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Working memory functions in children with different degrees of intellectual disability

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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

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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 metal 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 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-

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

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

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.

dren 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-Beurren 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; Weiß 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 5½-17, 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.

Tasks

Working memory was assessed by a battery of eight tasks: three phonological tasks (memory span for digits, one-syllable non-words, non-word repetition), three visual-spatial tasks (memory span for locations, Corsi block simple and complex), two central executive tasks (backward span digits, counting span). Although these tasks can be differently considered in different working memory models (Miyake & Shah 1999; Cornoldi & Vecchi 2003; Cowan 2005) we adhere to the working memory model of Baddeley (1986) and proved in a recent study that our battery fits to the three component model, also for children with learning disabilities (Schuchardt *et al.* 2008b). Tasks were presented in a fixed order: location span, digit span, Corsi block simple and complex, non-word repetition, 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 continuing 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). Children 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 auditorily 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 component 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 gradually 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 analysed 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 students 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, $F_{2,63} = 25.39$, MSE = 1.12, $P < 0.001$; Corsi block complex: $F_{2,63} = 40.97$, 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, $F_{4,124} = 14.84$, $P < 0.001$, 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, $P < 0.001$). Subsequent post hoc tests performed to obtain more detailed information on the group differences showed that the MID group was significantly outperformed by the BID group on all working memory tasks, which was in turn significantly outperformed 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 significant 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, $F_{6,118} = 2{,}25$, $P < 0.05$. Univariate tests revealed that the only significant difference between the groups was in the non-word repetition task (digit span: $F_{2,60} = 2.70$, MSE = 0.34, $P > 0.05$; non-word span: $F_{2,60} = 2.32$, MSE = 0.36, $P > 0.05$; non-word repetition: $F_{2,60} = 3.53$, 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 functioning, than children of the same mental age. Both

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

	C-7 (*n* = 22)	BID-10 (*n* = 19)	C-15 (*n* = 25)	BID-15 (*n* = 19)	MID-15 (*n* = 22)
Phonological loop					
Digit span	4.01 (0.49)	3.67 (0.62)	6.29 (0.86)	5.25 (0.79)	3.64 (0.64)
Nonword span	3.20 (0.54)	2.82 (0.63)	4.34 (0.79)	3.58 (0.69)	3.13 (0.64)
Nonword repetition	15.82 (4.17)	13.32 (3.73)	21.28 (1.90)	19.63 (2.19)	12.49 (0.64)
Visual-spatial sketchpad					
Location span	3.98 (0.65)	4.20 (1.04)	6.59 (0.79)	5.75 (1.10)	4.14 (1.00)
Corsi block simple	5.44 (1.05)	5.72 (1.12)	7.44 (0.79)	6.72 (1.06)	5.26 (1.29)
Corsi block complex	4.65 (0.69)	4.72 (0.82)	6.72 (0.95)	5.47 (0.80)	4.20 (1.07)
Central executive					
Backward digit span	2.88 (0.76)	3.14 (0.43)	5.05 (1.07)	4.16 (0.89)	2.77 (0.54)
Counting span	2.95 (0.58)	2.93 (0.48)	5.17 (1.04)	4.17 (0.84)	2.89 (0.60)

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

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; Mähler & 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 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 & Mähler 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 & Mähler 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 & Mähler (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.

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