Analogies solving by individuals with and without intellectual disability: Different cognitive patterns as indicated by eye movements[☆]

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ABSTRACT

Eighteen adults with intellectual disability (ID) and 20 children with typical development (TD) matched for cognitive level, participated in this study. Participants solved perceptual and conceptual analogies (from the Conceptual and Perceptual Analogical Modifiability Test—CPAM) while having their eye movements monitored. As predicted, the overall percent of correct answers was significantly higher for the TD group compared to that of the ID group. Comparison of the eye movement pattern of each group while solving the analogies revealed that in addition to the quantitative difference between the groups, there is a qualitative difference in the process of solving the analogies. The difference in the scanning pattern between the TD and the ID groups is interpreted as a reflection of two different types of strategies, Constructive matching and Response elimination, respectively.

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Analogy is ubiquitous in human learning and discovery (Gentner, Holyoak, & Kokinov, 2001; Holyoak, 2005) and has long been viewed as a core component of intelligence (Sternberg, 1977). Analogical reasoning requires the ability to retrieve information from semantic memory, together with the ability to form and manipulate mental representations of relations between objects and events. Computational analyses as well as empirical evidence suggest that the processes of binding and mapping used in analogical reasoning require activation of the working memory (WM) system (Baddeley & Della Sala, 1996; Morrison, Holyoak, & Truong, 2001; Waltz et al., 2000), which in turn depends on developmental changes in the prefrontal cortex. Processing analogies is likely to utilize inhibitory mechanisms to manage information in the WM. There is also a consensus that reasoning by analogy refers to fluid intelligence (Snow, Kyllonen, & Marshalek, 1984) as opposed to crystallized intelligence (Cattell, 1963), and is considered a measure of general intelligence.

The cognitive process involved in analogies is central to everyday learning. For example, orientation in the community is related to the understanding of analogical rules (i.e., a doctor is to a hospital like a teacher is to a school). Carrying out vocational skills is also related to an understanding of analogical rules (i.e., if nails of size X fit box A, then nails of size Y should fit box B). It is therefore obvious why it is important to impart analogies to populations with intellectual disability (ID).

Individuals with a low cognitive level constitute a heterogeneous group with regard to IQ level, etiology and associated disorders. They exhibit poor language (Fink & Cegelka, 1982), vocabulary and syntax (Borkowski & Büchel, 1983) and language as a tool for supporting thinking and reasoning processes is deficient.

Attention deficits cause difficulties in problem solving (Zeaman & House, 1969), limitations in dealing with several aspects of a problem situation simultaneously (Campione & Brown, 1984), focusing on non-relevant information, and incapacity to shift attention (Reed, 1996). Paöur (1992) claimed that individuals with ID do not spontaneously abstract relations between pairs of objects. There is inefficient short-term memory (Belmont & Butterfield, 1974; Campione & Brown, 1984; Ellis, 1970) and difficulties in working memory (Numminen, Service, & Ruoppila, 2002). The above limitations and the belief that individuals with mild and moderate ID cannot go beyond a concrete level of reasoning (Inhelder & Piaget, 1958; Jensen, 1970) prevent psychologists and educators from exposing these individuals to abstract cognitive problems.

There is a dearth of research on analogical reasoning among populations with ID. Studies carried out to date have tapped two main issues: some looked at the cognitive mechanism that underlies the ability to solve analogical problems in this population (Henry & MacLean, 2003; Swanson, Christie, & Rubadeau, 1993). Other studies examined the effect of training on the performance of individuals with ID in analogical reasoning (Büchel, Schlatter, & Scharnhorst, 1997; Lifshitz, Tzuriel, & Weiss, 2005; McConaghy & Kirby, 1986, 1987). It should be noted that most of these studies used Sternberg's (1977) analogical reasoning model which is comprised of four components: encoding, inference, mapping, and application. *Encoding* relates to identifying the relevant traits in each analogy and their maintenance in the working memory; *Inference* relates to detecting the relation between terms A and B in the analogy; *Mapping* relates to detecting the relation between terms A and C in the analogy; *Application* relates to matching the relationship between terms A and B to the relationship between terms C and D.

Swanson et al. (1993) examined the relation between meta-cognition and analogical reasoning among individuals with ID (CA = 12–14; IQ = 50–70) versus individuals with TD, using learning disability (LD) and gifted children with the same CA. The operative goals of their study were to examine whether individuals with high and low cognitive levels have comparable inter-correlational patterns among analogy, meta-cognitive, and IQ measures. The performance of individuals with ID was inferior to the other groups across the meta-cognitive questionnaire and analogical reasoning. The findings indicate that when covariate of the IQ was carried out, the performance of the ID group was identical to that of individuals with TD in the moderate demands. Different patterns of correlations between meta-cognition and analogical reasoning were found between the groups. Correlations between the two cognitive measures were found in the groups with ID and LD but not in the groups with higher cognitive levels. Furthermore, a significant correlation emerged for the meta-cognitive knowledge of problem solving and knowledge of strategy scores and analogical reasoning in the group with ID. The authors suggested that this pattern of correlations accords with Detterman's (1987) claim of a depressed central processing deficiency across processes. That is, a general processing deficiency may account for more of the total variation among the ID group than in the higher ability groups.

While the above study focused on the relation between meta-cognition and analogical reasoning, Henry and MacLean (2003) focused on the relation between analogical reasoning and the different components of the WM (in Baddeley's et al., 1996, model). They examined the relationships between WM and expressive vocabulary and arithmetic reasoning among three groups: children with ID (CA = 11–12) versus children with TD with the same MA and children with TD with the same CA. They found that for participants with ID, measures that tap the "central executive" were the most significant predictors of both expressive vocabulary and arithmetic reasoning. For participants with TD with the same CA, arithmetic reasoning ability was predicted by visual memory and to a lesser extent by phonological memory. For participants with TD with the same MA, arithmetic reasoning was also best predicted by central executive with an additional contribution of phonological memory. Different WM resources are used by children of varying ages and ability levels when carrying out the same cognitive tasks. Carrying out cognitive tasks such as arithmetic reasoning makes demands on both processing and storage abilities, similar to those required in carrying out central executive type memory span tasks. Rather than being able to draw upon stored knowledge (e.g., stored definitions of words, number knowledge, memorized material), children with ID may have to work out solutions to questions from scratch each time.

