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Working memory development in children with mild to borderline intellectual disabilities

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Abstract

Background The purpose of the current cross-sectional study was to examine the developmental progression in working memory (WM) between the ages of 9 and 16 years in a large sample of children with mild to borderline intellectual disabilities (MBID). Baddeley's influential WM model was used as a theoretical framework. Furthermore, the relations between working memory on the one hand, and scholastic skills (arithmetic and reading) on the other were examined.

Method One-hundred-and-ninety-seven children with MBID between 9 and 16 years old participated in this study. All children completed several tests measuring short-term memory, working memory, inhibition, arithmetic and single word reading.

Results WM, visuo-spatial short-term memory and inhibition continued to develop until around age 15 years. However verbal short-term memory showed no further developmental increases after the age of 10 years. Verbal short-term memory was associated with single word reading, whereas inhibition was associated with arithmetic.

Discussion The finding that verbal short-term memory ceases to develop beyond the age of 10 years in children with MBID contrasts with results of studies involving typically developing children, where verbal short-term memory develops until around age 15 years. This relative early developmental plateau might explain why verbal short-term memory is consistently considered weak in children with MBID.

Keywords: intellectual disabilities, short-term memory, working memory, inhibition, arithmetic, speeded reading, development

Introduction

Although there is a substantial literature on how short-term memory (STM) and working memory (WM) develop with age in typical children (e.g. Alloway et al., 2006; Gathercole et al., 2004a), there is very little work tracking such developmental changes in children with mild to borderline intellectual disabilities (MBID; IQ score 50-85). The purpose of the current cross-sectional study was to examine a large sample of children with MBID from a wide age range to determine how STM and WM develop. We hoped this would further our understanding of why children with MBID perform *below* their mental age levels in some aspects of STM and WM. We also examined how various aspects of STM and WM are related to important scholastic abilities, adding to the limited research evidence in this area.

The starting point for this work was existing cross-sectional research on STM and WM in participants with MBID. Although this work has focused almost exclusively on samples of individuals with MBID with restricted age ranges, findings have shown consistent short-term memory (STM) and working memory (WM) delays compared to chronological age matched typically-developing children (CA control group; Alloway, 2010; Hasselhorn & Maehler, 2007; Henry, 2001; Henry & MacLean, 2002; Schuchardt et al., 2010; Van der Molen et al., 2007; 2009). This is not surprising considering that children with MBID have younger mental ages than CA control children. However, more noteworthy is that delays on some types of STM and WM tasks have been reported in children with MBID compared to younger typically-developing mental age matched children (MA control group; Henry & MacLean, 2002; Henry & Winfield, 2010; Van der Molen et al., 2007; 2009). This suggests that at least some aspects of STM and / or WM are characterised by difficulties that go beyond mental age level in children with MBID. Such marked memory problems are of particular concern because STM and WM are important factors contributing to multiple scholastic abilities such as reading and arithmetic (Henry & Winfield, 2010; Van der Sluis et al., 2004).

In terms of theoretical approaches, one generally accepted view is that the cognitive abilities of people with non-organically (or non-detectable organically) based intellectual disabilities (true for most children with MBID, see Heikura et al., 2005), fall at the lower end of the normal distribution. On this account, cognitive abilities in children with MBID should develop along a broadly comparable trajectory to that of typically-developing children, but at a slower rate. A further prediction of this account is that cognitive abilities in children with MBID are expected to plateau at a lower level than in the typically developing population (Bennet-Gates & Zigler, 1998). The first aim of the present study was, therefore, to explore if and how STM and WM developed in a cross-sectional sample of children with MBID between the age of 9 and 16 years.

The theoretical framework for this research was Baddeley's working memory model (Baddeley, 2007), which is frequently used to explain and explore STM and working memory WM in populations of children with and without developmental disorders, including those with MBID (e.g. Henry, 2012). This model comprises four components: (1) a phonological loop to temporarily hold and maintain verbal information, with an accompanying automatic rehearsal component that prevents information from fading away; (2) a visuo-spatial sketchpad to temporarily hold and maintain visual and spatial information; (3) a central executive which functions as an attentional control system by focusing, directing and switching attention (this system is hypothesised to be involved in a range of 'executive' functions relevant for goal-directed behaviour such as executive-loaded working memory, switching and response inhibition – here we focused on executive-loaded working memory and response inhibition); and (4) an episodic buffer, a multidimensional storage system that binds information from different sources into a coherent experience (Baddeley, 2000). In the current terminology, STM is represented by the phonological loop (verbal STM) and the visuo-spatial sketchpad (visuo-spatial STM) while WM refers to the capacity to simultaneously store and manipulate information over brief periods of time, i.e. on memory tasks with a ‘central executive’ load.

