Analogical reasoning in adolescents with intellectual disability: Effects of external memories and time processing

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Abstract

Analogical reasoning involves the comparison of pictures as well as the memorisation of relations. Young children (4-7 years old) and students with moderate intellectual disability have a short memory span, which hamper them in succeeding traditional analogical tests. In the present study, we investigated if, by providing external memory hints, the visual aid could enable these participants to succeed in analogies comprising more relations than their memory span was able to manage.

Our analogical test, composed of 2×2 matrices, was administered in two versions: The standard version, similar to traditional tests, required the participant to memorise all the relations involved in order to discover the solution, whereas the construction version required him/her to construct the answer part by part by using external memories, which potentially increased success by offloading the memory.

Our results show that students with moderate intellectual disability reached results similar to typically developing control children when provided with external memory hints (referred to as external memories). Moreover, in the most complex levels of the test, they did not spend more time than control children in solving the analogies.

Key words

Analogical reasoning; memory span; external memories; processing time

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Theoretical background

Defining Analogical reasoning

Analogical reasoning, as part of inductive reasoning, is considered to be an important mechanism in learning and problem-solving (Gentner 2003; Holyoak 2005), as well as in cognitive development and intelligence (Goswami 2001, 2002). Generally, the traditional analogy format, usually called the classic analogy, is displayed as *A : B :: C : D*, either in linear form or in a 2 × 2 matrix form. In order to discover the solution, the participant needs to find the fourth element of a group (*D*), by inducing the relationship between the first two elements of the task (*A* & *B*) and applying it to the third element (*C*). For instance, if we have “black” (*A*) and “white” (*B*) as the first two elements and “elephant” (*C*) as the third, the student should discover that the fourth element is “mouse” (*D*). In other words, the answer *D* can be found by following the rule “A is to B, what C is to D” (Pellegrino, 1985). Several processes are required for solving the analogies such as encoding, inference, mapping, application, justification, and response as described by Sternberg (1977a) in his componential theory.

Analogical reasoning in typically developing young children

Studies have demonstrated that young children get lower performances in analogical tasks when compared with older children (Abdellatif 2007; Foorman, Sadowski & Basen 1985; Green, Fugelsang, Kraemer et al. 2006; Richland, Morrison & Holyoak 2006; Singer-Freeman 2005). Several reasons justify this finding, such as a cognitive deficit, a lack of instruction, the complexity of the material used, or the development of the prefrontal regions of the brain.

Halford’s concern (1987, 1992, 1993) was about the processing load determined by the number of relations involved in the analogies. When more than one relation had to be inferred, Halford stated that the processing load was too extensive for children below 4 to 5 years of age. That might be the reason why children’s poor performance on classical analogy tasks had traditionally been attributed to a cognitive deficit representing the inability to treat several relations at the same time (Goswami 1989). Alternatively, Goswami (1995) argued that young children’s difficulty to reason about relations was not determined by the processing load capacity as Halford stated, but rather by the relational knowledge they possessed, a theory corroborated by other researchers (Abdellatif, Cummings & Maddux 2008).

Singer-Freeman (2005) explained young children's failure by the fact that they did not always know what they had to do in the proposed tasks. The goals were sometimes unclear for them, whereas older children were able to understand them without instruction. Direct instruction has improved young children's performance in analogical reasoning tasks (Abdellatif 2007; Alexander, White, Haensly et al. 1986, 1987; Phye 1990, 1991; Rattermann & Gentner 1998; Robins & Mayer 1993; Sternberg & Ketron 1982).

The differences of performance between young and older children in analogical reasoning can also be interpreted in light of current neuroscience findings. The prefrontal regions are known to develop gradually through childhood, adolescence and adulthood (Gogtay, Giedd, Lusk et al. 2004; O'Donnell, Noseworthy, Levine et al. 2005), and it is widely assumed that the development of the prefrontal cortex directly influences the ability to represent several rules in problem solving (Luo, Perry, Peng et al. 2003; Wright, Matlen, Baym et al. 2008). Recent neuroimaging research has described the prominent role of the prefrontal cortex in tasks requiring analogical reasoning (Christoff, Prabhakaran, Dorfman et al. 2001; Green, Fugelsang, Kraemer et al. 2006; Wharton, Grafman, Flitman et al. 2000).

Analogical reasoning in individuals with moderate intellectual disability[1]

For individuals with moderate intellectual disability (IQ: 35-40 to 50-55, mental age: 4-7 years, DSM-IV-TR, 2003[2]), which represent part of our population study, analogies are difficult to solve. Generally, these individuals have challenges attending to the task due to its complexity. For example, they encounter difficulties during the encoding process, as they spend less time exploring the information than typically developing individuals (Sternberg 1977a). Moreover, they often treat the information superficially by focusing directly on the elements of the answer and not on the matrix (Dulaney & Ellis 1997). They show a deficit of attention, as they can concentrate on the task only for a brief moment (Hulme & Mackenzie 1992;

[1] Moderate intellectual disability is equivalent to severe and complex learning difficulties in the UK.

[2] DSM-IV-TR (2003) definition was followed, as the participants were chosen in 2006.