Other studies that used analogical reasoning in populations with ID examined the efficacy of training in imparting this cognitive task. McConaghy and Kirby (1986, 1987) carried out two experiments in which they examined the performance of participants with borderline level ID (IQ = 70–85) versus participants with TD with the same CA (18–27) on the People Piece analogy task. They found that participants with borderline level had longer solution times and higher error rates than participants with TD. The former also spent less time on encoding and more time on subsequent components and overall solution time. Training was found to improve the results of participants with ID, increased the time spent on encoding and reduced the error rate. However, the training did not produce a positive advantage for later processing or overall solution time.

Büchel et al. (1997) and Hessels-Schlatter (2002) succeeded in teaching abstract reasoning to students with moderate ID using a dynamic assessment (DA) procedure. However, not all the participants with moderate ID succeeded in acquiring the task. Lifshitz et al. (2005) administered the CPAM (*Conceptual and Perceptual Analogies Modifiability*, Tzuriel & Galinka, 2000) which represents a classical model in the form of A:B::C:D and is also based on Sternberg's (1977, 1985, 1986) four-component model, to adolescents and adults with ID. The findings demonstrated the efficacy of the DA approach in improving analogical problems solving. However, even after teaching with a DA procedure, not all participants solved all tasks and reached the maximum scores.

Several models for explaining the thinking process of participants with TD while solving analogies have been proposed (Bethell-Fox, Lohman, & Snow, 1984; Carpenter, Just, & Shell, 1990; Emerston, 1992). These methods were based mainly on

verbal protocols, which are difficult to apply to populations with ID. In the current study we examined the process of thinking while solving analogical problems in a population with ID using an eye-tracking technique.

Various studies have shown that eye movements are reflective of attentional shifts as well as of underlying functional organizations of mental representations, visual perception or mental imagery (Carlin, Soraci, Goldman, & McIlvane, 1995). With respect to mental reasoning in spatial configuration problems, eye tracking during the mental construction phase of a solution model can be employed to actively assess individual preferences of certain spatial configurations (Carlin et al., 1995). Monitoring eye movements can help elucidate perceptual processing and may shed light on the relations between our primary perception of the world and higher processing performed with the absorbed information.

When we read or observe a visual scene, we created a series of rapid eye movements (saccades) that are separated by periods in which the eyes are relatively fixed (fixations). The mean duration of the fixations is between 40 and 500 ms. Because of the rapidity of the saccades (150–170 ms), it is almost impossible to absorb information while the eyes are moving (Wolverton & Zola, 1983). The movements focus the fovea, in which visual acuity is greatest, on that section of the visual field which is being processed. It should be indicated that the duration and frequency of the fixations increase as the level of difficulty of understanding the visual scene or text increases, whereas the duration of the saccades decreases (Rayner, 1995).

Recent technological developments have enabled researchers to use the eye tracking technique for providing information on cognitive processing in populations with ID (Carlin et al., 1995; Carlin, Soraci, Dennis, Strawbridge, & Chechile, 2002; Dube et al., 1999). Soraci, Carlin, and Wiltse (1998) used eye tracking to examine the ability of participants with ID aged 11–21 with an IQ = 66.8 versus participants with TD with the same CA to discover minute changes in a naturalistic scene. The differences between two scenes were expressed in location (in the center of the picture or in the periphery) and in dimension (color, shape, the presence or absence of one of the stimuli). In both groups the search time was shorter when the change in location was in the central region than in the periphery. The search time for a change in color was shorter than the search time for the other dimensions. However, the primary response time among those with ID (the latency) was longer than among those with TD, and they focused their gaze on the central region of the picture longer than those with TD. In another study Carlin et al. (2002) found a shorter search time for a change in the color of the item in participants with ID and their CA matched control. However, when the difference between the pictures was expressed in the spatial orientation (movement of one of the items, etc.), the individuals with ID were less efficient than those with TD.

In the above studies, the comparison between groups with/without ID was based on chronological age (CA) and not mental age (MA). Furthermore, the above studies focused on visual perceptual tasks. The current study employed an eye tracking array while solving high-order cognitive tasks, such as analogical reasoning problems.

In the present study we administered the computerized version of the Conceptual and Perceptual Analogical Modifiability test (CPAM) (Tzuriel & Galinka, 2000) to adults with ID and to a control group of children with TD matched for cognitive level. It is predicted that the ID group would be impaired compared to the TD group in solving, both perceptual and conceptual analogies. Analyses of the eye movements would allow us to address the question whether the differences between the two groups stems from a quantitative or qualitative difference in the process of solving the analogies.

1. Method

1.1. Participants

The sample was comprised of two groups: adults with ID and children with TD with matched cognitive level. The Raven Standard Progressive Matrices (RSPM) (Raven, 1983) was administered in order to match the basic cognitive level between the adults with ID and children with TD. The mean raw scores for the ID and TD groups were 16.35 (SD = 3.82) and 16.30 (SD = 3.94), respectively. The groups did not differ significantly on the RSPM score ($t(36)$ = 3.84, p > .05).

Participants with ID: This group was composed of 18 persons with ID aged from 20 to 55 years (*mean age* = 35.95; SD = 10.08). The participants' IQ level ranged from 40 to 69 and was based on data collected from their personal files. These participants were recruited from residential or vocational facilities of adults with ID under the supervision of the Division of Mental Retardation, the Israel Ministry of Welfare. All participants met the criteria set for the current research: Chronological age between 20 and 55 years, mild/moderate ID according to the traditional AAMR definition (Grossman, 1983), independent in terms of Activities of Daily Living (ADL) Skills, absence of maladaptive behavior, hyperactive or attention problems, absence of visual or hearing problems. Authorizations were obtained from the Ministry of Welfare, the University Ethics Committee, and the Division of Mental Retardation in the Ministry of Welfare. Consent for taking part in this research was obtained from the parents of the participants with TD and from parents or legal guardians of the participants with ID. Ten participants who attended the eye tracker laboratory were dropped from the study because of calibration problems of the eye tracker due to a high diopter or strabismus.