Several studies have focussed on the development of STM and WM in typically developing children. The results regarding verbal STM are mixed. Some have reported improvements until around 11 years (Alloway et al., 2006), after which verbal STM performance levels off; whereas others have reported a more extended period of development up to around 15 years (Conklin et al., 2007; Gathercole et al., 2004a). Turning to visuo-spatial STM, a distinction is generally made between visual STM and spatial STM. Research on spatial STM has provided evidence of a linear improvement from 4 to 10 years (Pickering et al., 2001), levelling off at around 15 years (Farrell Pagulayan et al., 2006; Gathercole et al., 2004a; Luciana et al., 2005), although note that one study found that spatial STM stabilized somewhat earlier at around 12 years (Conklin et al., 2007). Visual, or static, STM seems to plateau somewhat earlier than spatial, or dynamic, STM, at around 11 years (Gathercole et al., 2004a).

For the more complex skill of WM, which requires executive control to co-ordinate both processing and storage concurrently, somewhat longer developmental trajectories might be predicted. Most studies have reported that WM develops linearly from 4 to 10 years, levelling off at around 15 years (Conklin et al., 2007; Gathercole et al, 2004a; Huizinga et al., 2006; Luciana et al., 2005; McAuley & White, 2011), but there is some evidence for a more protracted development in WM - up until age 20 (for visual WM; Hamilton et al., 2003) or even age 45 (for visual and verbal WM; Swanson; 1999). In the current data set, we also had the opportunity to look at response inhibition, another function ascribed to the central executive component of Baddeley's working memory system (Baddeley, 1996). In terms of previous research on typical children, the development of response inhibition may reach its asymptotic level at around age 7 years (Gerstadt et al., 1994) or around late adolescence / beginning young adulthood (Huizinga et al., 2006; McAuley & White, 2011; although in this study, the developmental changes disappeared when corrected for processing speed; Williams et al., 1999). Nevertheless, there is also research showing that inhibition performance may plateau by the age of 10 years (Welsh et al., 1991; Klenberg et al., 2001, Lehto et al., 2003). As such, the developmental time course for improvements in inhibition shown by typical children remains unresolved in the literature.

Although findings regarding the development of STM, WM and inhibition in typical children are not entirely consistent, it does seem that STM and WM develop at least until around age 15 years. Note, however, that the only study on visual STM indicated that this construct may level off earlier at around age 11 years and some studies show a levelling off at age 10-11 years for verbal STM and inhibition.

Although there is no existing work that focuses specifically on the developmental trajectories of STM and WM in children with MBID, there is some relevant work that points to areas of relative strength and weakness. For example, many studies have found that verbal STM is particularly vulnerable in children with MBID. Performance levels on measures such as digit span and / or word span in children of 10 years or older have been reported as below mental age in several studies (Bayliss et al., 2005; Henry & MacLean, 2002; Henry & Winfield, 2010; Russell et al., 1996; Schuchardt et al., 2010; Van der Molen et al., 2007; 2009). One exception was a study by Hasselhorn and Mähler (2007) who found no difficulties relative to mental age on verbal STM in 10-year-old children with MBID. Henry (2001) also pointed out that different areas of STM and WM may be differentially affected by the severity of the intellectual disability, with children who have borderline ID showing fewer relative difficulties compared to typical age-matched comparisons (only verbal STM was weaker), than children with mild ID (all aspects of STM and WM were weaker).

By contrast, visuo-spatial STM may be either at mental age level or possibly slightly higher as indicated by studies that included MA control children (Henry & MacLean, 2002; Henry & Winfield, 2010; Rosenquist et al., 2003; Schuchardt et al., 2010; Van der Molen et al., 2007; 2009; although see Bayliss et al., 2005 for contradictory findings). Existing findings in relation to WM are also somewhat contradictory, but many indicate that the performance levels of children with MBID compared to MA control children, are at mental age level or just below (e.g. Bayliss et al., 2005; Henry & MacLean, 2002; Henry & Winfield, 2010; Van der Molen et al., 2007; Van der Molen et al., 2009). Research on inhibition in children with ID suggests that performance may be somewhat below that of MA control children and, therefore, below mental age level (Danielsson et al., 2012), although Van der Molen et al. (2007) found that 15-year old adolescents with mild to borderline ID performed as well as CA control children on inhibition scores from the Random generation task (Towse & Mclachlan, 1999). In a further study, 15-year old adolescents with borderline ID performed better on the Stroop task (Hammes, 1971), than their mild ID peers (Ponsioen & Van der Molen, 2002). Although differences in study outcomes might be due to differences in methodology, this inconsistent picture makes it hard to formulate specific predictions in relation to inhibition skills in children with MBID.