Tomporowski & Tinsley 1997). They lack comparative behavior, which hampers them from comparing the elements in terms of similarities and differences (Schlatter, Büchel & Thomas 1997). Alternatively, they are unable to reach the necessary level of abstraction, which are necessary processes for solving analogies (Primi 2001). In addition, several authors claimed and proved that individuals with moderate intellectual disability do not use memory strategies as well as typically developing individuals, which could enable them to maintain the information longer in memory (Bebko & Luhaorg 1998; Dulaney & Ellis 1997). This issue usually leads them to obtain lower performances than typically developing individuals when measured on memory tasks (Henry & MacLean, 2002). Furthermore, their working memory capacity can only treat 2-3 elements at the same time (Hulme & Mackenzie 1992; Jarrold, Baddeley & Hewes 2000), whereas typically developing adults can treat 7 ± 2 elements (Miller 1956). Their limited memory capacities lead them to lose part of the information, and, consequently, give up the task because of a memory overload (Alloway, Gathercole, Kirkwood et al. 2009; Cowan & Alloway 2009).

Time component in analogical reasoning

Variations in the duration of the task may vary among the participants. In typically developing children, differences may lie in the processing time needed for solving the tasks. Several authors provide evidence that young children need more time than older children (Alexander, Willson, White et al. 1987; Foorman, Sadowski & Basen 1985; Pellegrino 1985; Sternberg 1977b; White & Alexander 1986). Sternberg and Rifkin (1979), for example, proposed analogies to 8, 10, 12, and 19 year-old participants. In a first experiment, they used schematic-pictures analogies which varied in four separable attributes: suit pattern (striped or polka-dotted), footwear (boots or shoes), hat colour (black or white), and hand gear (briefcase or umbrella). In a second experiment, they used *People Piece* analogies, which also varied in four integral attributes: sex (male or female), weight (fat or thin), height (short or tall), and garment colour (black or white). Results showed that in both experiments the solution time required to solve the analogies decreased across age levels, as well as error rates. In other words, 8 year-old children spent more time and made more errors than 10 year-old children, who in turn spent more time and made more errors than 12 year-old children and so on. Even if both kinds of analogies seemed to be quite similar, they required different strategies. Consequently, separable attributes needed to be considered one by one, and they took more time to be solved, whereas integral attributes needed the encoding of all attributes in a single operation. Young children were perhaps not able to consider an analogy as a whole operation, because they were not able to perform such an intricate encoding procedure, and therefore, had to break down the different terms into several attributes which took more time. These experiments are interesting for our own research because our analogical reasoning test is either composed of integral attributes, or separated attributes.

With regard to individuals with moderate intellectual disability, they also present differences in processing time for solving the analogies compared to typically developing individuals. McConaghy and Kirby (1987) used Sternberg’s (1977a) componential theory to observe differences between children with average intelligence and below average intelligence (IQ range 55-85). They found that children with below average intelligence did not spend sufficient amount of time encoding information, which led to poor analogy performance. The authors proposed a training phase designed to teach the participants how to solve the analogies. Due to the training, the participants spent more time on encoding and hence reduced the error rate. However, the results did not show significant changes in the analogical processes. In order to explain these results, the authors suggested that this could be related to difficulties the below average group experienced in maintaining information in memory. The amount of information being processed by the participants went beyond their working memory capacity, and thus, they did not spend enough time finishing the information-processing function. This finding was also corroborated by other researchers (Pellegrino 1985; Sternberg & Nigro 1980).

In addition, several studies have shown that time increased according to the number of elements involved in the analogies, which justifies that complexity and processing time are positively related (Arendasy & Sommer 2005; Bethell-Fox, Lohman & Snow 1984; Foorman, Sadowski & Basen 1985; Sternberg 1977b). Mulholland, Pellegrino and Glaser (1980) have shown that an increase in the number of elements produced an increase of processing time. They also discovered that the most difficult items were also those composed of multiple transformations. Moreover, an increase in the number of elements led to an increase of error rates (Holzman, Pellegrino & Glaser 1982).

Computerized testing

Static tests or IQ tests assessing analogical reasoning capacity are mostly presented on a paper-and-pencil format. Theorist and professionals more and more agree that these tests do not give a picture of the cognitive intellectual potential of individuals, particularly for those with intellectual disability. As a result, individuals with intellectual disability usually show floor effects, and their competences are underestimated (Resing 2000).

Several authors have shown that tests presented on a computer are more effective for individuals with moderate intellectual disability than paper-and-pencil tests (Bosseler & Massaro 2003; Fletcher-Flinn & Gravatt 1995; Hetzroni & Tannous 2004; McArthur, Haynes, Malouf et al. 1990; Stock, Davies & Wehmeyer 2004). Specifically, the laptop computers were presented to be the most promising devices for this population (Davies, Stock & Wehmeyer 2002, 2004; Stock, Davies, Davies et al. 2006; Tanis, Palmer, Wehmeyer et al. 2012). Moreover, these individuals often have motor skill deficits, which hamper them from manipulating the computer mouse. Touch screen computers seem to be the best option for this population because their movements do not need to be as precise as with the computer mouse. Furthermore, the touch screen is also known to improve the motivation and the attention span of the participants (Foshay & Ludlow 2005; Lee, McGee & Ungar 2001).

The present study

By taking into account all the beneficial effects of computers for individuals with moderate intellectual disability, we designed an analogical reasoning test using a touch screen, the Construction of Analogical Matrices Test-Revised (CAM-R; Denaes 2011), which constitutes an elaboration of a previous test, the CAM (see Angeretas & Gonzalez 2002; Büchel 2006). This revised test is composed of two versions. One version includes external memories, which unloads the working memory, and the other, a standard test, bears on working memory (for a complete description, see below).