Participants with TD: the group was composed of 20 children aged from 6 to 7.5 (*mean age* = 7.02; SD = .54) who were recruited from kindergartens and elementary schools. The participants with TD met the criteria set for the current research: absence of hyperactive or attention problems, and absence of visual or hearing problems. Two participants who attended the eye tracker laboratory were excluded from the study because of calibration problems of the eye tracker due to a high diopter or strabismus.
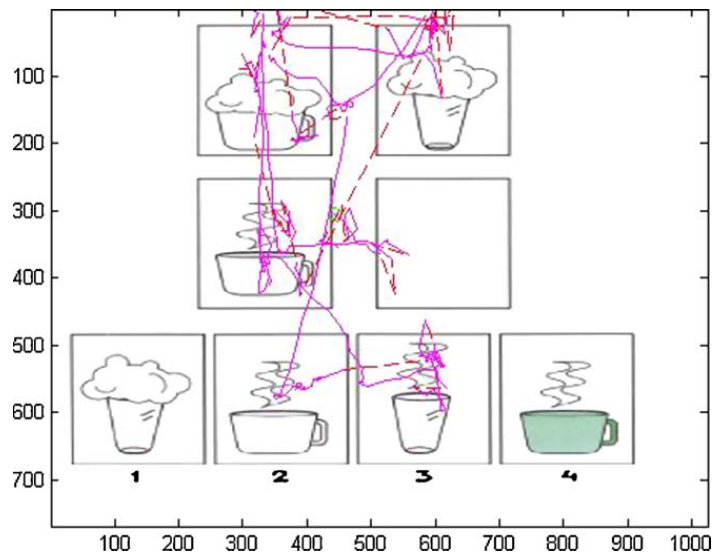
Fig. 1. An example of an item from the perceptual subtest.

1.2. The Conceptual and Perceptual Analogical Modifiability test (CPAM)—Closed Analogies Version (Tzuriel & Galinka, 2000)

A computerized version of the test was used which was synchronized with the Eye Tracker. The test is composed of two sets of analogical problems: conceptual and perceptual. The *conceptual set* is composed of 40 items, 20 for the pre-teaching and 20 for the post-teaching stages of the test. The *perceptual set* is comprised of 32 items, 16 for the pre-teaching and 16 for the post-teaching stages of the test. In this study we used only the 20 conceptual and 16 perceptual pre-teaching items. Each problem is formatted in a 2 × 2 matrix (A:B:C:D) and is presented in a pictorial colored modality at the top of the page. Four answers, only one of which is correct, appear on the bottom of the page. Examples of items from the perceptual and conceptual subtests are presented in Figs. 1 and 2.

Each correctly solved analogy receives a score of 1, with maximum possible scores of 16 and 20 for the perceptual and conceptual subtests, respectively. In order to enable comparison of the two subtests the raw scores of number of correct responses were transformed to percent scores.

1.3. Eye tracking

Stimulus presentation: The participants were seated 100 cm from a 32LG10R color monitor on which the stimuli were displayed. SuperLab (Cedrus, Inc.) software controlled the stimulus display and linked the timing of stimulus presentation with the computer that recorded eye movements. The experiment was conducted in a room with normal ambient illumination.
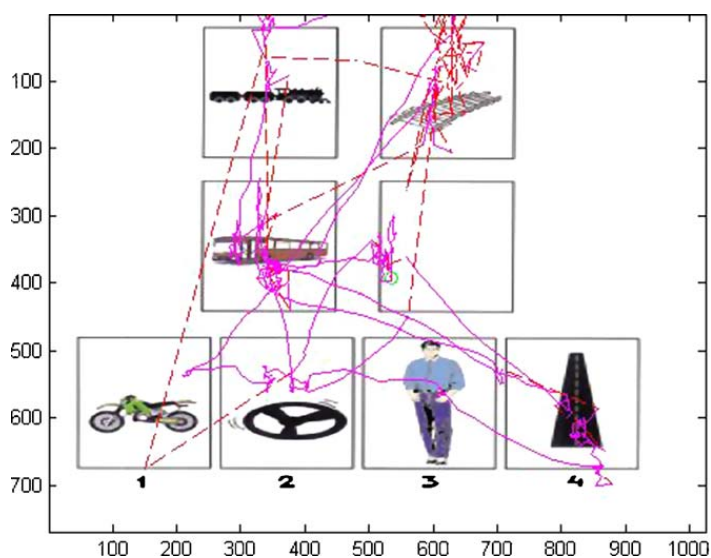

Fig. 2. An example of an item from the conceptual subtest.

Response recording: Participants viewed 36 question items of the *CPAM* test, each—for as long as it took to generate an answer. The experimenter was the one to navigate between the screens. Participants provided the answers to questions orally, by naming aloud the number of the answer they deemed correct. The answer was recorded by the experimenter.

Eye movement recording: Horizontal and vertical coordinates of gaze direction were collected with a eye monitor (ISCAN Eye Tracking Laboratory, Model ETL-400), which has a temporal resolution of 60 Hz and a spatial resolution of 1° over the range of visual angles used in this study. A camera with an attached infrared light source to illuminate the pupil was placed in front of the monitor, below eye level, and 45 cm from the participant. Because the camera automatically compensated for small head movements, no head restraint was used. We calibrated eye position for each participant at the beginning of the session by focusing the camera on the participant's right eye and having him/her look at dots in the center and four corners of the screen. These positions were recorded as the targets of eye gaze. This procedure was repeated every 10 questions if necessary due to excessive head movement—altogether three times during an experiment.

1.4. Procedure

The study was carried out in two stages. In the first stage the Raven Standard Progressive Matrices (RSPM) (Raven, 1983) was administered in the vocational and residential facilities of participants with ID or in the homes of participants with TD. During the second stage participants with ID and TD attended the eye tracking laboratory, at the Gonda Multidisciplinary Brain Research Center, Bar-Ilan University. The children with TD were escorted to the laboratory by their parents. Adults with ID were brought to the laboratory by cab and were escorted by special education students.