Therefore, based on the previous literature, the following general prediction was tested concerning developmental changes in STM and WM in children with MBID in relation to chronological age: STM and WM develop linearly with chronological age in children with MBID as they do in typical children. The developmental trajectories of children with MBID show the same general characteristics as those of typically developing children. In other words, development proceeds in a linear manner in relation to chronological age, but some areas of STM and WM may plateau earlier than others.

Finally, the importance of STM and WM in the development of scholastic abilities has been demonstrated in several studies. Verbal STM is related to reading and spelling in typically developing children (e.g. Leather & Henry, 1994) and in children with intellectual disabilities (Henry & Winfield, 2010). Furthermore, visual and spatial STM is related to early number skills (e.g. Bull et al., 2008) in typically developing children, but probably not in children with intellectual disabilities (Henry & MacLean, 2003; Henry & Winfield, 2010). Concerning WM, there is extensive evidence that it is an important predictor of achievement in reading (e.g. Christopher et al., 2012; Gathercole et al., 2004b) and arithmetic (e.g. Bull & Scerif, 2001; Gathercole et al., 2004b) in typically developing children. In children with intellectual disabilities, WM has been shown to be a predictor of number skills in these children (Henry & MacLean, 2003; Henry & Winfield, 2010). Studies on the relationship between inhibition and arithmetic and reading are sparse and results are ambiguous. A positive, although modest, relationship between inhibition and arithmetic has been observed by some researchers (Bull & Scerif, 2001, Diamantopoulou et al., 2007;

Kroesbergen et al., 2009; St Claire-Thompson & Gathercole, 2006). However, recent studies using latent variable analysis showed inhibition had no predictive value for arithmetic (Van der Ven et al., 2011) or reading (Christopher et al., 2012). Relevant data for children with ID are not currently available. Therefore, the second aim of the study was to assess how STM, WM and inhibition skills contributed to important scholastic achievements; in particular the speed and accuracy of single word reading and arithmetic.

In summary, this study examined developmental changes in STM and WM in a large sample of children who had MBID, and went on to explore relationships between the memory measures and scholastic achievement in this group. As much is already known about STM and WM development in typical children, and the methods and measurements chosen here were comparable to those used in studies with typically developing children, no control group of MA matched children was deemed necessary to address our central question: How do STM and WM change over age in children with MBID?

Method

Participants

A total of 197 young people with MBID attending schools for special education were available for this study. A criterion for entrance in this type of school is an IQ score in the range 50/55 - 85. The mean age of the MBID group was 12.09 (SD = 2.31, range 9.0 - 16.08) and their mean IQ score, based on the Raven Standard Progressive Matrices (SPM; Raven, Court, & Raven, 1990, German norm scores of 2009), was 70 (SD = 9.37, range 50-85). We explored whether STM and WM developed similarly or differently for children with MID versus BID, therefore the details for both separate groups are presented here. The MID group consisted of 107 children (56 boys, 51 girls) with a mean age of 12.04 (SD = 2.13, age range 9.05 - 16.05) and a mean Raven IQ score of 62 (SD = 5.16, range 50-70). The BID group comprised 90 children (54 boys, 36 girls) with a mean age of 13.03 (SD = 2.43, age range of 9.0 - 16.08) and a mean Raven IQ of 78 (SD = 4.35, range 71-85). An ANOVA revealed that the mean age of the BID group was significantly higher than that of the MID group, $F(1, 195) = 9.09$, $p < .00$.

There was no main effect of gender for the eight memory scores, $F(1, 187) = 1.24$, $p = .28$, so this will not be considered further.

Adolescents diagnosed by psychiatrists as having attention deficit/hyperactive disorder, pervasive developmental disorder-not otherwise specified, or other specific etiologies were excluded because these psychiatric problems are associated with specific working memory strengths and weaknesses (Gathercole & Alloway, 2006), which might influence the results. Informed consent was obtained for every participant. All participants had normal or corrected vision and were reported to be healthy; none of them were taking psychotropic medication. All children were born in The Netherlands.

Materials

To be able to test our hypotheses, a comprehensive battery of tests was composed, measuring short-term memory, working memory, inhibition, arithmetic and reading speed. Only tests with a proven track record for use in MBID populations in the Netherlands were included (e.g., Alloway, 2010; Van der Molen et al., 2009; 2010).

Short-term memory tasks

Two verbal and two visual STM tests were used. *Digit Recall* and *Nonword Recall* (Pickering & Gathercole, 2001) both measure verbal STM and require children to repeat items, respectively digits or (Dutch sounding) nonwords, in the same order as presented. For both tests there were six trials per list length. List lengths increased incrementally, provided at least four of the six trials were completely correct. When four trials of a list length were correctly repeated with no errors, the next list length was immediately offered, with the omitted trials awarded one point each. Memory scores represented the number of trials that were completely correct. Digit Recall started with a list length of two digits with a maximum list length of eight digits, therefore scores varied from 0 to 42. Nonword Recall started with a list length of 1 nonword with a maximum list length of six nonwords, therefore scores varied from 0 to 36.

