Working memory functions in children with different degrees of intellectual disability

K. Schuchardt,1 M. Gebhardt1 & C. Mäehler2

1 University Hildesheim, Institut Psychology, Hildesheim, Germany
2 Stiftung Universität Hildesheim, Institut für Psychologie, Hildesheim, Germany

Abstract

Background In recent years, there has been increased research interest in the functioning of working memory in people with intellectual disabilities. Although studies have repeatedly found these individuals to have weak working memory skills, few investigations have distinguished between different degrees of intellectual disability. This study aims to help close this research gap and, in so doing, to examine whether the deficits observed reflect a developmental lag or a qualitative deviation from normal development.

Method In a 5-group design, the working memory performance of a group of 15-year-olds with mild intellectual disability (IQ 50–69) was compared with that of two groups of children (aged 10 and 15 years) with borderline intellectual disability (IQ 70–84) and with that of two groups of children with average intellectual abilities (IQ 90–115) matched for mental and chronological age (aged 7 and 15 years). All children were administered a comprehensive battery of tests assessing the central executive, the visual-spatial sketchpad, and the phonological loop.

Results The results showed deficits in all three components of working memory, and revealed that these deficits increased with the degree of intellectual disability. The findings indicate that, relative to their mental age peers, children with learning difficulties show structural abnormalities in the phonological store of the phonological loop, but developmental lags in the other two subsystems.

Conclusions Similar patterns of results emerged for both subgroups of children with intellectual disability, indicating that problems with phonological information processing seem to be one of the causes of cognitive impairment in individuals with intellectual disability.

Keywords borderline intellectual disability, mild intellectual disability, working memory

Introduction

In recent years, increased research attention has been paid to the deficits associated with below-average intelligence. The International Classification of Diseases (ICD-10; World Health Organization 2005) and the Diagnostic and Statistical Manual of Mental Diseases (DSM-IV-TR; American Psychiatric Association 2000) distinguish different degrees of intellectual disability (ID) as measured in terms of IQ, with moderate ID being defined by an IQ...
between 35 and 49, mild ID (MID) by an IQ between 50 and 69, and borderline ID (BID) by an IQ between 70 and 84. Numerous studies on ID are reported in the literature, often focusing on groups with specific etiologies, such as Down syndrome (Jarrold et al. 2000; Kanno & Ikeda 2002; Purser & Jarrold 2004). However, few studies have distinguished between subgroups with different degrees of ID (e.g. Gathercole & Pickering 2001; Henry & MacLean 2002). Instead, it is frequently assumed that these subgroups share similar cognitive characteristics.

In the context of the developmental-difference controversy (Zigler & Balla 1982), numerous studies were conducted to examine whether the cognitive development of children with ID simply lags behind that of children without ID (developmental lag hypothesis) or whether there are specific differences in these children’s cognitive structures (difference hypothesis). Studies with control groups matched for chronological and mental age revealed a mixed pattern of results for various aspects of cognitive functioning (Weiss et al. 1986). Memory performance was one of the variables examined in this context (Henry & MacLean 2002; van der Molen et al. 2007), often on the basis of the British working memory model by Baddeley (1986). This model has proved a useful theoretical basis for identifying specific deficits in various conditions, including dyslexia and dyscalculia (e.g. Alloway & Gathercole 2006; Pickering 2006; Schuchardt et al. 2008a). The model has three components: the modality-free central executive is a kind of supervisory system that serves to control and regulate the cognitive processes occurring in its two limited-capacity slave systems, the phonological loop and the visual-spatial sketchpad. Further functions of the central executive that have since been identified by Baddeley (1996) include coordinating the slave systems, focusing and switching attention, and retrieving representations from long-term memory. The two slave systems perform modality-specific operations. Verbal and auditory information are stored temporarily and processed in the phonological loop. Two components of the phonological loop are distinguished: the phonological store and the subvocal rehearsal process. The visual-spatial sketchpad is concerned with remembering and processing visual and spatial information; it comprises a visual cache for static visual information and an inner scribe for dynamic spatial information.

To date, the picture emerging from empirical studies on working memory functioning in children and adults with ID is inconsistent and difficult to interpret. This can be attributed to the diversity of both the samples examined and the memory tasks administered. Most comparisons of children of the same chronological age with and without ID have pointed to broad deficits in all three subcomponents of working memory (Henry 2001; Pickering & Gathercole 2004; van der Molen et al. 2007; Mähler & Schuchardt 2009).