The study aim and the procedure were explained to all participants prior to beginning the study. The participants signed an informed consent form for participation in scientific research. This form is administered to all students who participate in research and was adapted to populations with ID and young children with TD.

All the children in the group with TD and the adults in the group with ID agreed to participate in the study. In line with the "normalization" principle (Wolfensberger, 1972, 2002) and in the light of the fact that students with TD who participate in eye tracking experiments receive payment, all children and adults with ID who participated in the current study received payment or a gift according to their choice.

The experiment: The CPAM test was administered in the Eye Tracker laboratory. Prior to seating near the eye tracker, a two-stage training phase (Vigneau, Caissie, & Bors, 2006) was carried out:

(a) The participants were introduced to the original printed version of the CPAM test. Standard instructions were given by the experimenter and the participants completed the first two preparatory items of the conceptual and perceptual analogies as practice items. These items are not included in the calculation of the scores.
(b) The participants were then seated on a chair with their face approximately 45 cm from the eye tracker system. The standard CPAM instructions were given again by the experimenter and the participants completed the same two preparatory practice items from the conceptual and perceptual analogies, this time on the computer. The participants were trained to vocally state the number of the alternative they chose as the response and the eye tracker technician entered the response number in the computer. We used this procedure with all the participants including those with TD.

Each of the two practice items and the test items started with the participants focusing on a fixation point in the center of the screen. Pressing the space bar on the keyboard while gazing at the fixation point initiated presentation of the item. This procedure ensures that all participants begin their visual inspection of all items from the same point on the screen. After inspecting the matrices and deciding on a response, the participants stated the number of the response they chose.

After completing the two practice items, the participants completed the test: 20 items in conceptual analogies and 16 items in perceptual analogies. The order of the analogies was counterbalanced. Since there was no time limit, the technician reminded the participants before each item that they have to look at the problem, concentrate and then find the missing entry. This remark was aimed to prevent impulsivity when solving the analogies and to focus the participants' attention on solving the analogy problem.

2. Results

2.1. Correct answers

Because of the unequal number of items (20 conceptual and 16 perceptual) the analysis was performed on the percent of correct, conceptual and perceptual, answers. Mixed ANOVA was conducted in order to analyze the percent of analogies (perceptual and conceptual) correctly solved by the two groups (TD *vs.* ID). The former is a within subjects factor and the latter is a between subjects factor. As can be seen in Fig. 3, the overall percent of correct answers was significantly higher for the TD group compared to that of the ID group, $F(1,33) = 23.49$, $p < .001$. The percent of conceptual and perceptual analogies correctly solved was not significantly different, $F(1,33) = 2.75$, $p > .05$. The interaction between the two did not reach significance, $F(1,33) = 1.63$, $p > .05$. Thus, overall the TD group solved correctly more analogies than the ID group, but for both groups the perceptual and the conceptual analogies were equally difficult.
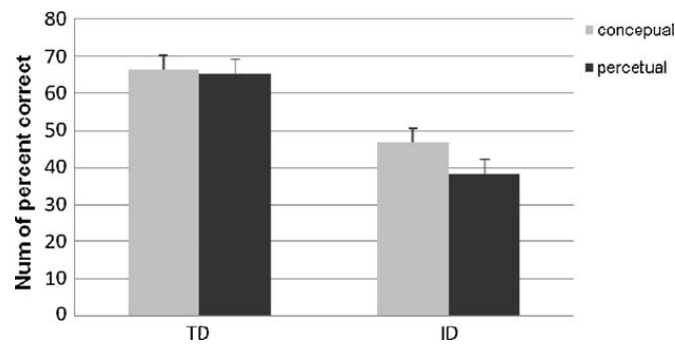
Fig. 3. The number of analogies (perceptual and conceptual) correctly solved by the two groups (TD *vs.* ID).
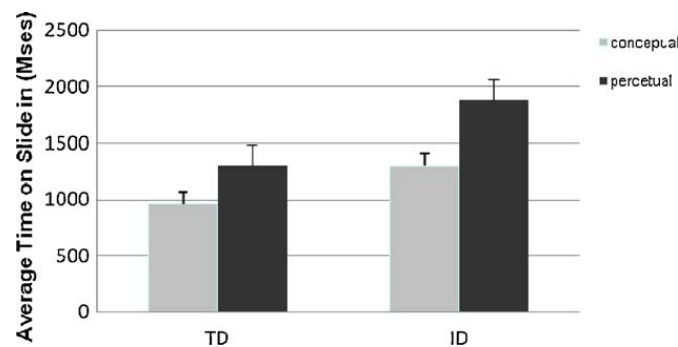

Fig. 4. Average time on slide.

2.2. Eye movement measures

Two primary dependent measures reflecting eye movements were analyzed: overall time on a region of interest and the number of switches from one region to the other. Each slide consists primarily of two regions of interest, the top part with the matrix and the bottom part with the answers options. The matrix consists of three sub-regions and the answers options consist of four sub-regions.

(1) Average time on slide

First, the average time on slide was analyzed (see Fig. 4). The ID group spent on average more time on the slides than the TD group, $F(1,32) = 6.12$, $p < .05$. More time was spent on the perceptual analogies than on the conceptual ones, $F(1,32) = 21.71$, $p < .001$. The interaction between the two did not reach significance, $F(1,32) = 1.50$, $p > .05$.

In order to avoid confounding between the average time on slide and the eye movement measures, all the measures were computed as a ratio of the time on slide. Thus, the findings reported below are beyond the basic difference between the groups on time on slide.

