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Difficulties in working memory updating in individuals with intellectual disability

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Abstract

Background Despite the critical role attributed to working memory (WM) updating for executive functions and fluid intelligence, no research has yet been carried out on its specific role in the vital case of fluid intelligence weakness, represented by individuals with intellectual disability (ID). Furthermore, the relationship between updating and other WM functions has not been considered in depth.
Method The current study examines these areas by proposing a battery of WM tasks (varying in degree of active attentional control requested) and one updating task to groups of ID individuals and typically developing children, matched for fluid intelligence performance.
Results Comparison between the group of ID individuals and a group of children showed that, despite being matched on the Raven test, the updating measure significantly differentiated the groups as well as the WM complex span. Furthermore, updating proved to be the task with the greatest power in discriminating between groups.
Conclusions Our results confirm the importance of the demand for active attentional control in explaining the role of WM in fluid intelligence performance, and in particular show that updating information in WM plays an important role in the distinction between typically developing children and ID individuals.

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Keywords working memory, updating, intellectual disability, fluid intelligence

Introduction

Executive functions (EF) are related to ability to control and flexibly adjust thoughts and actions in relation to activities to be carried out. However, EF are usually involved when tasks are not automated, but instead demanding in terms of attentional control. For example, EF are only moderately implicated in tasks measuring vocabulary knowledge, while they are strongly involved in fluid intelligence tasks. The concept of EF is also crucial for the definition of working memory (WM) – in fact most WM models have postulated that the fundamental aspect of WM is connected with controlled attention, i.e. the flexible management of attentional resources (Kane & Engle 2002). Within EF, updating has received particular attention for its strict relationship with typical WM tasks (e.g. Miyake *et al.* 2000) and for its role in fluid intelligence performance (e.g. Friedman *et al.* 2006). Updating represents a particular case of WM elaboration as it refers to the ability to dynamically modify the

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content of memory according to task requests (Morris & Jones 1990). By this definition, some information is entered in a temporary memory system during updating, while other information previously maintained is excluded. Maintenance, continuous exclusion of material and its substitution by new material based on a pre-defined criterion are needed in order to meet the task request (Kessler & Meiran 2006; Carretti *et al.* 2007). In contrast, in the classical complex memory spans, new information is simply added to the memory set without any operation of substitution.

As regards the relationship between WM updating and other aspects of WM, Miyake *et al.* (2000) used the structural equation model to demonstrate that within EF the latent factor derived from different updating tasks significantly predicted performance in the operation span task; in contrast, the paths from inhibition and shifting were not significant. Recently, other authors studied the relationship between updating and complex span tasks. Results were sometimes inconsistent, and in some cases updating and WM were modestly correlated (0.20, see Kane *et al.* 2007), whereas in other cases the correlation was relatively high (0.55, Shamosh *et al.* 2008) or extremely strong (0.96, Schmiedek *et al.* 2009), to such an extent that updating and complex span performance is suggested to be impossible to distinguish.

The relationship between WM and intelligence has been documented in an extensive number of studies. For example Engle *et al.* (1999) demonstrated that a latent variable derived from the complex span tasks predicts general fluid intelligence performance (measured by Raven's and Cattell's tests), whereas the latent variable derived from the simple span tasks does not. Furthermore, Engle *et al.* (1999) found that in removing the variance common to the WM latent variable and the short-term memory latent variable, the relationship between WM and fluid intelligence was still significant. In addition, Kane *et al.* (2004) demonstrated that this relation was independent of the type of material used (verbal or visuospatial). They provided evidence that the increase in attentional resources needed to carry out typical WM span tasks results in the disappearance of domain specific differences, because all the WM measures are loaded on a single general common factor. In contrast with this view, Ackerman *et al.* (2005) showed that WM and fluid intelligence are not isomorphic constructs. In addition, Ackerman *et al.* (2005) did not confirm the complete a-modal nature of the relationship between WM and fluid intelligence, finding that the correlations between tasks with overlapping content for WM and fluid intelligence were higher than those for non-overlapping tasks. For the particular case of
WM updating, it has been suggested that this predicts fluid intelligence performance to the same extent as other WM measures (Schmiedek *et al.* 2009). Nevertheless, in recent years interest in a specific role of updating in fluid intelligence performance has been particularly intense. For example, addressing the distinction between three fundamental EF components (inhibition, updating and shifting), Friedman *et al.* (2006) investigated the differential contribution of these components to intelligence performance. From their results, it was clear that the process of updating represents the component with highest correlation with fluid and crystallized intelligence. In addition, these latter results were extended by a large twin study in which Friedman *et al.* (2008) showed updating to represent the most critical and biologically rooted component of EF (for conflicting results see Colom *et al.* 2008). Moreover, Friedman *et al.* (2008) demonstrated that IQ performance is more strongly related to updating than the other two EF (i.e. inhibition and shifting), because of the common genetic substrate. In addition, studying subjects aged 18–80 years, Chen & Li (2007) found updating to be the critical mediator between age and fluid intelligence. Recently, Belacchi *et al.* (2010) administered a battery of tests to children of different ages and found that performance in a variant of the relevance-based updating proposed by Palladino *et al.* (2001) was the best predictor of fluid intelligence. They also showed the rate of growth in fluid intelligence and in the relevance-based updating task from 4 to 11 years old to be comparable.