Studies comparing people with mild and moderate ID with control groups matched for mental age have also produced an inconsistent pattern of results overall. Henry & MacLean (2002) and van der Molen et al. (2007) found that children with ID did not perform more poorly than their mental age peers on measures of the central executive component of working memory, indicating a possible developmental lag. Findings on the visual-spatial sketchpad also point to a developmental lag (Numminen et al. 2002; Pickering & Gathercole 2004); other studies have even found evidence for structural differences in favour of persons with ID (see Henry & MacLean 2002; Rosenquist et al. 2003). However, research on the phonological loop has repeatedly shown children with ID to be outperformed by their mental age peers, indicating a particular structural deficit here (Jarrold et al. 2000; Henry & MacLean 2002; Rosenquist et al. 2003; van der Molen et al. 2007). Although few studies have examined children with BID, evidence for a specific deficit in the phonological subsystem has also been found in this group (Henry 2001; Hasselhorn & Mähler 2007).

As some studies have found evidence supporting the developmental lag hypothesis, whereas others have observed structural deviations from normal memory development, and as few studies to date have differentiated between subgroups with different degrees of ID, the specific cognitive characteristics of these children have not yet been clearly established.

This study therefore used a comprehensive battery of tests to examine the functioning of the three subcomponents of working memory in chil-
Children with low intellectual functioning. Within our study design, children with MID were compared with children of the same chronological age or mental age with BID or average intellectual ability. This approach made it possible to identify specific deficits in the memory functioning of children with ID and to determine whether these deficits can be interpreted as reflecting a quantitative or a qualitative deviation from normal development.

Methods

Participants

A total of 107 students participated in the study. Within a five-group design, a group of 15-year-old students with MID (IQ 50–69; MID-15; n = 22) was compared first with a group of 15-year-old students with BID (IQ 70–84; BID-15; n = 19) and a control group of 15-year-olds with average intellectual abilities (IQ 90–115; C-15; n = 25) in a chronological age comparison, and second with a group of 10-year-old students with BID (BID-10; n = 19) and a control group of 7-year-olds (C-7; n = 22) in a mental age comparison. The control group children came from mainstream schools and those with BID from three special schools for children with learning disabilities. The children with MID were recruited from two special schools for children with mental disabilities. Most of these children were characterised by ID of unknown etiology, while only two were children with genetic disorders (Down syndrome and Williams-Beuren Syndrome); as these children did not produce any extreme data, they were not excluded from the sample. In view of the large age differences, different non-verbal intelligence tests (figural reasoning) were used to assess IQ: the C-7 and BID-10 groups were administered the Columbia Mental Maturity Scale (CMMS; Schuck et al. 1985); the C-15 and BID-15 groups completed the Culture Fair Intelligence Test (CFT 20; Weiβ 1998). Because no normative data for these measures of IQ are available for the MID-15 group, individual intelligence scores (on various IQ tests, e.g. HAWIK-IV, Petermann & Petermann 2007; K-ABC, Melchers & Preuß 2001; SON 5/2-17, Tellegen & Laros 2003) were obtained from these students’ school records. Although different intelligence tests cannot be assumed to result in exactly comparable scaling we consider the assignment to the different groups relatively valid. For our study the exact matching for mental age is most important and that was performed using only one measure: the groups (MID-15, BID-10, C-7) were matched for mental age using raw scores on the CMMS. Table 1 presents the sample parameters of the five groups investigated.

Table 1 Means (SD) of selected descriptive characteristics of the subgroups

<table>
<thead>
<tr>
<th></th>
<th>C-7 (n = 22)</th>
<th>BID-10 (n = 19)</th>
<th>C-15 (n = 25)</th>
<th>BID-15 (n = 19)</th>
<th>MID-15 (n = 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (m/f)</td>
<td>13/9</td>
<td>12/7</td>
<td>13/12</td>
<td>12/7</td>
<td>11/11</td>
</tr>
<tr>
<td>Age (months)</td>
<td>85 (3.95)</td>
<td>122 (4.85)</td>
<td>186 (5.49)</td>
<td>189 (5.75)</td>
<td>181 (13.90)</td>
</tr>
<tr>
<td>IQ</td>
<td>104.91 (8.56)</td>
<td>81.21 (6.05)</td>
<td>109.80 (9.92)</td>
<td>82.63 (6.33)</td>
<td>61.82 (5.95)</td>
</tr>
<tr>
<td>CMMS</td>
<td>24.64 (4.52)</td>
<td>24.84 (4.13)</td>
<td>–</td>
<td>–</td>
<td>24.68 (7.38)</td>
</tr>
<tr>
<td>Mental age (years; months)</td>
<td>7; 1</td>
<td>7; 1</td>
<td>–</td>
<td>–</td>
<td>7; 1</td>
</tr>
</tbody>
</table>