(2) Proportional time on the right answer (out of all options)

Overall the TD group spent more time on the correct answer, proportionally to the overall time spent on all four possible answers ($M = .32$, $SD = .054$) than the ID group ($M = .27$, $SD = .047$), $F(1,33) = 6.96$, $p < .05$. Neither the difference between the conceptual and perceptual analogies, $F(1,33) = 0.11$, $p > .05$, nor the interaction reached significance, $F(1,33) = 0.34$, $p > .05$. Notice that the proportional time spent by the ID group on the correct answer (.27) is very close to chance (.25, one out of four optional answers)

(3) Time on matrix as a ratio of the overall slide time

Groups did not significantly differ overall on the proportional time on matrix, $F(1,33) = 2.08$, $p > .05$. More time was spent on the matrices of the perceptual as compared with the conceptual analogies, $F(1,33) = 38.76$, $p < .001$. These two main effects should be interpreted cautiously because of the interaction between them. As can be seen in Fig. 5, the significant interaction, $F(1,33) = 6.28$, $p < .05$, is due to the fact that while the ID group spent more time than the TD group on the conceptual analogies, the groups did not differ on the perceptual analogies.

(4) Overall number of switches across all 7 regions of interest in the matrix and the answer options

The groups did not differ overall in the number of switches they made, $F(1,32) = 1.86$, $p > .05$. More switches were made while solving the perceptual than the conceptual analogies, $F(1,32) = 11.06$, $p < .005$. As can be seen in Fig. 6, the interaction was marginally significant, $F(1,32) = 3.25$, $p = .08$, indicating that while the groups did not differ in the number of switches on the conceptual analogies, the ID group made more switches than the TD group on the perceptual analogies.

Fig. 5. Time on matrix as a ratio of the overall slide time.

Fig. 6. Overall number of switches across all 7 regions of interest in the matrix and the answer options.

(5) Proportional number of switches in matrix

Overall the groups did not differ in the number of switches they made, $F(1,32) = 2.54$, $p > .05$. More switches were made while solving the perceptual than the conceptual analogies, $F(1,32) = 41.24$, $p < .001$. As can be seen in Fig. 7, the interaction was marginally significant, $F(1,32) = 2.88$, $p = .099$, indicating that while the groups did not differ in the number of switches on the conceptual analogies, the ID group made more switches than the TD group on the perceptual analogies.
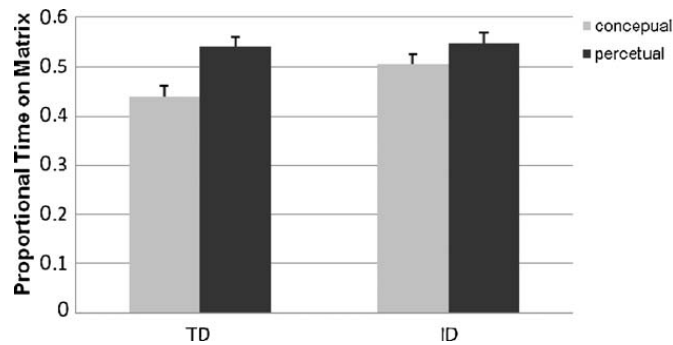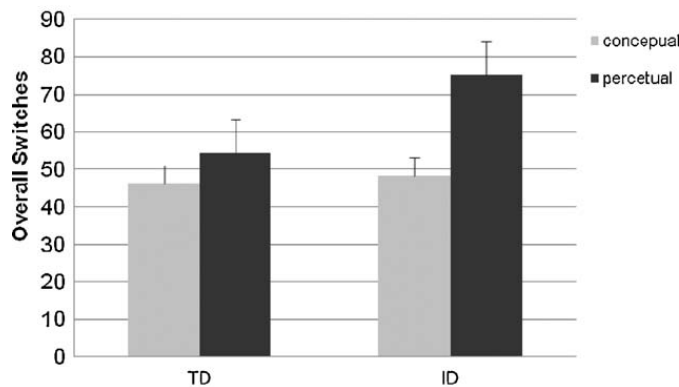
(6) Proportional number of switches in options

Overall the groups did not differ in the number of switches they made, $F(1,32) = 1.26$, $p > .05$. There was a tendency to make more switches while solving the perceptual than the conceptual analogies, $F(1,32) = 3.12$, $p = .087$. As can be seen in Fig. 8, the interaction was marginally significant, $F(1,32) = 3.67$, $p = .06$. This finding indicates that while the groups did not differ in the number of switches on the conceptual analogies, the ID group made more switches than the TD group on the perceptual analogies.

(7) Proportional number of switches between matrix and options

Overall the groups did not differ in the number of switches they made, $F(1,32) = 1.53$, $p > .05$. More switches were made while solving the perceptual than the conceptual analogies, $F(1,32) = 5.66$, $p < .05$. The interaction did not reach significance, $F(1,32) = 1.467$, $p > .05$, indicating that there was a similar increase in switches between matrixes and options, from conceptual to perceptual analogies, for both groups (see Fig. 9).
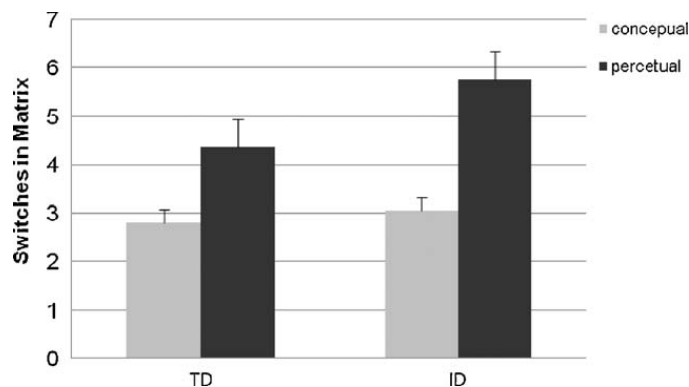

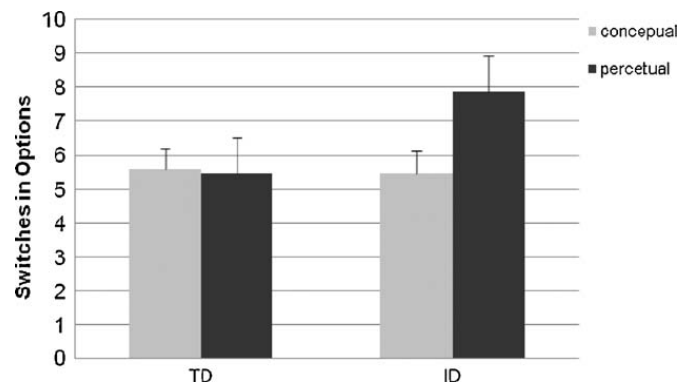**Fig. 7.** Proportional number of switches in matrix.