Updating, WM and fluid intelligence in ID

Research to date has explored the structural and functional characteristics of WM in individuals with ID, but has not examined the specific case of updating. In particular, in the case of adults with

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ID, Numminen *et al.* (2000) reported that WM performance in ID adults has two components, one 'phonological', the other described by Numminen and co-authors as 'general'; furthermore, Numminen and colleagues demonstrated that only this latter component predicted fluid intelligence performance, as measured using Raven's Coloured Matrices.

In a subsequent study, Numminen *et al.* (2002) found no differences between ID and typically developing (TD) groups matched for fluid intelligence in forward and backward digit span, whereas differences were evident in the Corsi block task and in a non-word span, the TD group outperforming the ID group. Consistently with this finding, Numminen *et al.* (2001) found poorer performance by the ID group in the Tower of Hanoi (TOH) task when their scores of rule violations and number of trials needed to complete the task were compared with scores of the fluid intelligence-matched group of children. In addition, Numminen *et al.* (2001) examined the role of the three components of Baddeley's WM model to explain TOH performance of ID individuals. Their findings demonstrated that the visuospatial and complex WM tasks (i.e. demanding in terms of attentional control) were significantly related to the TOH performance of persons with ID, whereas phonological WM tasks were not.

As a whole, these findings suggest that – similarly to the case for children (e.g. Lanfranchi *et al.* 2004) – WM performance of adults with ID differs from that of TD individuals especially when WM tasks are demanding in terms of attentional control. This conclusion forms the basis of our present study, the main objective being to investigate not only the WM but also the updating performance of individuals characterised by a weakness in fluid intelligence. To this aim, a group of adults with ID was presented with a battery of WM tasks, varying in demand for active attentional control, and an updating task.

The distinction between WM tasks according to their level of attentional control was introduced following the theoretical proposal by Cornoldi & Vecchi (2003). In their WM model, Cornoldi & Vecchi (2003) argued that it is possible to distinguish WM tasks by reference to two dimensions, i.e. domain (horizontal continuum) and degree of attentional control (vertical continuum), and stated that, within the WM tasks themselves, the degree of controlled activity can vary along a continuum. In fact, they considered each memory task to require a certain level of control activities (vertical continuum), the degree of involvement depending on the task demands. They proposed a distinction between more passive processes (simple recall of previously acquired information), and various degrees of active processing (manipulation of information to produce an output different from the original inputs). In less active tasks, denoted by Cornoldi and Vecchi as passive memory tasks or simple span tasks (i.e. forward digit span, see also Engle *et al.* 1999), the degree of controlled processes is very low, as participants only have to reproduce the item just presented. To do this, rote rehearsal of items is usually sufficient. Along the vertical continuum, the backward word span comes next, as it is assumed to require slightly more control, the subject having to perform a simple operation on the material (i.e. reverse the word order). Examples of tasks at a high level of active processing are those requiring active processing and temporary maintenance of information, such as the WM span following the procedure of Daneman & Carpenter (1980) and EF tasks such as the updating tasks.