Visual STM was assessed using *Block Recall* and the *Visual Patterns test*. Block Recall is identical to the Corsi test (see Lezak, 1995), but in this study we used the instructions from Pickering and Gathercole (2001). The experimenter taps a sequence of three-dimensional blocks that the child has to repeat in the same order. The task started with one block, and the maximum list length was nine blocks. For each list length, there were six trials. List length increased incrementally, provided at least four of the six trials were completely correct. When four trials of a list length were correctly repeated, the next list length was offered immediately, with the omitted trials awarded one point each. Scores varied from 0 to 54.

In the Visual Patterns test (Della Sala et al., 1997) the child was shown a matrix depicted on a stimulus card, varying from 2x2 to 5x6 squares, with half of the squares being marked. After inspecting a stimulus card, the child had to indicate the marked squares using a blank grid on the response sheet. Three stimulus cards were available for each of the fourteen list lengths. List length referred to how many individual squares had to be recalled from a particular matrix. Each stimulus card was always shown three seconds, regardless of list length. List length increased incrementally, provided at least two of the three trials were completely correct. Scores varied from 0 to 42.

Working memory tasks

Two verbal tests and one visual WM test were used. The two verbal WM tests were *Backward Digit Recall* and *Listening Recall*. Backward Digit Recall (Pickering & Gathercole, 2001) requires the repeating back of spoken lists of digits, but in the reverse order. Listening Recall (Pickering & Gathercole, 2001) requires listening to simple statements to determine whether they are true or false, whilst at the same time remembering the last word of each statement. Following each trial, these last words had to be repeated in the same order as presented. Trials in Backward Digit Recall started with a list length of two digits, with a maximum list length of seven digits, while Listening Recall started with a list length of one sentence, up to a maximum list length of six sentences. For each list length, there were six trials. List length increased incrementally, provided at least four of the six trials were completely correct. When four trials of a list length were correctly repeated, the next list length was offered immediately, with the omitted trials awarded one point each. Scores varied from 0 to 36 for both tests.

Visual WM was examined using a manual version of the *Spatial Span* (Alloway, 2007). A card is shown with two shapes of which the right one has a red dot on top. The right shape can be exactly the same (p−p) or opposite (p−q) to the left shape and it can be rotated in three different ways (0°, 120° and 240°). The child has to decide whether the shape on the right is the same as the shape on the left or different At the same time, the position of the red dot on the right shape has to be remembered. This position can be at three different locations according to the three rotation possibilities. After each trial, the child has to point to a response card with three dots (at 0°, 120° and 240°) to indicate which dots were on the stimuli cards and in which sequence. The trials started with a list length of one card, with a maximum list length of six cards. For each list length, there were six trials. List length increased incrementally, provided at least four of the six trials were completely correct. When four trials of a list length were correctly repeated, the next list length was offered immediately, with the omitted trials awarded one point each. Scores varied from 0 to 36.

Response inhibition

The Stroop (Hammes, 1978), measuring response inhibition, consists of three cards. First, the participant has to read as quickly as possible the names of four colours (yellow, red, green and blue) written on the first card. Then on the second card, the participant sees blocks filled in with the four colours and has to name these colours as quickly as possible. Finally on the third card, the words of the four colours are written and printed in a different coloured ink. The participant has to name the colour in which the words are printed and inhibit the prepotent response to name the word. The total (inference) score is the amount of time in seconds needed to read out the third card minus the time in seconds needed for the second card (seconds needed to ‘read’ card three – seconds needed to ‘read’ card two). Scores can vary, as they depend on how long the participant takes to read aloud cards two and three. The lower the interference time, the better the achievement.

The Stroop is used more often in studies with MID children (e.g. Alloway, 2010; Van der Molen et al., 2010) and already in 1976 a study by Bassett and Schellman revealed that the Stroop colour word task can be used in ‘retardates’ with an average IQ score of 61. Also, a study presented at the 2010 APA Annual Convention (Ikeda et al., 2010), showed that the Stroop is suitable for adults with ID with a mean mental age of 7 years. Furthermore, a recent article by Ikeda et al. (2011), showed that typically developing children from age 7 years on were able to read the words, most of them showing no errors in the word reading.

Scholastic abilities

Two tests were administered to tap scholastic abilities, one test for arithmetic and another one for reading abilities. In the *Arithmetic test* (De Vos, 1992) the child was presented five rows for different arithmetic operations: adding subtracting, multiplying, dividing and a row combining these four operations. In this study, only the total score for three rows, adding, subtracting and multiplying was used, as most of the children with MBID did not know how to solve dividing sums. The child had to complete as many items in each row as possible within one minute by writing down the correct answers. For every correct answer, one point was given. Total scores reflected correct performance on the three rows, and varied between 0 and 120.

