 1989; 1990; Gathercole, Service, Hitch, Adams & Martin,
1999; Michas & Henry, 1994). Although no one model of cognitive development in
children with learning disabilities was supported, we have offered a tentative
explanation for these results. “Baseline” performance of children with learning
disabilities, without regard to strategy use, may be better than those matched for
mental age (possibly due to greater experience and familiarity with items), although
still poorer in comparison with those matched for chronological age. However,
children with learning disabilities may not begin to use rehearsal strategies, as
typically developing children do from around the age of 7 years, leading to weak
performance on working memory tasks that benefit from such strategies.
References


Figure 1

Response card at list length two showing two rectangular blank boxes, divided into three sections for the odd one out span task

Figure 2

Examples of figures used in the odd one out span task
Table 1
Details of participants.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Learning Disabilities</th>
<th>Mental Age Match Group</th>
<th>Chronological Age Match Group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chronological Age</strong></td>
<td>11 years 11 months</td>
<td>7 years 11 months</td>
<td>12 years 1 month</td>
</tr>
<tr>
<td></td>
<td>(s.d. 6 months)</td>
<td>(s.d. 6 months)</td>
<td>(s.d. 5 months)</td>
</tr>
<tr>
<td><strong>Mental Age</strong></td>
<td>7 years 5 months</td>
<td>7 years 10 months</td>
<td>13 years 0 months</td>
</tr>
<tr>
<td></td>
<td>(s.d. 15 months)</td>
<td>(s.d. 13 months)</td>
<td>(s.d. 16 months)</td>
</tr>
<tr>
<td><strong>General Conceptual</strong></td>
<td>57.2</td>
<td>100.9</td>
<td>103.8</td>
</tr>
<tr>
<td><strong>Achievement (GCA)</strong></td>
<td>(s.d. 11.7)</td>
<td>(s.d. 12.3)</td>
<td>(s.d. 9.3)</td>
</tr>
</tbody>
</table>
Table 2

Correlations between all of the memory span tasks and mental age. Correlations given in italics are those between memory span tasks with mental age partialled out.

<table>
<thead>
<tr>
<th></th>
<th>Word</th>
<th>Pattern</th>
<th>Spatial</th>
<th>Listen.</th>
<th>Odd</th>
<th>Reverse</th>
<th>MA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digit Span</td>
<td>.56*</td>
<td>.46**</td>
<td>.40**</td>
<td>.47**</td>
<td>.40**</td>
<td>.49**</td>
<td>.65**</td>
</tr>
<tr>
<td></td>
<td>.30**</td>
<td>.12</td>
<td>-.05</td>
<td>.05</td>
<td>.11</td>
<td>.18</td>
<td></td>
</tr>
<tr>
<td>Word Span</td>
<td>.20</td>
<td>.24*</td>
<td>.36**</td>
<td>.25*</td>
<td>.35**</td>
<td>.56**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-.20</td>
<td>-.21</td>
<td>-.06</td>
<td>-.05</td>
<td>.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pattern Span</td>
<td></td>
<td>.60**</td>
<td>.52**</td>
<td>.47**</td>
<td>.32**</td>
<td>.59**</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>.34**</td>
<td>.19</td>
<td>.25*</td>
<td>-.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Span</td>
<td></td>
<td>.66**</td>
<td>.49**</td>
<td>.47**</td>
<td>.66**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>.38**</td>
<td>.25*</td>
<td>.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listen. Span</td>
<td></td>
<td>.49**</td>
<td>.55**</td>
<td>.69**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>.23*</td>
<td>.26*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odd span</td>
<td></td>
<td>.44**</td>
<td>.50**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>.23*</td>
<td>.58**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** p < .001

* p < .01
Mean memory span scores for children in each of the study groups. Standard deviations are given in brackets.

<table>
<thead>
<tr>
<th>Memory Span Task</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Learning Disabilities (LD)</td>
</tr>
<tr>
<td>Digit span</td>
<td>4.3 (.9)</td>
</tr>
<tr>
<td>Word span</td>
<td>3.8 (.7)</td>
</tr>
<tr>
<td>Pattern span</td>
<td>3.8 (.9)</td>
</tr>
<tr>
<td>Spatial span</td>
<td>4.5 (1.2)</td>
</tr>
<tr>
<td>Listening span</td>
<td>2.1 (.9)</td>
</tr>
<tr>
<td>Odd one out span</td>
<td>3.0 (1)</td>
</tr>
<tr>
<td>Reverse digit span</td>
<td>3.1 (.7)</td>
</tr>
</tbody>
</table>
### Appendix – Listening span task

<table>
<thead>
<tr>
<th>Sentence</th>
<th>Response</th>
<th>Recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children go to SCHOOL</td>
<td>T</td>
<td>SCHOOL</td>
</tr>
<tr>
<td>People are covered in FUR</td>
<td>F</td>
<td>FUR</td>
</tr>
<tr>
<td>Grass grows in the HOUSE</td>
<td>F</td>
<td>HOUSE</td>
</tr>
<tr>
<td>Trees are covered in LEAVES</td>
<td>T</td>
<td>LEAVES, NEST</td>
</tr>
<tr>
<td>People live in a NEST</td>
<td>F</td>
<td>FORK, GROUND</td>
</tr>
<tr>
<td>I drink with a FORK</td>
<td>F</td>
<td>PARK, HAND</td>
</tr>
<tr>
<td>Worms live in the GROUND</td>
<td>T</td>
<td>MILK, CHAIRS, BITE</td>
</tr>
<tr>
<td>There are swings at the PARK</td>
<td>T</td>
<td>COT, NOSE, NIGHT</td>
</tr>
<tr>
<td>My toes are on my HAND</td>
<td>F</td>
<td>HAIR, NECK, RED</td>
</tr>
<tr>
<td>I wash my face with MILK</td>
<td>F</td>
<td>PEN, SKY, EYES, PLATE</td>
</tr>
<tr>
<td>At school I sit on CHAIRS</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>Snakes and spiders can BITE</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>Babies sleep in a COT</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>I wear lipstick on my NOSE</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>The sun comes out at NIGHT</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>I can brush my HAIR</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>Giraffes have a long NECK</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>The colour of water is RED</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>I write with a PEN</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>Dogs fly in the SKY</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>I talk with my EYES</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>I eat from a PLATE</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>In winter it is HOT</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>The sky is GREEN</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Fish live in the SEA</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>At school I learn to READ</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>I swim in the SAND</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Cars drive on the ROAD</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>Oranges are BLUE</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Food goes in my MOUTH</td>
<td>T</td>
<td></td>
</tr>
</tbody>
</table>