Assuming the distinction between WM tasks on the basis of the dimension of active control, Lanfranchi *et al.* (2004) explored the role of control processes in verbal and visuospatial WM performance of individuals with Down syndrome (DS). For verbal WM, as expected from the literature (Jarrold *et al.* 2000), the DS group showed poorer performance regardless of the involvement of control. In contrast, in the case of visuospatial WM, the results demonstrated that individuals with DS are poorer in highly controlled visuospatial WM whereas they can be as good as TD children with the same mental age in low-control visuospatial WM tasks. Lanfranchi *et al.* (2004) concluded that a core deficit of mentally retarded individuals could reside in a controlled WM deficit. Convergent findings on the importance of WM control for understanding variations in fluid intelligence performance were reported by Lanfranchi *et al.* (2009) investigating the case of individuals with Fragile X syndrome. In the latter study, Lanfranchi and colleagues compared groups of individuals with and without Fragile X syndrome in two batteries of four

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verbal and four visuospatial WM tasks requiring different levels of control. Children with Fragile X syndrome showed performance equal to controls in WM tasks requiring low and medium-low control but significant impairment where greater control was required. Their results show that participants with Fragile X syndrome present a WM deficit only when the task demands high control, supporting the hypothesis that control can be a critical variable distinguishing WM functions and explaining intellectual differences.

Overview of the study

A review of the literature showed that exploration of WM performance of individuals with ID might reveal an interesting functional distinction in comparison to TD individuals, even when level of general intelligence is controlled for. This is particularly the case when considering WM tasks demanding in terms of attentional control, such as complex spans and updating tasks.

The main objective of the current study was therefore to investigate this latter point by presenting a verbal WM battery in which the demand of attentional control was manipulated, together with an updating task that represented unequivocally a high level of WM control. According to the Cornoldi & Vecchi (2003) model, we predicted that the dimension distinguishing the two groups would be related to the request for attentional control. Thus performance on tasks requiring few attentional resources (e.g. simple span) would not differ in the two groups. In contrast, differences would emerge where an active manipulation of the information is requested. Differences would be particularly evident in tasks requiring high attentional control, as is the case not only in complex span tasks but also in the updating task.

In this study, updating was measured using the relevance-based updating task, proposed by Palladino *et al.* (2001), in which participants had to listen to a list of words (objects or animals) and then remember the three smallest items, assuming relevance to be defined by item size. Palladino *et al.* (2001) demonstrated that the relevance-based updating task was more successful than the task used by Morris & Jones (1990) (where subjects have simply to recall the last items of a list of unknown length) in capturing individual differences in reading comprehension, revealing in particular the difficulty encountered by poor comprehenders in controlling irrelevant items (see also Carretti *et al.* 2005). Palladino and colleagues speculated on this result, suggesting that the relevance-based updating task required an active processing of information typical of cognitive everyday tasks, such as reading comprehension, where updating is required. Subsequent studies lent further support to the usefulness of the relevance-based updating task, demonstrating a strong relation with problem solving (Passolunghi & Pazzaglia 2004, 2005) and fluid intelligence (Belacchi *et al.* 2010).

Consistently with previous studies, the ID group was compared with a group of TD children matched on Raven's Coloured Matrices performance. ID individuals were considered independently of their organic aetiology but with reference to a clinical diagnosis of poor level of fluid intelligence supported by problems in everyday life associated with their condition of intellectual weakness. Analysis of this population enabled us to test the hypothesis that, even for individuals with an intellectual weakness matched with controls with the Raven test, the discriminative power of controlled WM (measured with complex span task and updating task) is maintained.

Method

Participants

A total of 28 adults (15 men, 13 women) with unknown aetiology of ID, diagnosis given by expert clinicians, participated. Table 1 shows the mean chronological age and the mean mental age estimated using performance on the Raven's Coloured Matrices. ID individuals had a mean mental age of 6 years and 2 months (the range of estimated IQ varied between 40 and 75). In the group, we included only participants without severe neurological signs or acute psychiatric disorders or dementia. Persons with ID were matched with a group of 28 children (15 men, 13 women) using the estimated mental age obtained in the Raven's Coloured Matrices.

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Table 1 Group characteristics

	ID group		TD group	
	M	**SD**	**M**	**SD**
Chronological age (in years)	38;4	12;3	6;5	1;3
Mental age (in years)	6;2	1;6	6;6	1;4
Raven total	17.36	4.46	17.50	4.28

ID, intellectual disability; TD, typically developing.