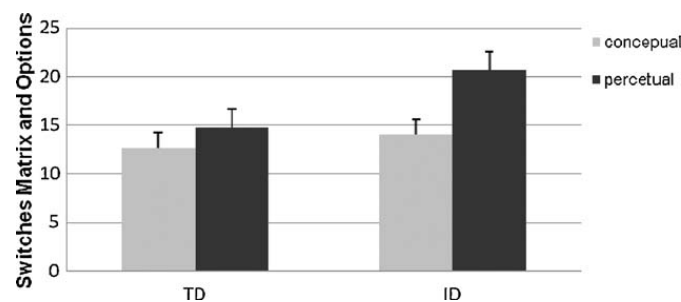**Fig. 8.** Proportional number of switches in options.

Fig. 9. Proportional number of switches between matrix and options.

3. Discussion

As predicted the TD group made more correct answers in the perceptual and the conceptual analogies of the CPAM test than the ID group. The ID group's performance was inferior to that of the TD group, despite the fact that they were matched on basic cognitive level as measured by the Raven Standard Progressive Matrices (RSPM) (Raven, 1983). A possible interpretation for these findings might be related to the nature of the instructions given for the CPAM test. As mentioned above "the technician reminded the participants before each item that they have to look at the problem, concentrate and then find the missing entry". This remark was aimed to prevent impulsivity when solving the analogies, and to focus the participants' attention on solving the analogy problem" (p. 14). It seems that the TD group benefited from the instruction to control and monitor their impulsivity more than the ID group, which needs a more powerful approach to self-regulation of their behavior.

Both groups spent more time on the matrices representing a perceptual analogy than on the matrices representing a conceptual analogy. Similar findings were shown with the number of switches; in both groups more switches were made within the perceptual than within the conceptual analogies. Apparently, the time spent focusing on a particular stimulus or region of interest as well as the number of switches made from and to a particular region, reflects the amount of cognitive elaboration allocated to that region. This finding might be explained by the difference between the two types of analogies. The conceptual analogies are based on semantic relations requiring consideration of a *single rule*. The perceptual analogies, on the other hand, are composed of several perceptual components (e.g., color, shape, and number), and require simultaneous consideration of several dimensions (e.g., transformations of color and shape). According to Halford (1998), the processing load for any step in a task is determined by the number of dimensions or relations that must be processed simultaneously to make the decisions required for that step. The fact that the conceptual analogies are based on one rule, as compared with perceptual analogies that are governed by at least two rules, might explain why the perceptual analogies were more difficult than the conceptual analogies for participants with ID. This finding is coincident with Piaget (1970), who argued that a classification based on one attribute relates to the pre-operational stage, while a classification based on two or three attributes that require simultaneous consideration of several sources of information relates to the concrete operations stage. As a result more eye movements are needed to scan all the relevant dimensions in the perceptual as compared to the single dimension in the conceptual analogies.

Although, as reported above, there are similarities in the eye movement pattern of the two groups, there are also differences reflecting qualitative group differences in processing analogies. Both groups spent more time on the perceptual than on the conceptual matrices. As can be seen in Fig. 5, both groups spent equal time on the perceptual analogies but on the conceptual ones the ID group spent more time than the TD group. Thus, the easier analogies (i.e., conceptual) differentiated better than the more difficult analogies (i.e., perceptual) between the groups when time on a region of interest is measured. However, when number of switches is measured, the ID group made more switches than the TD group on the perceptual but

not on the conceptual analogies (see Figs. 6–9). Thus, the groups do not differ in the amount of time spent proportionally on the perceptual analogies, but they do differ (ID more than TD) in the number of switches made while processing them. In contrast, on the conceptual analogies the groups do not differ in the number of switches made, but they do differ (ID more than TD) in the amount of time spent proportionally processing these analogies. This difference in the scanning pattern, between the groups, is interpreted below as a reflection of two different types of strategies, Constructive matching and Response elimination (Bethell-Fox et al., 1984; Vigneau et al., 2006).

The groups' eye movement pattern differed in some other interesting ways. First, the ID group spent more time scanning each slide (analogy) before responding than the TD group. Thus, even though the ID group spent more time processing the analogies, they still solved fewer analogies correctly than the TD group. This indicates that their information processing speed is slower than that of the TD group.

The results of the present study, in which the ID group exhibits longer latency on the analogies compared with participants with TD, are compatible with previous findings. Results of reaction time studies of individuals with ID have clearly established that their performance is slower, more variable, and less accurate than that of individuals without ID (Maisto & Baumeister, 1984; Nettelbeck & Wilson, 1997; Stanovich, 1978). Loranger et al. (2002) found a correlation of .65–.75 between the Stanford Binet Intelligence test and the reaction time, and correlations of .55–.70 between the Kaufman Assessment Battery for Children (Kaufman & Kaufman, 1983) among children with mild ID (CA = 3–16; IQ = 55). Better results in the intelligence test were associated with shorter response latency on various cognitive measures.

Campione and Brown (1984) claimed that individuals with ID use strategies such as encoding and comparison less effectively than individuals with TD. Hence, inefficient strategy use by individuals with ID may be linked to limited resources for executing the strategies, and may cause a longer reaction time. In the current study, participants with ID used a less efficient strategy for solving the analogies. In perceptual analogies they made more switches than participants with TD. In conceptual analogies they spent more time on the matrices. Furthermore, participants with TD spent more time scanning the correct answer in proportion to the other response options, than participants with ID.

Bethell-Fox et al. (1984) and Vigneau et al. (2006) made a distinction between two types of strategies among participants with TD when solving analogical problems: Constructive matching and Response elimination. Constructive matching involves planning, observation and construction of an optimal answer which is then compared to the response alternatives of the response choice. That is, the participants analyze the components of the task prior to solving the problem, and only then search for the alternative answers. This strategy was found to be used by higher ability participants (Bethell-Fox et al., 1984; Vigneau et al., 2006).