Reading fluency was assessed by the *One minute Reading test* (Brus & Voeten, 1979). The child was presented with a list with 116 unrelated words of increasing difficulty and had to read aloud as many words as possible within one minute. Total scores reflected the number of correctly read words, and varied from 0 to 116.

Procedure

All children were tested at their schools in two sessions. In the first session Digit Recall, Block Recall, Listening Recall and Raven's SPM were administered. The remaining tasks were administered in the second session. At the end of the second session the participants received a small present. Ethical approval for the study was granted from the Research Ethics committee of the Department of Psychology of the University of Amsterdam.

Results

First the data were screened for outliers. Therefore, all scores were converted to Z-scores. Of the 1,970 subtest scores, 8 had a Z-score more than 2.58 above or below the mean. All those scores were from different participants, except two scores which were from the same participant. These data were normalized by replacing them with values corresponding to Z-scores = +/- 2.59 as appropriate (Field, 2009). Next, the relation between IQ and age was explored in both groups. First we did some correlational analyses. For the total group, the correlation between age and IQ was low and non-significant, r= .10. Dividing the group in two: the correlation for MID was r= -.09 and for BID it was r= -.17. These correlations were both non significant. Then, we assessed whether the relations between age and IQ differed between both groups. We therefore ran a linear regression analysis with IQ as the dependent variable and in the first step group and age as predictors, and in the 2nd step dummy x age for the interaction effect. The BID group had a higher IQ (as expected), age did not explain IQ (as we knew from the correlation analyses) and there was no interaction effect. In short, the relation between age and IQ was similar for both the MID and BID groups.

In order to test our predictions concerning developmental changes in WM and STM, a series of eight linear regression analyses were carried out with each of the eight STM, WM and Inhibition Z-scores included as the dependent variables. In each case, chronological age, group (MID, BID) and age x group were included as predictors. Quadratic and cubic models were also tried, but they yielded virtually no improvement over the linear model for all of the eight scores, so they will not be considered here. A second series of two linear regression analyses were then carried out with the two separate scholastic-based Z-scores as dependent variables in order to test the relations between these variables and the various STM and WM predictors. The predictors for these regressions were the eight STM, WM and Inhibition Z-scores in the first step, and chronological age, group and age x group in the second step. The order of steps was determined this way, because some of the variables were more affected by age than others, which could distort the findings. Again, quadratic and cubic models were tried, but yielded no improvement over the linear model of the two scholastic-based scores.

Mean scores and standard deviations for each raw STM, WM and Inhibition variable by age are provided in Table 1. Raw scores rather than z-scores are included to give an impression of the data according to the original scales.

Table 1 about here

The development of STM, WM and inhibition

The first series of regression analyses examined the development of STM, WM and inhibition, assessing whether chronological age, group, and the interaction between age and group explained variance in each score. The findings showed that age was a significant predictor of all scores except Nonword Recall. Age accounted for 3.1% of the variation in Digit Recall, 1.1% of the variation in Nonword Recall, 19.2% of the variation in Block Recall, 38.5% of the variation in the Visual Patterns Test, 9.6% of the variation in Listening span, 21.5% of the variation in Backward Digit task, 10.8% of the variation in Spatial Span, and 18.4% of the variation in inhibition (the Stroop task). See Table 2 for details of these analyses.

There was also an effect of group on several tasks: the children with BID performed better than the children with MID on Block Recall, Visual Patterns Test, Backward Digit task, Spatial span and the Stroop task but not on Digit Recall, Nonword Recall and Listening span.

There were no interaction effects of group x age: Both groups developed similarly on all tasks.

Table 2 about here

The development of reading and arithmetic, and how they are influenced by STM, WM and inhibition

Table 3 gives details of the second series of regression analyses, which examined the extent to which STM, WM and inhibition Z-scores were able to predict the Z-score on the Reading test and the Arithmetic test.

Of particular interest was the effect on the Reading and Arithmetic tests, of the eight STM, WM and Inhibition scores. These measures were entered in step one of each regression, and were significant predictors of performance in both analyses. Looking at the individual beta-values, Digit Recall and Inhibition significantly predicted the score on the Reading test. When age was entered in step 2, the effect of Inhibition disappeared. As Digit Recall and Nonword Recall are supposed to measure the same; verbal STM, additional analyses were done to see what the shared variance of both tasks is in predicting the score on the Reading task. This shared variance was 5%.