BID, children with borderline intellectual disability; MID, children with mild intellectual disability; C, control children with average intellectual abilities; m, male; f, female; CMMS, raw Columbia Mental Maturity Scale scores.
ponent model, also for children with learning dis-
abilities (Schuchardt et al. 2008b). Tasks were
presented in a fixed order: location span, digit span,
Corsi block simple and complex, non-word repeti-
tion, backward digit span, counting span, non-word
span. Despite the Corsi block task, all tasks were
presented using a computer. A detailed description
of all tasks follows below.

Phonological loop

The digit span is the conventional measure used to
assess the short-term phonological capacity. A series
of digits (1–9) was presented acoustically at a rate
of one digit per second, starting with two and con-
tinuing up to a maximum of eight digits per
sequence. Participants had to repeat the digits
immediately in the given order. The one-syllable non-
word span task (e.g. fen, sim) was presented in the
same manner as in the digit span measure. The
German non-word repetition task administered was
developed by Hasselhorn & Körner (1997). Chil-
dren had to repeat 24 word-like non-words of two,
three or four syllables (e.g. vorluch, karflumen,
sulibritzen) immediately after their presentation.
Nonwords of different lengths were presented audi-
torily in random order. The number of correctly
repeated non-words was taken as the score for this
task.

Visual-spatial sketchpad

In the location span task, children were shown series
of green dots at different locations on a 3x3 matrix
and asked to recall these locations in the correct
order, starting with two and continuing up to a
maximum of eight dots per sequence. Corsi block
tasks were used to assess the dynamic spatial com-
ponent of visual-spatial working memory. The
experimenter taps out a sequence on an array of
red blocks on a grey board at the rate of one per
second. The child then has to reproduce this
sequence. We used two variations of the Corsi block
task: simple sequences involving short distances
between blocks without path crossings, and
complex sequences involving long distances
between blocks with path crossings (Zoelch &
Schumann-Hengsteler 1999).

Central executive

The same items and procedures were used for the
backward digit task as for the forward digit span, the
only difference being that participants were required
to recall the sequences of items in reverse order.
The complex counting span task, a measure of
storage and processing efficiency, was based on a
task designed by Case et al. (1982). Maps of yellow
circles (target items) and squares (distractor items)
were presented in a random, computer-generated
pattern. Children were instructed to count the
number of circles on each map. The experimenter
then asked the child to recall the number of circles
counted on each map in a sequence. The number of
maps presented per sequence was steadily increased
up to a maximum of eight.

Stop criterion

We used the same stop criterion for all span tasks.
The length of the sequences presented was gradu-
ally increased, beginning with a minimum of two,
and increasing to a maximum of eight items. There
were four trials at each sequence length. If a child
succeeded on two successive trials of the same
length, the task continued with the next span
length. If a child failed on two successive trials of
the same length, he or she was not presented with
any further sequences of the same length, but with
a sequence one item shorter. The dependent
measure for all span tasks was the longest sequence
of items repeated in correct order. Children were
credited an extra 0.25 points if they repeated a
further sequence of the same length correctly (e.g. a
score of 5.25 was awarded if two of four five-item
sequences were recalled correctly, 5.5 if three of
four sequences were recalled correctly and 5.75 if all
four sequences were recalled correctly).