This study followed two objectives. The main objective consisted of checking whether a testing procedure offering the decomposition of the answer alternatives (also called external memories; i.e., construction version) helped individuals with moderate intellectual disability to get better performances than a version without such a support (i.e., standard version). The second aim was to investigate how the processing time needed for solving the analogies changed from one version to the other and also from one complexity level to the next. Both these aims are related in that individuals with moderate intellectual disability and young children usually spend more time than older typically developing children. Even if both versions of our test seem quite similar, they required different strategies: As demonstrated by Sternberg and Rifkin (1979), separable attributes (construction version) need to be considered one by one and require accordingly more time to be solved, whereas integral attributes (standard version) necessitate encoding of all attributes in a single operation. Individuals with moderate intellectual disability and young children might not be able to consider an analogy as a whole operation because they would be not able to perform such an encoding procedure, and therefore, would have to break down the different terms into several attributes, which takes more time. A control group matched on both mental age and memory capacities was included in order to contrast the results of individuals with moderate intellectual disability with typically developing children.

Method and Material

Participants

Prior to data collection, ethical approval was obtained from the ethics committee of the University of Geneva. We selected participants with moderate intellectual disability from 2 special institutions in the area of Geneva (Switzerland), composing the "group with intellectual disability" (*n* = 26). We asked both these institutions to give us the names of volunteer students, who had moderate intellectual disability according to their personal files (assessed by IQ tests). The institutions refused to give us information about the diagnosis considered strictly confidential, but they assured us that all the participants had a moderate intellectual disability. The ages of the students varied from 15 to 18 years, the mean age being 16.8 (SD=10.9 months).

Despite our criticism of using static tests with disabled individuals, we decided to apply one of them as a measure of mental age. The Raven's Progressive Matrices (Raven, Court & Raven 1990; Raven, Raven & Court 1998) was chosen because it measures analogical reasoning like the CAM-R. In addition, its nonverbal format supported was an advantage given that several participants with moderate intellectual disability could not speak. We administered the Colored (CPM) version designed for children between 4 and 11 ½ years of age and for individuals with moderate intellectual disability[3].

We also administered short-term and working memory tests, both verbal and visuospatial in order to assess our participants' memory capacities. Lanfranchi, Cornoldi and Vianello (2004) used these tasks with children with Down Syndrome, Fragile X, Prader-Willi and Cornelia de Lange syndromes, as well as typically developing children between 4 and 6 years old. These populations shared approximately the same mental age as our participants, which subsequently, led to the use of the material format provided by Lanfranchi.

The results of the Raven CPM (raw scores), the short-term and working memory tasks are presented in Table 1 below.

Insert Table 1 about here

The ANOVA with regard to the 3 scores as dependent variables and institution as between-subject factor revealed significant differences between both institutions. Institution 2 got better performances than Institution 1. For this reason, it was decided to keep the participants apart from each other rather than to put them together in a single group. Despite the fact that we asked for students with moderate intellectual disability, we were forced to recognize that only half of them really had this level of intellectual disability, whereas the other half had more a mild intellectual disability (IQ: 50-55 to approximately 70, DSM-IV-TR, 2003). As both degrees represent different memory abilities and different general capacities, we decided to keep students of the Institution 1 in order to test the memory overload hypothesis mentioned in the introduction, and to keep students of the Institution 2 in order to observe the limits of this hypothesis. Institution 1 was called "ID-low" (i.e.

[3] The CPM produced a single raw score that could be converted into a percentile score based on normative data, which concerned children between 4 and 11 ½ years of age. With the raw scores, it was then possible to define the participants' mental age, which was the age at which the mean percentile score was equal to their raw score (Raven, Court & Raven 1990).

participants with intellectual disability and low mental age) and Institution 2 was called "ID-high" (i.e. participants with intellectual disability and high mental age).

As we wanted to compare the performances of participants with intellectual disability with those of typically developing children of the same mental age, we selected one typically developing control group composed of children without intellectual disability between 4 and 8 years old (*n* = 32; *M* CA = 6.2). These children came from 4 schools in Geneva and were separated according to their grade level: pre-kindergarten (CA: 4-5 years), kindergarten (CA: 5-6 years), 1st grade (CA: 6-7 years), and 2nd grade (CA: 7-8 years). All had French as their mother tongue. The school teachers were asked to give us names of children that were achieving in the average range at school and who would be interested in participating in our research. We administered the same tests to the typically developing children, that is firstly the CPM and then the memory tasks. Table 2 presents their results with regard to the Raven CPM (raw scores), the short-term and the working memory tasks.

Insert Table 2 about here

The ANOVA revealed significant differences between all the classes in the 3 tests. We noticed that the scores in the working memory tasks were quite low compared with the scores at the Raven CPM and at the short-term memory tasks. Only children of the 2nd grade got almost half of the points. According to the 3 tests results, 2 groups emerged: one composed of the pre-kindergarten and kindergarten, and the other composed of the 1st and 2nd grade (except for working memory tasks, where only 2nd grade was significantly different from the others classes).