Materials

WM updating word span

This task was an adaptation of the relevance-based updating task proposed by Palladino *et al.* (2001) (see Belacchi *et al.* 2010). The task used words with high values of concreteness and familiarity (Barca *et al.* 2002) and referred to objects easily comparable for size. For each level of WM load (from 1 to 5), two trials composed of two lists were presented to the participant who had to remember an increasing number of items (from 1 to 5) according to the criterion 'recall the smallest object/s within each list' and in the order of presentation. In particular, the number of words in the list was twice (first trial) and two and a half times (second trial) the number of words to be recalled. An example of first type level-2 trial (i.e. two items to be recalled) might be: pillow, ladder, pen, tree. In this case the correct response is pillow and pen.

WM battery

The battery consisted of four verbal WM tests, already used in previous studies (Belacchi *et al.* 2010), all comprising the same type of material as that used for the WM updating span. The graduation in controlled attention requested by the task was carried out according to Lanfranchi *et al.* (2004). In the forward word span (low control), lists of 2–7 words were presented to the participant who had to repeat the list immediately and in the order of presentation. In the backward word span (medium-low control), again lists of 2–6 words were presented, but the participant was asked to repeat each list in reverse order immediately after presentation. In the selective word span (medium-high control), for each level of memory load (from 2 to 5), two trials composed of two lists were presented to the participant who had to recall the first word of each list after presentation of the entire series. Thus at level 2, in the first trial, the participant was presented with two 2-word lists, in the second trial, with two 4-word lists, at level 3, with three 2-word lists and then three 4-word lists and so on. For example, the second trial was as follows: (1) school, evening, fish, arrow; and (2) ground, mother, leaf, wood. The child thus had to remember the words school and ground. Finally, in the dual task word span (high control), lists of 2–5 words were shown to the participant who was asked to remember the last word on the list and to tap on the table when an animal noun was presented. For each level of memory load (from 2 to 5), two trials composed of two lists were presented to the child. Thus at level 2, in the first trial, the participant was presented with two 2-word lists, in the second trial, with two 4-word lists, at level 3, with three 2-word lists and then three 4-word lists and so on. Participants were informed they were wrong if they remembered the word correctly but forgot to tap.

In order to facilitate comprehension of instructions, practice trials were administered for each task. In all tasks (updating and WM), the experimenter presented words verbally at the rate of one per second. Each task moved progressively from shortest to longest lists, with two lists of the same difficulty for each trial. However, to avoid frustrating and difficult situations, the task was halted if the participant failed on both lists of the same length; the remaining items were considered incorrect. All the updating and WM tasks have good reliability indices, ranging from 0.70 to 0.90 (for details see Belacchi *et al.* 2010). Performance was scored similarly for all five tasks, by calculating the number of correctly recalled words.

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Procedure

Participants were tested individually in a single 1-h session; the order of presentation of the tasks was fixed (Raven test, Forward word span, Backward word span, Selective word span, Dual task word span, Updating word span) to minimise any error due to participant by order interaction.

Results

To analyse the contribution of WM to the discrimination between ID and TD individuals, a multivariate ANOVA was run, with Group (ID vs. TD groups) as between subjects factor, on the correct recall score in the four WM tasks (forward word span, backward word span, selective word span and dual task word span) and in the updating task. Using the Pillai's Trace the main effect of Group was only marginally significant $F(5, 50) = 2.054$ $\eta^2 = 0.17$ $P = 0.087$; however, separate univariate ANOVAs on the performances in the five tasks revealed differences in the updating word span and the dual task word span, with higher performance for the TD group than for the ID group (see Table 2).

The multivariate ANOVA was followed by a discriminant function analysis designed to identify which task(s) were better at discriminating between the two groups. A stepwise analysis was used on the updating and WM scores. Box's M statistic was not significant ($P > 0.77$), indicating that the homogeneity of variance assumption was met. The only measure resulting from the analysis was performance on the updating task, Wilks' λ (Lambda) = 0.91 indicating that this was the variable best separating the two groups. The discriminant function analysis had a reliable association with ID, χ^2 (1) = 4.87, $P < 0.01$. In fact, the updating task alone was able to correctly classify 75% of ID individuals (i.e. 22/28), whereas in the case of TD children only 50% were correctly classified (i.e. 14/28). It should be noted that all five measures highly correlated (Pearson's correlations ranged between 0.40 and 0.69), which might explain why only one measure was included in the discriminant function.