For the Arithmetic test, three significant predictors emerged: Inhibition, Block Recall and Backward Digit recall. When age was entered in step 2, the effects of Block Recall and Backward Digit recall disappeared. Shared variance for both Block Recall and Visual Patterns test were calculated, as they are both visuo-spatial STM measures. Shared variance was in this case 9%. Again the same was done for Backward Digit recall and Listening Recall, both verbal WM tests. Here, shared variance was 7%.

As might be expected, age was a significant predictor of the Reading test and the Arithmetic test. There was no effect of group in either regression, nor was there an interaction between age and group. Hence, the developmental changes in the Reading and Arithmetic tests were comparable in both the MID and BID group (see Table 3).

Table 3 about here

Discussion

The first purpose of the present study was to explore the development of verbal and visuo-spatial STM, WM and inhibition in a large sample (N=197) of 9- to 16-year-old children with mild to borderline intellectual disability (MBID). The second purpose was to explore the relative influence of STM, WM and inhibition on arithmetic and reading.

In terms of the first research question, the key findings were as follows: verbal STM hardly improved between 9 and 16 years of age in children with MBID. Age accounted for a non-significant 1% of the variance in nonword recall and accounted for just 3% of the variance in digit recall (this was, however, significant). These were very modest age effects and they contrasted with the other measures of visual and spatial STM, verbal and visual WM, and inhibition. Age accounted for between 10 and 39% of overall performance on these other variables, providing evidence of the linear increases in performance with chronological age. These findings suggest that children with MBID show relatively little improvement with age in verbal STM; reflecting their underperformance compared to younger typically developing children matched on mental age (MA control group) in previous work (e.g. Henry & MacLean, 2002; Van der Molen et al., 2009). We speculate that the findings of Schuchardt et al. (2010), who did not show mental age-relative underperformance in 10-year-old children with ID, might have been a reflection of the age group they studied. At the age of 10 years, children with ID may have only just reached their maximum performance (plateau) on measures of verbal STM, therefore demonstrating their best relative performance in relation to mental age. These chronological age-related developmental paths did not differ between children with mild intellectual disability (MID) and children with borderline intellectual disability (BID), as demonstrated by the lack of an interaction between age and group in all analyses. Further, the MID and

BID groups did not differ in terms of level of verbal STM performance, providing further evidence that this was a particularly weak memory skill in children with MBID, irrespective of IQ score. By contrast, the severity of the ID was relevant for other aspects of STM and WM performance: the BID group outperformed the MID group on four assessed memory constructs including visual STM, spatial STM, verbal WM and visual WM.

Compared to the existing research on typically developing children, there were some differences in the developmental memory paths of children with MBID, varying according to working memory component. Studies of typically developing populations have shown verbal STM improvement until around age 15 (Conklin et al., 2007; Gathercole et al., 2004a; although see Alloway et al., 2006), but a more truncated improvement in visual STM only until around age 11 (Gathercole et al., 2004a). This contrasts with the current results. Here, for children with MBID, very little or no verbal STM development was found between 9 and 16 years of age, but, instead, an improvement in visual STM was observed until at least age 16. The latter finding may not come as a surprise, as some studies have found visual STM performance to be at the level of typically developing peers in children with BID (Henry, 2001), and in many studies, visual STM performance reaches or exceeds mental age level (Henry & MacLean, 2002; Henry & Winfield, 2010; Rosenquist et al., 2003; Schuchardt et al., 2010; Van der Molen et al., 2009). In summary, there were two key differences between typical children and children with MBID: verbal STM in children with MBID did not develop after age 10 and appeared to be particularly weak; while visual STM developed until at least age 16 and appeared to be relatively intact.

An important question concerns why verbal STM is relatively weak in children with MBID shown here and elsewhere (e.g. Bayliss et al., 2005; Henry & MacLean, 2002; Henry & Winfield, 2010; Russell et al., 1996; Schuchardt et al., 2010; Van der Molen et al., 2007; 2009). One possibility concerns automatic rehearsal in the phonological loop. Typically developing children, from age 7-9 years, show automatic rehearsal (e.g. Gathercole et al., 1994; Henry & Millar, 1993). Information that is kept in the verbal short-term store is automatically repeated to prevent this information of fading away. Studies investigating automatic rehearsal in children with MBID are not straightforward in their conclusions. Several studies have found no evidence for automatic rehearsal in children with MBID (e.g. Hasselhorn & Maehler, 2007), whereas others have reported some evidence for either speech coding or verbal rehearsal (Henry, 2008; Schuchardt et al., 2011; Van der Molen et al., 2007). In a recent study, Schuchardt et al. (2011) concluded that automatic rehearsal was intact in both children with MID and BID, provided the children had mental age levels of at least 7 years. However, although these authors claimed that verbal processing kept pace with mental age, they, nevertheless, concluded that the verbal short-term store itself was severely impaired in children with MID. Here, the fact that Nonword recall did not develop with age whereas Digit recall did (slightly) could support this position. Nonwords may be more difficult and time-consuming to rehearse because, lacking lexical entries, they require greater processing time; whereas digits can be processed rapidly due to their high familiarity.