According to the raw scores of the Raven CPM, we defined the participants' mental age, which was the age at which the mean percentile score was equal to their raw score (Raven, Court & Raven 1990). According to this analysis, 2 distinct groups emerged: one with a mental age between 4 and 6 and another between 7 and 8. Following these results, we used a matching procedure based on the participants' mental age (obtained through Raven CPM)[4] and their memory score (obtained at the short-term and working memory tasks). The group called "TD-low" (i.e. typically

[4] The mental age for both institutions was not computed because the normative data of the CPM were available only for children between 4 and 11 ½ years old.

developing children with low mental age) was composed of the Pre-Kindergarten and Kindergarten children and was comparable to ID-low participants (i.e., common mental age of 4-6). The group called “TD-high” (i.e. typically developing children with high mental age) was composed of the 1st and 2nd grade children and was comparable to ID-high participants (i.e., common mental age of 7-8). Table 3 below indicates number, percentage, chronological age (CA), and mental age (MA) for all participants in their respective group.

Insert Table 3 about here

Material

The analogical reasoning test that we developed, called the *Construction of Analogical Matrices Test-Revised* (CAM-R), was designed with the Authorware software (Macromedia Authorware 7 © Adobe Systems). This test is presented in a game-playing format (touch screen with pictures) because several studies have shown that a material adjustment is more favorable than a traditional material (Alexander, Willson, White et al. 1987, 1989; Tzuriel & Klein 1985, 1987).

Previous studies with the CAM showed that students with moderate intellectual disability did not demonstrate a problem in analogical reasoning, but rather suffered from a working memory limitation, which hampered them from solving the analogies with success (Angeretas & Gonzalez 2002; Büchel 2006). In order to prove this hypothesis, we developed two versions: a standard version, similar to classical analogies, and a construction version, designed to unload the memory. In both versions of the CAM-R, participants were confronted with 2×2 matrices, in a figurative concrete modality, presented on a touch screen, where they perceived the *A*, *B* and *C* terms. The elements that potentially constructed the answer were available permanently at the bottom of the screen. Once touched, the pictures (in the standard version) or the separated elements (in the construction version) slid into the *D* zone of the matrix.

In the standard version, answer *D* needed to be chosen among several pictures, with only one being correct. In order to find out the correct picture, the participants needed to memorize all the relations at the same time, which could potentially lead them to a memory overload. In contrast, in the construction version, answer *D* needed to be constructed with the elements available permanently at the bottom of the screen. The advantage of the construction version was that it allowed the participants to consider one relation after another, without the burden of remembering those previously taken into account. The elements of the answer represented external memory hints, and could potentially unload the participants' memory. Figure 1 presents the "Beach" Item in the standard version and construction version respectively.

Insert Figure 1 about here

Each version was composed of sixteen items. The 16 items of the construction version showed high internal consistency, with a KR-20 of .91 and the 16 items of the standard version, also showed high internal consistency, with a KR-20 of .94.

The sixteen items of each version were shared among 4 levels of complexity, characterized by the number of relations. In both versions, the number of elements grew according to the levels of complexity, from 2 relations at the first level to 5 relations at the fourth level. In order to avoid possible frustrations among our participants, no more than 5 relations were used, which was a little more than their memory span (approximately 2-3 elements; Hulme & Mackenzie 1992) can incorporate at a time.

The number of relations between the *A*, *B*, and *C* terms for each level is presented in Table 4.

Insert Table 4 about here

The possible answers (separated elements in the construction version and pictures in the standard version) were available at the bottom of the screen together with incorrect elements, which were associative elements. In Figure 1, the associative element is the boat. The items contain 1 or 2 associative elements. We decided to put in these associative elements in order to observe if our participants were attracted by them by using associative reasoning or if they were really reasoning by analogy (see Denaes 2012).

Procedure

The CAM-R followed an individual administration. Each participant was seen by an experimenter in an independent room, free from disturbance. Each participant was randomly assigned to receive one version and then 6 weeks later the other version. For the first version, we began with moderate intellectual disability participants, then with the typically developing children. When the first round was over, we began again with moderate intellectual disability participants for the other version, and finally with the typically developing children. The 6 weeks interval between the administrations of both versions was the same for all the participants. This interval, including holidays (Christmas or Easter holidays), was judged to be long enough by the ethics committee of the University of Geneva to prevent the participants from remembering the items they saw during the first round.

Test items were preceded by 8 training items, allowing the students to familiarize themselves with both the task and the touch screen. In addition, the participants had the opportunity to solve each item a second time if they failed at the first attempt, which meant if they did not find the right picture (in the standard version) or if they did not choose all the necessary elements constituting the answer (in the construction version). In this case, they received standardized help, such as, “You saw that the colour changed between *A* & *B*, but look closer to the change between *A* & *C*” and she/he could try the item a second time.

We decided to attribute 1 point for each correct relation, which brings the maximum number of points to 56 representing the total number of relations. We chose to proceed in this way, in order to give value to our participants’ reasoning. Indeed, if we had decided to give 1 point for one item entirely correct and 0 point for one entirely wrong, which was our first intention, we would have underestimated partially correct answers; for instance, 2 correct relations on a total of 3, or 4 on a total of 5.

The Authorware software (Macromedia Authorware 7 © Adobe Systems) recorded the number of correct and wrong relations, as well as the time spent (expressed in seconds) to solve each item for all participants.

Results

Our first hypothesis stated that all participants would obtain better scores in the construction version compared to the standard version, due to the external memories. The construction version of the CAM-R is a version in which one can construct the answer step by step. The external memories allow the student to treat one relation after another without constantly needing to remember the relations already taken into account by a previous choice. In contrast, the standard version of the CAM-R does not propose such a support; hence all the relations involved in the matrix have to be memorized in order to select the correct picture, which can overload the participants' working memory. Results for each group according to both versions are presented in Table 5.