Table 2 also gives the effect sizes, describing the mean standardised difference in updating and WM tasks between ID and TD groups. The magnitude of effect sizes was interpreted according to Cohen's (1988) guidelines ($d = 0.20$ small; $d = 0.50$ medium; $d = 0.80$ large). A d value of 0.5, equivalent to a medium effect size, indicates that the means differed by half a standard deviation. From a correlational viewpoint, a higher d corresponds to a higher degree of association between the variables considered. As seen in Table 2, the magnitude of d varies as a function of the hypothesised attentional control involvement. Not only are higher values associated with tasks requiring both maintenance and manipulation of information, but the highest values concern the tasks with the greatest request of control. Here, d values for the updating and dual tasks can be considered to lie in the medium range, while for the other WM measure the index falls within the range of a small effect size (see Cohen's guidelines 1988). The effect size indices were used to estimate the relationship between active attentional control and the magnitude of group differences, following the procedure adopted by Lanfranchi *et al.* (2004). According to the theoretical model of WM proposed by Cornoldi and Vecchi,

Table 2 Descriptive statistics, multivariate ANOVA statistics and effect size index (d) for the performance of the two groups on the WM tasks and updating

	ID group		TD group					
	M	SD	M	SD	*F*	*df*	*P*	*d*
Forward word span	12.04	5.75	12.64	4.94	0.18	1,54	0.67	0.11
Backward word span	8.29	8.03	10.39	3.75	1.58	1,54	0.21	0.34
Selective word span	4.43	4.81	6.46	4.97	2.42	1,54	0.12	0.42
Dual task word span	3.04	2.83	4.93	3.51	4.32	1,54	0.042	0.59
Updating word span	5.04	3.76	7.29	3.98	4.87	1,54	0.031	0.58

ID, intellectual disability; TD, typically developing; WM, working memory.

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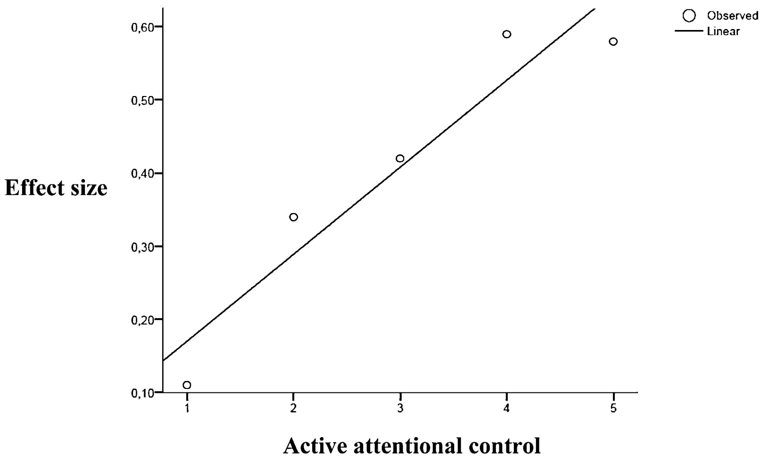

Figure 1 Line describing the relationship between increases in active attentional control and magnitude of effect size between groups (small circles correspond to the actual difference values). 1 = Forward word span; 2 = Backward word span; 3 = Selective word span; 4 = Dual task word span; 5 = Updating word span.

the differences in demand of attentional control expressed by the five tasks were operationalised assigning to each task an ordinal number from 1 to 5. The four WM tasks were ordered (see Procedure) on the basis of the assumed level of required attentional control (as suggested by Cornoldi & Vecchi 2003, and Lanfranchi *et al.* 2004) and the updating task was considered at the highest control level. This measure was used to estimate the magnitude of group differences. The relationship was found to be representable by a straight line (see Fig. 1) with positive gradient, according to the following equation:

Effect size of the difference between groups = 0.119 + 0.051c (level of attentional control)

The interpolation was significant ($P < 0.05$); note that the equation was also significant reversing the order of the value of effect size in the dual task word span with that of the updating task ($P < 0.01$). Other combinations were not significant.