Results

The data obtained from the five groups were analy-
sed in two separate steps. The level of significance
was set to $\alpha = 0.05$. Table 2 presents mean scores
on all working memory tasks by subgroup.
In a first step, we investigated whether students
with ID showed a developmental lag relative to stu-
dents of the same chronological age by comparing
the performance of the BID-15, MID-15 and C-15
groups for all three components of working memory
separately. Scores on the three tasks assessing the
phonological loop were entered in a MANOVA. The
multivariate group effect, $F_{6,124} = 15.36$, $P < 0.001$,
reached statistical significance. Univariate tests
revealed significant differences among the groups
for all tasks (digit span: $F_{2,63} = 69.82$, MSE = 0.59,
$P < 0.001$; non-word span: $F_{2,63} = 17.38$,
MSE = 0.51, $P < 0.001$; non-word repetition:
$F_{2,63} = 45.69$, MSE = 10.80, $P < 0.001$). Scores on
the three tasks assessing the visual-spatial sketchpad
were examined in a second MANOVA. Here again, a
significant multivariate group effect emerged,
$F_{6,124} = 10.52$, $P < 0.001$, and univariate tests
revealed significant differences among the groups
on all measures (location span: $F_{2,63} = 39.08$,
MSE = 0.92, $P < 0.001$; Corsi block simple,
$F_{5,63} = 25.39$, MSE = 1.12, $P < 0.001$; Corsi block complex: $F_{4,63} = 40.97$, MSE = 0.94, $P < 0.001$).
Third, the scores on the two central executive tasks
were subjected to a MANOVA. Again, a significant
group effect emerged, $F_{1,124} = 14.84$, $P < 0.001$, and
univariate tests showed significant differences
among the groups on both tasks (digit backward
span: $F_{2,63} = 40.19$, MSE = 0.76, $P < 0.001$; counting
span: $F_{2,63} = 41.55$, MSE = 0.74, $P < 0.001$). Subse-
quent post hoc tests performed to obtain more
detailed information on the group differences
showed that the MID group was significantly out-
performed by the BID group on all working
memory tasks, which was in turn significantly out-
performed by the control group of children with
average intellectual abilities. In other words, relative
to students of the same chronological age, children
with ID showed functional deficits in working
memory, and these deficits increased with the
degree of ID.

In a second step, we compared working memory
performance in children of the same mental age. To
this end, we analysed the data of the MID-15,
BID-10 and C-7 groups in exactly the same way,
with separate MANOVAS for all three components
of working memory. There were no statistically signifi-
cant group effects for the visual-spatial sketchpad
$F_{6,118} = 1.19$, $P > 0.05$, or the central executive,
$F_{4,120} = 1.06$, $P > 0.05$, but the group effect for the
phonological loop did reach statistical significance,
$F_{1,74} = 2.25$, $P < 0.05$. Univariate tests revealed that
the only significant difference between the groups
was in the non-word repetition task (digit span:
$F_{2,56} = 2.70$, MSE = 0.34, $P > 0.05$; non-word:
$F_{2,56} = 2.32$, MSE = 0.36, $P > 0.05$; non-word repeti-
tion: $F_{2,56} = 3.53$, MSE = 18.60, $P < 0.05$). Further
post hoc tests revealed that the MID and BID
groups differed significantly from the 7-year-olds
with average intellectual abilities on the non-word
repetition task, but not from each other. We can
thus conclude that children with ID show lower
levels of phonological loop functioning, but not of
visual-spatial sketchpad or central executive func-
tioning, than children of the same mental age. Both

Table 2 Means (SD) of working memory measures by subgroups

<table>
<thead>
<tr>
<th></th>
<th>C-7 (n = 22)</th>
<th>BID-10 (n = 19)</th>
<th>C-15 (n = 25)</th>
<th>BID-15 (n = 19)</th>
<th>MID-15 (n = 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phonological loop</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit span</td>
<td>4.01 (.49)</td>
<td>3.67 (.62)</td>
<td>6.29 (.86)</td>
<td>5.25 (.79)</td>
<td>3.64 (.64)</td>
</tr>
<tr>
<td>Nonword span</td>
<td>3.20 (.54)</td>
<td>2.82 (.63)</td>
<td>4.34 (.79)</td>
<td>3.58 (.69)</td>
<td>3.13 (.64)</td>
</tr>
<tr>
<td>Nonword repetition</td>
<td>15.82 (4.17)</td>
<td>13.32 (3.73)</td>
<td>21.28 (1.90)</td>
<td>19.63 (2.19)</td>
<td>12.49 (6.4)</td>
</tr>
<tr>
<td><strong>Visual-spatial sketchpad</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location span</td>
<td>3.98 (.65)</td>
<td>4.20 (1.04)</td>
<td>6.59 (.79)</td>
<td>5.75 (1.10)</td>
<td>4.14 (1.00)</td>
</tr>
<tr>
<td>Corsi block simple</td>
<td>5.44 (1.05)</td>
<td>5.72 (1.12)</td>
<td>7.44 (.79)</td>
<td>6.72 (1.06)</td>
<td>5.26 (1.29)</td>
</tr>
<tr>
<td>Corsi block complex</td>
<td>4.65 (.69)</td>
<td>4.72 (.82)</td>
<td>6.72 (.95)</td>
<td>5.47 (.80)</td>
<td>4.20 (1.07)</td>
</tr>
<tr>
<td><strong>Central executive</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backward digit span</td>
<td>2.88 (.76)</td>
<td>3.14 (.43)</td>
<td>5.05 (1.07)</td>
<td>4.16 (.89)</td>
<td>2.77 (0.54)</td>
</tr>
<tr>
<td>Counting span</td>
<td>2.95 (.58)</td>
<td>2.93 (.48)</td>
<td>5.17 (1.04)</td>
<td>4.17 (.84)</td>
<td>2.89 (0.60)</td>
</tr>
</tbody>
</table>

BID, children with borderline intellectual disability; MID, children with mild intellectual disability; C, control children with average intellectual abilities.