Insert Table 5 about here

A mixed 2 (version as within-subject factor) × 4 (groups as between-subject factor) multivariate analysis of variance with repeated measures was performed. The data revealed a significant effect of the version ($F(1,54) = 6.481$, $MSE = 89.446$, $p < .05$, $\eta^2 = .11$) and a significant interaction effect versions × groups ($F(3,54) = 3.908$, $MSE = 53.931$, $p < .05$, $\eta^2 =.18$). Firstly, this means that there were scores differences according to test version and secondly, that the range of these differences varied according to group members.

Then we performed ANOVAs separately for the construction version ($F(3,54) = 9.864$, $MSE = 215.817$, $p < .01$, $\eta^2 = .35$), and for the standard version ($F(3,54) = 14.156$, $MSE = 476.260$, $p < .01$, $\eta^2 = .44$). Post hoc comparisons using Tukey's-b statistic[5] revealed no significant differences between the versions for TD-low, TD-high, and ID-high. However, individuals in ID-low showed a significant difference between the versions by getting better performances in the construction version ($M = 46.23$) than in the standard version ($M = 40.38$). Our hypothesis was therefore confirmed only for ID-low.

Our second hypothesis stated that at each level, participants with moderate intellectual disability would spend more time than typically developing children

[5] As the TD participants were in greater number than the ID participants, we checked our results with the Gabriel test (for unbalanced design), which gave the same results.

because their intellectual disability induces slower processes (e.g., McConaghy & Kirby 1987). Table 6 presents the mean and standard deviations of time spent at each level and in both versions. The time is expressed in seconds and represents the mean time spent per item.

Insert Table 6 about here

A mixed 4 (levels as within-subject factor) × 2 (version as within-subject factor) × 4 (groups as between-subject factor) analysis of variance with repeated measures was performed. The data showed an effect of the levels ($F(2.103, 113.586) = 129.287$, $MSE = 23400.322$, $p < .01$, $\eta^2 = .71$), and an effect of the version ($F(1,54) = 74.902$, $MSE = 4515.90$, $p < .01$, $\eta^2 = .58$). We also found several interaction effects: an interaction effect version × group ($F(3,54) = 4.041$, MSE`= 243.633, $p < .05$, $\eta^2 = .18$); an interaction effect level × version ($F(2.815, 152.028) = 12.487$, $MSE = 807.873$, $p < .01$, $\eta^2 = .19$).

Post-hoc analyses revealed that our hypothesis was partially confirmed. In the construction version, ID-low was only comparable to ID-high. That group spent more time than both typically developing groups but only at the 1st level. As for the standard version, ID-low was also only comparable to ID-high in the first and second levels. Finally, there were no significant differences between the groups at the 3rd and 4th levels. With regard to typically developing children, we mentioned before that young children usually spend more time than older children (Sternberg & Rifkin 1979). Our results strongly indicate the opposite, as there were no significant differences between TD-low and TD-high in every level and both versions.

In addition, we assumed that for all the participants and in both versions, the time needed to solve the items would increase from one complexity level to the next because there was always one more relation to consider at each level. Logically, as the number of elements involved in the analogies grew along with the levels, the participants should take more time to consider them (Arendasy & Sommer 2005; Bethell-Fox, Lohman & Snow 1984; Foorman, Sadowski & Basen 1985; Mulholland, Pellegrino & Glaser 1980; Sternberg 1977b). Table 6 showed that all the groups spent more time at each level in the construction version. In the standard version, the same results were found for the typically developing groups, and for the ID-high group, but the ID-low group spent approximately the same amount of time at the four levels.

Finally, we also supposed that all the participants would spend more time in solving the analogies in the construction version than in the standard version, because separated elements usually take more time to be considered than integral elements (Sternberg & Rifkin 1979). Table 7 presents the Total Time spent at each level and in each version for all the participants.

Insert Table 7 about here

A repeated measures analysis of variance (levels as within-subject factor) × (versions as between-subject factor) was computed. The results showed that there was an effect of the level ($F(2.045, 116.59) = 133.141$, $MSE = 24548.585$, $p < .01$, $\eta^2 = .70$), and an effect of the version ($F(1,57) = 65.291$, $MSE = 4566.55$, $p < .01$, $\eta^2 = .53$). We also found an interaction effect between the levels and the versions ($F(2.658, 151.479)$[6] $= 13.178$, $MSE = 802.447$, $p < .01$, $\eta^2 = .19$).

Trend analyses (polynomial contrasts) showed a linear trend for the construction version ($F(3,54) = 2.155$, $MSE = 71.935$, $p < .01$, $\eta^2 = .82$), and for the standard version ($F(3,54) = 5.687$, $MSE = 261.067$, $p < .01$, $\eta^2 = .24$). Neither quadratic nor cubic effects were significant in both versions, which confirmed the supremacy of the linear trend. On the basis of these results, our hypothesis was confirmed. In addition, we noticed a progression of approximately 10 seconds between each level in the construction version, whereas this progression consisted of approximately 4 seconds between the first 3 levels in the standard version. Moreover, the same time was spent between the 3rd and the 4th levels, which could indicate saturation from the participants due to the difficulty of the version.

[6] Mauchly test determined that the assumption of sphericity was violated, both for the levels effect ($\epsilon = .682$, $\chi^2(5) = 47.141$, $p < .01$) and for the interaction levels × versions ($\epsilon = .886$, $\chi^2(5) = 22.137$, $p < .01$). Therefore degrees of freedom were corrected using Huynh-Feldt.