If the verbal short-term store is constrained in children with ID, this leads to further questions as to whether it is constrained from birth (or before), or whether it is something that changes with development. Further research utilising brain scanning techniques would be valuable, to see how these children’s brains react to verbal STM tasks from infancy and/or toddlerhood until around age 10 years (after which we suggest that it does not develop further). Studies in the typically developing population have shown that WM tasks activate brain regions like dorsolateral and ventrolateral prefrontal cortex and superior parietal cortex, and that these regions become more activated as children grow older (e.g. Klingberg et al., 2002). Verbal STM is especially associated with ventral regions (Conklin et al., 2007), although dorsolataral regions become involved in adults when the number of items to be recalled increases (Veltman et al., 2003). This is in line with Gathercole et al. (2004a) who argued that typically developing children, as they get older, take greater advantage of the central executive to enhance the limited verbal STM storage. The question remains whether or not ventral regions in children with MBID become sufficiently involved when performing verbal STM tasks, and if this activation increases with age. Furthermore, as STM tasks rely increasingly on dorsolateral regions when memory load increases, it is of interest to explore if children with MBID do show (increasing) activation in that brain region when task load increases, to see whether they rely on the central executive like typically developing children do.

Therefore, although we conclude that verbal STM develops very little after the age of 10 years in children with MBID, we still do not know if and how it develops before that age. Future research should, therefore, focus on memory performance in these children at earlier ages (below 10 years). However, mental ages should preferably not be below 4 years to be able to test the children with a range of practical instruments (e.g. the Automated Working Memory Assessment for children, AWMA, Alloway, 2007, is appropriate for children from 4 years of age and older), although some STM and WM tasks can be adapted for children with weak (visuo-spatial) memory performance (Nutley et al., 2010). Furthermore, the period after age 16 years should be examined to see if the developments in visual and spatial STM, WM and inhibition continue beyond mid-adolescence.

Relatively few of the STM, WM and inhibition measures were predictors of reading and arithmetic in children with MBID, and even fewer were significant after age and group had been controlled. However, the shared variance of both administered verbal STM measures in predicting the score on the Reading task was 5%. This finding is in line with some previous work suggesting that verbal STM is the best predictor of reading and spelling in children with ID (Henry & Winfield, 2010), although such findings have not been reported by everyone (Alloway & Temple, 2007; Bayliss et al, 2005). Such a relationship implies that the basic ability to hold speech items in mind for brief periods of time is crucial for reading in those with intellectual disabilities, although we might expect stronger contributions from measures of WM in typical children (Christopher et al., 2012). It is important to note, however, that before age was controlled, inhibition also made a significant contribution to reading, suggesting that the ability to inhibit incorrect 'guesses' when reading might be an important skill that develops with age.

With respect to arithmetic, previous work has been relatively consistent in demonstrating a link between WM and arithmetic in children with ID (Alloway & Temple, 2007; Henry & MacLean, 2003) and in typically developing children (e.g. Bull & Scerif, 2001; Raghubar et al., 2010). We found similar relationships: one measure of WM, Backward Digit recall, was a significant predictor of arithmetic before age was controlled; and so was Block Recall (a measure of visuospatial STM), giving some evidence that these skills may be important predictors of arithmetic in populations of children with MBID. Arithmetic is said to depend on WM as calculating sums involves simultaneously holding partial information whilst processing new information to arrive at a solution (Raghubar et al., 2010). However, it is important to note that once age had been controlled, the only variable to relate to arithmetic was inhibition. In fact, the links between WM and arithmetic are likely to be complex, probably depending on several factors like age, skill level and the type of sum (Raghubar et al., 2010). The current finding that arithmetic and inhibition were related in children with MBID is in line with some studies carried out with typically developing children (e.g. Bull & Scerif, 2001, Kroesbergen et al., 2009; but see Van der Ven et al., 2011). It is assumed that inhibition is involved in arithmetic when inappropriate strategies have to be suppressed like for example addition when multiplication is required (Toll et al., 2011). If inhibition is indeed a predictor of arithmetic, then it might be worthwhile to explore the possibilities for training inhibition, for example by Braingame Brian, a cognitive training package that includes response inhibition (Prins et al., 2013).

In conclusion, the current findings showed that most aspects of STM, WM and inhibition in children with MBID developed between 9 and 16 years of age. However, contrary to the typically developing population, very little or no verbal STM development was found between 9 and 16 years of age. Again, contrary to the typical population, an improvement in visual STM was observed until at least age 16. Why verbal STM hardly improves in children with MBID beyond the age of 10 years, remains an unresolved question, but given the link found between verbal STM (digit span) and reading, this should be a priority for future research.