© 2010 The Authors. Journal Compilation © 2010 Blackwell Publishing Ltd
groups of students with ID (borderline and mild) showed the same performance profile for the three components of working memory.

Discussion
This study examined the functioning of working memory in children with borderline and MID, as compared with average-intelligence children of the same chronological and mental age. The results showed that 15-year-old children with ID showed deficits on all measures of the central executive, the visual-spatial sketchpad and the phonological loop administered. The deficits increased with the degree of ID: the average-ability students showed better working memory performance than their chronological peers with BID, who in turn showed better performance than their chronological peers with MID. This clear pattern of results points to a general dysfunction in working memory depending on the level of intelligence. Previous studies have also found specific subgroups of children with ID to have broad deficits in working memory functioning (van der Molen et al. 2007; Mähl er & Schuchardt 2009). Only Henry (2001) found the subgroup of respondents with BID to have a specific impairment in the phonological subsystem. Although this suggests conflicting evidence, the pattern of results is well compatible with our results discussed further down.

We further examined whether the functional disorders observed were associated with mental age. The central executive and visual-spatial performance of the MID-15 and the BID-10 groups was equivalent to that of the control group of 7-year-olds matched for mental age. Children with ID thus show a developmental lag in these components of working memory that corresponds to the deficit in general mental performance. In other words, their development in these components is in line with their general intellectual ability. A contrasting picture emerged for phonological working memory performance, where children with ID showed serious deficits relative not only to their chronological age peers, but also to their mental age peers. Within the framework of the developmental-difference controversy, these findings can be seen as evidence for a structural difference and thus as a qualitative deviation from normal development.

Surprisingly, both ID subgroups showed the same pattern of results in this study; we did not find characteristic patterns of working memory performance that would be useful in a differential diagnosis. A particularly severe deficit in phonological functioning was found for both the BID and the MID subgroups. How can this specific structural deficit in the phonological loop be explained?

Further analyses showed that it is important to take the specific task demands into account. Whereas the children with ID performed at their mental age level on tasks measuring the total capacity of the phonological loop (i.e. memory span for digits and non-words), their performance on the task assessing the storage component (i.e. non-word repetition; Gathercole et al. 1994) was much lower. Interestingly, in contrast to numerous studies showing deficits in these children’s rehearsal skills (Rosenquist et al. 2003; Hasselhorn & Mähl er 2007), our data thus pinpoint the weakness in their phonological performance to a specific qualitative deviation in the phonological store. The findings of studies that have further specified the functioning of this component of working memory point in the same direction (Hasselhorn & Mähl er 2007). For example, it is possible to extend Baddeley’s (1986) model by differentiating two functional characteristics of the storage component of the phonological loop: storage capacity, as measured by non-word-repetition, and accuracy of processing, as measured by the acoustic similarity effect (Hasselhorn et al. 2000). The acoustic similarity effect describes the finding that recall of items in memory span tasks is better when they are dissimilar than when they are similar in sound. Similar sounding items are more difficult to distinguish phonologically, making phonological coding within the store more difficult, resulting in lower recall performance. Hasselhorn & Mähl er (2007) and Rosenquist et al. (2003) found evidence for corresponding acoustic similarity effects in children with ID and in their chronological and mental age peers with average intellectual abilities. Parallel to our main study, we also presented the children in our MID group with sequences of similar sounding and dissimilar sounding items. Analyses revealed an acoustic similarity effect in this group as well ($t(21) = 5.43$, $P < 0.05$).

Hence, the poorer phonological performance of the children with ID does not seem to be attributable
to a poorer accuracy of processing; rather, it seems to be due to a reduced storage capacity of the phonological loop. Further research is needed to examine the exact limitations in the capacity of the phonological store.

References


*Accepted 10 February 2010*
This document is a scanned copy of a printed document. No warranty is given about the accuracy of the copy. Users should refer to the original published version of the material.