Discussion

In conducting this study, we had the following aims: First, we assessed the effect of a testing device that offered external memory aids in comparison to a classical testing procedure for students with intellectual disability compared to typically developing children of the same mental age. Secondly, we investigated the behavior of the groups in terms of time spent in processing items at different levels of complexity using two versions. The rationale behind these two aims was to observe whether separable attributes would be easier to solve and would take more time to consider than integral attributes. Observation of participants' behavior across several levels of complexity, we considered, would provide information about which analogies could be treated as a whole operation and which would need to be treated separately.

The effect of external memories on the ability to reason analogically

Our first hypothesis, which stated that all groups would obtain better scores in the construction version than in the standard version was confirmed only for the ID-low participants indicating that the external memories were beneficial only for this group but not for the three other groups.

As stated by Büchel (2006), the main difficulties of individuals with moderate intellectual disability in analogical reasoning is a problem of working memory limitation that could be reduced by the use of external memories, as demonstrated by our results. In the construction version, students with moderate intellectual disability (i.e., ID-low) were able to obtain similar performances compared to TD-low children, due to the presence of external memories. Despite the fact that both groups shared the same memory capacities and the same mental age, the typically developing children received better performances in the standard version at each level.

With regard to the common memory capacities, it seems that the ID-low students could not reach the same level of performances, probably because of a working memory overload. They were able to reason by analogy but probably had more problems in treating several relations at the same time than typically developing children. Several authors demonstrated that differences in working memory capacity depended on several factors, such as the amount of information the participants could memorize (Shah & Miyake 1996; Sweller 1994), knowledge and skills (e.g., Ericsson

& Kintsch 1995), or the amount of available resources (Just & Carpenter 1992). In addition, deficits in working memory were also found in the moderate intellectual disability population compared to typically developing individuals of the same mental age (Baker, Hooper, Skinner et al. 2011; Carretti, Belacchi & Cornoldi 2010; Carretti & Lanfranchi 2010; Laws 2002; O'Hearn, Courtney, Street et al. 2009). Moreover, individuals with moderate intellectual disability present a shorter memory span compared to typically developing children of the same mental age (Detterman 1979; Ellis 1978; Hulme & Mackenzie 1992).

With regard to the common mental age, it seems that the intellectual disability played a crucial role in the performances, more than the mental age. Even if ID-low students and TD-low children shared a common mental age in our pretests, their performances on analogies differed which means that the measure of mental age was only theoretical. One explanation for this statement lies in the criticisms made against intelligence tests. For instance, these tests measure a person's actual level of performances and its acquired knowledge and skills at one moment of time. Even when scores reflect mental age, they do not give a precise picture of the intellectual functioning of the tested persons (Chen & Siegler 2000). Moreover, test scores are normed on the general population and are based on the assumption that all persons are exposed to the same learning opportunities (Tzuriel 2001). Intelligence tests are not suitable for special populations comprising individuals with intellectual disability because they cannot estimate the performances of these persons precisely enough (Bosma & Resing 2006; Reschly, Myers & Hartel 2002). Intelligence tests tend to ignore social and practical skills as well as the influence of factors such as motivation, anxiety, self confidence, locus of control and so on which become very consequential for the task completion (Luckasson, Borthwick-Duffy, Buntinx et al. 2010; Tzuriel 2001).

Processing time in participants with intellectual disability

Our second hypothesis, which stated that, at each level, participants with intellectual disability would need more time to solve the analogies than the typically developing children, was partially confirmed. Results showed that for levels 3 and 4 in both versions, which were also the most difficult of our test, all groups spent approximately the same amount of time in solving the analogies, the differences being not statistically significant. Our hypothesis was confirmed only for ID-low in levels 1 and 2 in the standard version and only in level 1 in the construction version. In fact, in the most difficult levels, participants with intellectual disability performed the same as participants without intellectual disability. These results were in contradiction with those of several authors (Hulme & Mackenzie, 1992; Jensen, Schafer & Crinella 1981; McConaghy & Kirby, 1987), which stated that children with below average intelligence spent more time solving analogies than children with average intelligence.

In addition, all the participants spent approximately 20 seconds at the maximum in the standard version, whereas they spent between 30 and 40 seconds in the construction version. We could explain these results by contrasting the format of each version. The action to construct the answer part by part could also retain the participants' attention, whereas the action to choose a picture among several others could be less motivating. There might, however, be another explanation of these findings: in the standard version, ID-low and ID-high spent approximately the same amount of time at the 4 levels, which indicated saturation due to the cognitive load of analogical items. In other words, they could not spend more time analysing the items, which explained the more subtle results. In addition, Hulme and Mackenzie (1992) argued that persons with intellectual disability had difficulty in concentrating on one object or one task and had greater distractibility than typically developing individuals. We have to keep in mind that each version lasted 30 minutes, which was already twice or three times more than what the participants were used to in their daily tasks. This decline in time was not found in the construction version perhaps because the construction modality maintained our participants' attention.

In addition, we found that all groups behave the same way in the construction version: as the test became more complex, participants needed more time to solve it. This was expected because there was one more relation to consider at each level. These results corroborated those of several authors (e.g., Arendasy & Sommer 2005; Bethell-Fox, Lohman, & Snow 1984; Foorman, Sadowski & Basen, 1985; Mulholland, Pellegrino & Glaser 1980; Sternberg & Rifkin 1979) by stating that time increased with the number of elements involved in the analogies.