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Tables

Table 1: Mean scores and SD per score for each year of age

STM, WM and inhibition tasks																
	DR		**NwR**		**VP**		**BR**		**LR**		**BD**		**SpS**		**Str.**	
Age (n)	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
9 (17)	17.65	4.69	14.06	4.08	10.24	3.01	22.65	4.96	8.41	3.04	8.24	1.71	10.88	5.58	88,13	42,91
10 (53)	17.98	4.04	13.96	3.17	10.17	3.13	22.34	4.04	9.57	3.66	9.15	3.00	11.34	5.51	78,54	32,85
11 (23)	19.22	5.02	14.39	2.27	11.30	2.57	22.39	3.46	10.78	4.19	9.48	2.79	14.22	4.45	86,24	41,83
12 (17)	17.94	4.05	12.88	2.67	9.82	3.11	23.00	3.62	11.29	3.65	10.00	3.24	11.53	4.94	65,65	16,89
13 (8)	20.63	3.50	14.13	2.75	13.13	3.52	25.38	3.42	12.88	4.67	11.87	12.88	14.75	6.41	50,75	16,77
14 (30)	19.40	4.09	14.23	3.11	14.60	3.79	25.67	4.45	11.30	3.39	10.87	11.30	15.07	5.84	50,66	20,18
15 (32)	19.06	3.47	12.81	2.43	16.06	4.57	27.47	4.46	12.16	3.98	11.91	4.14	15.03	6.25	53,94	25,54
16 (17)	21.18	6.56	14.65	3.24	15.94	4.55	26.24	6.08	11.82	4.47	15.35	5.16	15.76	5.12	57,18	21,39

Note: DR = Digit Recall, NwR = Nonword Recall, VP = Visual Patterns, BR = Block Recall, LR = Listening Recall, BD = Backward Digit Recall, SpS = Spatial Span, Str = Stroop

Table 2**:** Details of the multiple regression analyses with the STM and WM scores as dependent variables and age, group and age*group as the predictors

		B	t	p
Digit Recall	Age	**.19**	**2.47**	**.01**
	Group	-.03	-.37	.71
	Age*Group	.00	-.00	1.0
Nonword Recall	Age	-.06	-.86	.39
	Group	.02	.25	.80
	Age*Group	.09	1.28	.20
Block Recall	Age	**.38**	**5.59**	**.00**
	Group	**.17**	**2.47**	**.01**
	Age*Group	.02	.25	.80
Visual Patterns	Age	**.50**	**8.70**	**.00**
	Group	**.28**	**4.86**	**.00**
	Age*Group	-.05	-.89	.38
Backward Digit	Age	**.39**	**5.99**	**.00**
	Group	**.19**	**2.85**	**.00**
	Age*Group	-.05	.78	.44
Listening Recall	Age	**.28**	**3.80**	**.00**
	Group	.11	1.60	.11
	Age*Group	-.01	-.13	.90
Spatial Span	Age	**.26**	**3.72**	**.00**
	Group	**.16**	**2.28**	**.02**
	Age*Group	-.06	-.81	.42
Stroop	Age	**-.40**	**-5.50**	**.00**
	Group	**-.17**	**-2.37**	**.02**
	Age*Group	.04	.60	.55

Note: In bold the significant results

Table 3: Linear regression models with arithmetic and reading as dependent variables and age, group, age*group and STM, WM and Inhibition scores as predictors (N= 191)

Dependent variables	Step	Predictors	R2change	F change	P F ch.	Beta	p
Arithmetic test	Step 1		.29	10.56	.00		
		DR				.09	.24
		NwR				-.11	.13
		BR				**.17**	**.03**
		VP				.15	.07
		BD				**.14**	**.02**
		LR				.04	.64
		SpS				.03	.62
		Stroop				**-.22**	**.00**
	Step 2		.33	8.07	.00		
		Age				**.27**	**.00**
		Group				.03	.61
		Group*Age				-.07	.24
Reading test	Step 1		.25	7.61	.00		
		DR				**.26**	**.00**
		Nonw R				.03	.68
		Block R				.05	.48
		Visual P				.14	.07
		BD				.05	.50
		List. R				.10	.21
		Spatial Sp.				-.06	.38
		Stroop				**-.19**	**.01**
	Step 2		.34	8.53	.00		
		Age				**.41**	**.00**
		Group				.03	.64
		Group*Age				-.04	.52

Note: In bold the significant results; DR = Digit Recall, NwR = Nonword Recall, BR = Block Recall, VP = Visual Patterns, BD = Backward Digit Recall, LR = Listening Recall, SpS = Spatial Span.