Response elimination involves a process of feature comparison between elements of the problem and elements of the alternatives. It is presumed that this comparison is aimed at eliminating incorrect alternatives in order to arrive at the correct answer by default. This strategy was used by lower ability participants (Bethell-Fox et al., 1984; Vigneau et al., 2006). Choosing one of the two strategies also depends on the complexity of the item: As the problem became more complex, some participants who used constructive matching appeared to shift to response elimination. It appears that in the current study, the participants with TD used the constructive matching strategy. As stated, they inspected the correct answer longer in proportional to the other response options, and in the perceptual analogies they made fewer switches than participants with ID. The participants with ID made more switches than the participants with TD in the perceptual analogies. It appears that they observed the components of the analogy superficially and tried to find the solution by comparing the items in the matrix to the alternative answers. They also spent less time on the correct answer. Thus, their thinking reflected the elimination response type. Their inefficient strategy when solving the analogies resulted in a longer reaction time in the conceptual analogies.

It has already been pointed out that the TD group, but not the ID group, spent more time scanning the correct answer in proportion to the other response options. That behavior might suggest that the TD group was more reflective when pondering the correct answer prior to their overt response. In contrast the ID group did not invest as much time on the correct answer relative to the other options, a behavior which might reflect impulsivity. A rapid but error-prone response reflects the impulsive style, whereas a slow but more accurate response is considered a reflective style (Kagan, 1965).

This is consistent with previous reports in which individuals with ID were found to be characterized by impulsivity as opposed to reflectivity when solving cognitive problems (Jackson & Haines, 1983). Reflectivity-impulsivity dimension is by definition related to the issue of "inhibition" and executive function. That is, impaired inhibition, as demonstrated by the tendency to offer the first answer without exploring various other possibilities, may account for individuals with ID (Borys & Spitz, 1978). It appears that they have difficulty in controlling regulatory processes in comparison to individuals with TD (Erickson, Wyne, & Routh, 1973).

In conclusion, analyses of the eye movements have provided additional information about standard behavioral performance, which is the number of correct answers. Eye tracking, being an implicit behavior, enables the analysis of the underlying cognitive processes leading to the explicit answer. As we have described above, this analysis has revealed divergent eye movement profiles between TD and ID groups, reflecting differences in the process of solving the analogies.

References

Baddeley, A. D., & Della Sala, S. (1996). Working memory and executive control. *Philosophical Transactions of the Royal Society of London B, 351*, 1397–1404.

Belmont, J. M., & Butterfield, E. C. (1974). The structural approach to developmental cognitive research. In R. Kail & J. Hagen (Eds.), *Perspectives on the development of memory and cognition* (pp. 125–135). Hillsdale, NJ: Erlbaum.

Bethell-Fox, C. E., Lohman, D. F., & Snow, R. E. (1984). Adaptive reasoning: Componential and eye movement analysis of geometric analogy performance. *Intelligence, 8*, 205–238.

Borkowski, J. G., & Büchel, F. P. (1983). Learning and memory strategies in the mentally retarded. In M. Pressley & J. R. Levin (Eds.), *Cognitive strategy research* (pp. 103–128). New York: Springer.

Borys, S. V., & Spitz, H. H. (1978). Reflection-impulsivity in retarded adolescents and non retarded children of equal MA. *American Journal Mental Deficiency, 82*, 601–604.

Büchel, F. P., Schlatter, C., & Scharnhorst, U. (1997). Training and assessment of analogical reasoning in students with sever learning difficulties. *Educational and Child Psychology, 14*, 83–94.

Campione, J. C., & Brown, A. L. (1984). Learning ability and transfer propensity as sources of individual differences in intelligence. In P. H. Brooks, R. Speber, & C. McCauley (Eds.), *Learning and cognition in the mentally retarded* (pp. 265–293). Hillsdale, NJ: Erlbaum.

Carlin, M. T., Soraci, S. A., Goldman, A. L., & McIlvane, W. (1995). Visual search in unidimensional arrays: A comparison between subjects with and without mental retardation. *Intelligence, 21*, 175–196.

Carlin, M. T., Soraci, S. A., Dennis, N. A., Strawbridge, C., & Chechile, N. A. (2002). Guided visual search in individuals with mental retardation. *American Journal on Mental Retardation, 107*, 237–251.

Cattell, R. B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology, 54*, 1–22.

Carpenter, M. A., Just, M. A., & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the Raven Progressive Matrices test. *Psychological Review, 97*, 404–431.

Detterman, D. K. (1987). Theoretical notion of intelligence and mental retardation. *American Journal of Mental Deficiency, 92*, 2–11.

Dube, W. V., Lombard, K. M., Farren, K. M., Flusser, D. S., Balsamo, L. M., & Fowler, T. R. (1999). Eye tracking assessment of overselectivity in individuals with mental retardation. *Experimental Analysis of Human Behavior Bulletin, 17*, 8–14.

Ellis, N. R. (1970). Memory processes in retardates and normals. In Ellis, N. R. (Ed.). *International review of research in mental retardation* (Vol. 4, pp. 1–32). New York: Academic Press.

Emerston, S. E. (1992). Measuring and validating cognitive modifiability as ability: A study in the spatial domain. *Journal of Educational Measurement, 29*, 25–50.

Erickson, E. A., Wyne, M. D., & Routh, D. K. (1973). A response-cost procedure for reduction of impulsive behavior of academically handicapped children. *Journal of Abnormal Psychology, 1*, 350–357.

Fink, W., & Cegelka, P. T. (1982). Characteristics of the moderately and severely mentally retarded. In P. T. Cegelka & H. Y. Prehm (Eds.), *Mental retardation* (pp. 231–259). Columbus, OH: Merrill.

Gentner, D., Holyoak, K. J., & Kokinov, B. N. (Eds.). (2001). *The analogical mind: Perspectives from cognitive science.* Cambridge: MIT Press.

Grossman, H. J. (Ed.). (1983). *Classification in mental retardation* (3rd ed.). Washington, DC: American Association on Mental Deficiency.