Finally, we hypothesized that the items of the construction version would need more time to be solved than those of the standard version. This hypothesis was confirmed as we found differences between both versions. The fact that the answer elements of the construction version were in greater numbers than that of the pictures in the standard version, led our participants to spend more time in the construction version. These results corroborated Sternberg and Rifkin's (1979) results, who demonstrated that separable attributes took more time to be considered than integral attributes.

Limits of the study

Firstly, our study only included fifty-eight participants; thus, our results must be interpreted with caution and their generalization is limited. Secondly, we mentioned that the typically developing children did not need external memories as much as the ID-low group because they obtained the same scores in both versions, which indicate that the test could be too easy for the children. In order to remediate this problem, we propose to add more levels of complexity in a revised version of the CAM-R, and hence more relations, which could suit the typically developing children. The benefit of adding more difficult levels could be twofold: firstly, it would indicate how many relations the children could treat, as they are perhaps able to treat more than 5 relations. Secondly, it might give value to the external memories, which were not especially effective to have 5 relations to treat at the same time in the construction version.

Conclusion

Our results have educational benefits for individuals with moderate intellectual disability because they showed that these participants were able to solve analogical matrices that were made up of different levels of complexity. They also received results equal to children of the same mental age when the test version offered external memories. These external memories enabled our participants to go beyond their memory span limit. Indeed, they were able to solve items composed of 5 relations, whereas their memory span can usually treat 2 or 3 relations at a time (Hulme & Mackenzie 1992), which was also true for the young children. In his article, Büchel (2006) stated that the problem was to know if persons with moderate intellectual disability had a limitation in analogical reasoning or rather a memory limitation. Our results indicated that, by having a support, these participants are completely able to reason by analogy and do not have a limitation in this area. On the contrary, their problem was more located in their memory, which could be enhanced with external help, as we demonstrated it. It seems that an appropriate device, in this case, a touch screen computer test with external memories, allows for better performances for individuals with moderate intellectual disability in analogical reasoning. Pedagogical implications of these types of studies go against what professionals generally assume, in that, persons with moderate intellectual disability are not able to reach higher abstract reason levels. On the contrary, the devices show that they were able to perform better than what is usually expected of them (e.g., Resing 2000).

In addition to these positive outcomes, we also observed that the level of attention span of our participants increased. As mentioned before, theoretically, individuals with moderate intellectual disability tend to demonstrate a lack of attention and tend to be distracted by disturbing elements. At the beginning of our study, we presented our test to support workers and teachers in the selected special institutions/schools. While they were very enthusiastic with regard to the touch screen computer test, they warned us about the duration of each version. They claimed that their daily tasks (academic tasks or leisure tasks) do not exceed 10 to 15 minutes. However, each of our versions lasted 30 minutes, which represented more than two times the maximal duration of their usual tasks. The positive outcome of our study is that all participants were able to reach the end of each version. Therefore, their attention was maintained twice or three times longer than their usual attention span, probably because of the attractive device and pictures.

Even if computers made their introduction into education in the early 1960s, touch screen computers were unknown by all our participants when we began our study. The daily tasks used by the school teachers and the support workers were always presented on a paper-and-pencil format. The use of a touch screen computer was seen as motivating because it was new, different and provides a feeling of agency or control over the task. Our choice to present a cognitive task composed of familiar pictures on a touch screen computer had the effect and perception of being in a game-like situation, thus, it is a procedure recognized as being very motivating (Burguillo 2010; Papastergiou 2009). Therefore, the touch screen can be effective for individuals with moderate intellectual disability for enhancing their cognitive skills (Brown 2011). It is known that persons with moderate intellectual disability have low expectations for success because they are too often confronted with failure experiences (Tassé, Morin & Aunos 2003; Woodward & Rieth 1997). In the CAM-R, each participant could work at his/her own rhythm. The touch screen computer increased the feeling of direct manipulation, which was very important for their self-confidence (e.g., Norman 1991).

Furthermore, some researchers argued that computer technologies have the potential to increase the attention span of individuals with moderate intellectual disability by presenting information under different categories, such as sound, colour or movement (Lee, McGee & Ungar 2001). All these elements were present in the CAM-R test, which could also retain the participants' attention span. Even if the use of computers cannot completely overcome the difficulties and limited functions that are associated with a moderate intellectual disability, our research showed that this device enhanced performances and reduced the memory load, as it was demonstrated by other studies (Brown 2011; Foshay & Ludlow 2005; Papastergiou 2009). Following the obtained results, we intend to develop a new version of the test composed of more levels and hence more relations, in order to observe and assess the maximum number of relations with which students with moderate intellectual disability and typically developing children can cope.

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Colour Work Agreement Form

Figure 1 does not need to be printed in colour. Black and white is completely suitable.

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Table legends

Table 1 Means and standard deviations for Raven CPM (raw scores) and memory scores for participants with intellectual disability

	Raven CPM [1] (max. 36 points)		STM tasks[2] (max. 48 points)		WM tasks[3] (max. 16 points)	
	N	*M* (sd)	*N*	*M* (sd)	*N*	*M* (sd)
Institution 1	13	$14.08\ (3.84)_a$	13	$13.31\ (8.43)_a$	13	$2.85\ (2.61)_a$
Institution 2	13	$23.69\ (5.66)_b$	13	$28.23\ (9.69)_b$	13	$7.62\ (4.74)_b$
$F(5,25)$		13.171		9.479		2.827
p		< .01		< .01		< .05
η^2		.56		.48		.21

[1]: the raw scores of the Raven CPM were used.
[2]: short-term memory tasks
[3]: working memory tasks
Note: Means sharing a subscript in common were not significantly different from each other in column-wise comparisons (Tukey test).