Discussion and conclusions

The current study was designed to discover whether functional differences can be found in the WM of ID individuals compared with TD individuals. The study started out from the consideration that WM control is critical in describing the cognitive impairment of individuals with ID. This led on to the hypothesis that, if WM control components are crucial in explaining fluid intelligence performance, then the differences between groups of individuals with ID (assumed to be poor in fluid intelligence) and TD children would involve WM when active processing of information is requested, even where the two groups were matched with the Raven test (which is also assumed to offer a measure of fluid intelligence). In particular, our study included a measure of WM updating, which a large body of research has indicated as a powerful predictor of fluid intelligence performance (Friedman *et al.* 2006, 2008), and a battery of WM tasks, graduated in terms of active attentional control. The battery included one task requiring only maintenance of information in memory without further manipulation (forward word span), plus others requiring increasing degrees of active processing, such as manipulation of information to be recalled (backward word span) or selection/inhibition of information (selective word span and dual span task). As expected, comparison between the group of ID individuals and a group of children showed that, despite being matched on the Raven test, specific differences can be found on WM measures. In particular, the results demonstrated that the updating measure significantly differentiated the groups as well as the dual task word span. Furthermore, updating proved to be the task with the greatest power in discriminating between groups. The fact that the other WM tasks could not be included in the discriminant function seems mostly due to the high correlations observed between tasks.

From the theoretical point view, our results are therefore in line with findings highlighting WM differences in active tasks between ID individuals and

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controls and a relevant overlap between WM, as measured by complex span tasks, and updating processes (see for example Schmiedek *et al.* 2009). In contrast, as previously demonstrated by Numminen *et al.* (2002), the groups' performances were comparable when the level of active processing was low, as is the case for example in the forward word span. Our findings show that, although the two groups performed similarly on a task assumed to measure fluid intelligence, the WM functioning differed, in the sense that the ID group was poorer at the highest levels of WM control. In line with previous findings for DS (Lanfranchi *et al.* 2004) and Fragile X syndrome (Lanfranchi *et al.* 2009), the control continuum postulated by the Cornoldi & Vecchi (2003) WM model offers a useful framework for understanding the complex relation between WM and fluid intelligence. In line with the assumptions associated with the control continuum, WM tasks appear to require different degrees of control, and degree of control is inversely related to performance in the case of individuals with ID. The regression line clearly depicts this relationship: the increase in active control is associated with a larger difference between ID and TD individuals, measured in terms of effect size. This suggests that the core deficit of this condition of mental weakness is related to the ability to flexibly manage attentional resources in WM. In addition, the discriminant function analysis demonstrated that the updating task was the measure most useful in discriminating groups: using this task, 75% of the ID group individuals were correctly classified, confirming that, in general, assessment of updating is crucial to the identification of ID individuals. However, this was not the case when the TD group was considered; in fact only 50% of the participants were correctly categorised.

To conclude, examination of the specific case of individuals with ID demonstrated that measures of updating and complex span task, which are associated to WM active attentional control, are crucial in understanding the core deficits of individuals with ID. Participants from the two groups were matched on Raven's Coloured Matrices to a group of TD children. This procedure allowed an understanding of whether functional differences occur in WM, keeping constant the level in an important measure of fluid intelligence. From research on TD individuals, it might be expected that the more the tasks used in the matching procedure give a measure of fluid intelligence, the more similar the groups are likely to be as regards central executive performance. However, results of current and previous research (e.g. Numminen *et al.* 2002) suggest this not to be the case. Even when matching ID adults and TD individuals on Raven's Coloured Matrices performance, the two groups did not show comparable levels of WM performance. In the case of ID individuals, poorer WM control processes emerged. Of particular relevance to the debate on intelligence is our finding that updating has a prominent role in discriminating between groups of individuals with and without ID, so providing further support for a strict relationship between WM updating and fluid intelligence (e.g. Friedman *et al.* 2008). The difficulty individuals with ID encounter in updating could also underlie the difficulties they have in a range of everyday situations such as language comprehension and reasoning, which also require continuous updating of information.

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