Table 2 Means and standard deviation for Raven CPM (raw scores) and memory scores for typically developing children

	Raven CPM[1] (max. 36 points)		STM tasks[2] (max.48 points)		WM tasks[3] (max. 16 points)	
	N	*M* (sd)	*N*	*M* (sd)	*N*	*M* (sd)
Pre-Kindergarten	10	$16.00\ (2.54)_a$	10	$21.70\ (4.83)_a$	10	$3.20\ (1.07)_a$
Kindergarten	8	$18.38\ (2.88)_a$	8	$24.25\ (3.69)_a$	8	$4.75\ (5.04)_a$
1st grade	8	$23.88\ (6.01)_b$	8	$30.00\ (8.49)_b$	8	$4.25\ (3.45)_a$
2nd grade	6	$27.50\ (3.83)_b$	6	$34.00\ (5.09)_b$	6	$7.50\ (4.64)_b$
$F(5,31)$		11.140		8.345		2.815
p		< .01		< .01		< .05
η^2		.52		.43		.19

[1]: the raw scores of the Raven CPM were used.
[2]: short-term memory tasks
[3]: working memory tasks
Note: Means sharing a subscript in common were not significantly different from each other in column-wise comparisons (Tukey test).

Table 3 Number, percentage, chronological age (CA), and mental age (MA) for each group

	N	Percentage	M_{CA} (sd)	CA min	CA max	M_{MA} (sd)
TD-low	18	31.0	5;3 (6.07)	4;6	6;3	5;07 (.81)
TD-high	14	24.2	7;3 (8.68)	6;5	8;3	7;8 (1.64)
ID-low	13	22.4	17;1 (9.67)	15;7	18;2	7;6 (1.76)
ID-high	13	22.4	16;5 (11.80)	15;3	18;1	5;0 (1.00)

CA = means and standard deviation at pretest

Table 4 Number of relations between the A, B, and C terms for each level

	1st level	*2nd level*	*3rd level*	*4th level*
Number of relations between A-B terms	1	2	3	3
Number of relations between A-C terms	1	1	1	2
TOTAL by item	2	3	4	5
TOTAL of relation by level	8	12	16	20

Table 5 Means and standard deviations for the scores concerning each group in both versions (min = 0; max = 56)

	TD-low (*N* = 18)	TD-high (*N* = 14)	ID-high (*N* = 13)	ID-low (*N* = 13)	TOTAL (*N* = 58)
	M (sd)	*M* (sd)	*M* (sd)	*M* (sd)	*M* (sd)
CO	47.17 (5.64)	53.86 (3.04)	52.92 (4.43)	46.23_a (4.89)	49.86 (5.66)
ST	47.17 (7.15)	54.00 (2.86)	51.54 (5.77)	40.38_b (6.08)	48.28 (7.55)

CO = Construction version; ST = Standard version

Note: Means sharing a different subscript were significantly different from each other in column-wise comparisons (Tukey-b test).

Table 6 Means and standard deviations of time spent at each level for all groups in both versions

	TD-low (N = 18) *M* (sd)	TD-high (N = 14) *M* (sd)	ID-high (N = 13) *M* (sd)	ID-low (N = 13) *M* (sd)
ST – 1st level	9.92* (4.14)$_a$	7.07 (3.18)$_a$	13.41 (5.76)$_b$	18.38 (7.24)$_b$
ST – 2nd level	13.01 (7.78)$_a$	11.29 (4.69)$_a$	20.58 (7.93)$_b$	18.56 (10.23)$_b$
ST – 3rd level	19.95 (22.97)	14.51 (6.59)	22.08 (9.15)	19.85 (8.48)
ST – 4th level	18.44 (9.17)	21.46 (11.4)	22.21 (7.65)	17.77 (4.96)
CO – 1st level	14.14 (6.24)$_a$	12.33 (3.94)$_a$	16.44 (8.92)$_{a,b}$	22.42 (7.86)$_b$
CO – 2nd level	23.59 (7.9)	22.04 (5.95)	29.58 (15.34)	26.43 (8.98)
CO – 3rd level	34.00 (12.41)	31.45 (8.32)	35.74 (19.17)	41.29 (15.99)
CO – 4th level	44.66 (12.48)	48.36 (17.34)	46.42 (16.37)	49.29 (20.61)

Note: Means sharing a subscript in common were not significantly different from each other in row-wise comparisons (Tukey-b test).
*Time in seconds

CO = Construction version; ST = Standard version

Table 7 Total time spent at each level and in each version for all the participants

	1st level	*2nd level*	*3rd level*	*4th level*
	M (sd)	*M (sd)*	*M (sd)*	*M (sd)*
CO	16.08* (7.66)	25.19 (10.06)	35.41 (14.33)	46.99 (16.26)
ST	11.91 (6.52)	15.53 (8.53)	19.09 (14.41)	19.86 (8.71)
t	4.632	6.528	6.675	14.033
p	< .01	< .01	< .01	< .01

*Time in seconds

CO = Construction version; ST = Standard version

Figure legends

Fig.1 Beach Item (standard version on the top and construction version on the bottom)