Halford, G. S. (1998). Development of processing capacity entails representing more complex relations: Implications for cognitive development. In R. H. Logie & K. J. Gilhooly (Eds.), *Working memory and thinking* (pp. 139–158). Hove, East Sussex, England: Psychology Press.

Henry, L., & MacLean, M. (2003). Relationships between working memory, expressive vocabulary and arithmetical reasoning in children with and without intellectual disabilities. *Educational and Child Psychology, 20*, 51–63.

Hessels-Schlatter, C. (2002). Dynamic test to assess learning capacity in people with severe impairments. *American Journal in Mental Retardation, 107*, 340–351.

Holyoak, K. J. (2005). Analogy. In K. J. Holyoak & R. G. Morrison (Eds.), *Cambridge handbook of thinking and reasoning.* Cambridge, UK: Cambridge University Press.

Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence*. New York: Basic Books.

Jackson, M. S., & Haines, A. T. (1983). Reflection-impulsivity in retarded adolescents and non-retarded children. *International Journal of Disability, Development and Education, 30*, 230–232.

Jensen, A. R. (1970). A theory of primary and secondary familial mental retardation. In Ellis, N. R. (Ed.). *International review of research in mental retardation* (Vol. 4, pp. 33–105). New York: Academic Press.

Kagan, J. (1965). Reflection impulsivity and the reading ability in primary grade children. *Child Development, 36*, 609–628.

Kaufman, A. S., & Kaufman, N. L. (1983). *Kaufman Assessment Battery for Children*. Circle Pines, MN: American Guidance System.

Lifshitz, H., Tzuriel, D., & Weiss, I. (2005). Effects of training in conceptual versus perceptual analogies among adolescents and adults with intellectual disability. *Journal of Cognitive Education and Psychology, 5*, 144–170.

Loranger, M., Blais, M. C., Hopps, S., Pepin, M., Boisvert, J.-M., & Doyon, M. (2002). Applications of measures if speed of mental operation among children with intellectual deficiency. *Education and Training in Mental Retardation and Developmental Disabilities, 37*, 184–192.

Maisto, A. A., & Baumeister, A. A. (1984). Dissection of component processes in rapid information processing tasks: Comparisons of retarded and nonretarded people. In P. H. Brooks, R. Sperber, & C. McCauley (Eds.), *Learning and cognition in the mentally retarded* (pp. 165–188). Hillsdale, NJ: Erlbaum.

McConaghy, J., & Kirby, N. H. (1986). Analogical reasoning and ability level: An examination of R.J. Sternberg's componential method. *Intelligence, 11*(2), 137–159.

McConaghy, J., & Kirby, N. H. (1987). Using the componential method to train mentally retarded individuals to solve analogies. *American Journal of Mental Deficiency, 92*(1), 12–23.

Morrison, R. G., Holyoak, K. J., & Truong, B. (2001). Working memory modularity in analogical reasoning. In *Proceedings of the twenty-fourth annual conference of the Cognitive Science Society* (pp. 663–668). Mahwah, NJ: Erlbaum.

Nettelbeck, T., & Wilson, C. (1997). Speed of information processing and cognition. In W. E. MacLean (Ed.), *Ellis' handbook of mental deficiency, psychological theory, and research* (pp. 245–274). Mahwah, NJ: Erlbaum.

Numminen, H., Service, E., & Ruoppila, I. (2002). Working memory, intelligence and knowledge base in adult persons with intellectual disability. *Research in Developmental Disabilities, 23*, 105–118.

Paöur, J. L. (1992). Piagetian approaches to mental retardation. Hopes, opportunities and convergence. In J. S. Carlson (Ed.), *Advances in cognition and educational practices* (pp. 392–398). Greenwich, CT: JAI Press.

Piaget, J. (1970). Piaget's theory. In P. Mussen (Ed.), *Carmichael's manual of child psychology* (3rd ed., pp. 103–128). New York: Wiley.

Raven, J. C. (1983). *Progressive matrices: A perceptual test of intelligence, individual form*. London: Lewis.

Rayner, K. (1995). Eye movements and cognitive processes in reading, visual search and scene perception. In J. M. Findlay, R. Walker, & R. W. Kentridge (Eds.), *Eye movement research: Mechanisms, processes and applications* (pp. 3–22). The Netherlands: Elsevier Science B.

Reed, T. (1996). Analogical reasoning in participants with autism, retardation, and normal development. *Journal of Development and Physical Disabilities, 8*, 61–76.

Snow, R. E, Kyllonen, P. C., & Marshalek, B. (1984). The topography of ability and learning correlations. In Sternberg, R. J. (Ed.). *Advances in the psychology of human intelligence* (Vol. 2, pp. 47–103). Hillsdale, NJ: Erlbaum.

Soraci, S. A., Carlin, M. T., & Wiltse, L. J. (1998). Facilitating visual attention. In S. Soraci & W. J. McIlvane (Eds.), *Perspectives on fundamental processes in intellectual functioning: A survey of research approaches* (pp. 45–65). Stamford, CT: Ablex.

Stanovich, K. E. (1978). Information processing in mentally retarded individuals. In Ellis, N. R. (Ed.). *International review of research in mental retardation* (Vol. 9, pp. 29–60). New York: Academic Press.

Sternberg, R. J. (1977). Component processes in analogical reasoning. *Psychological Review, 84*, 353–378.

Sternberg, R. J. (1985). *Beyond IQ: A triarchic theory of human intelligence*. Cambridge, UK: Cambridge University Press.

Sternberg, R. J. (1986). Toward a unified theory of human reasoning. *Intelligence, 10*, 281–314.

Swanson, H. L., Christie, L., & Rubadeau, R. J. (1993). The relationship between meta cognition and analogical reasoning among mentally retarded, learning disabled, and gifted children. *Learning Disability Research and Practice, 8*, 70–81.

Tzuriel, D., & Galinka, E. (2000). *The conceptual and perceptual analogical modifiability (CCPAM) test: Closed analogies-instruction manual*. Ramat-Gan, Israel: School of Education, Bar-Ilan University.

Vigneau, F., Caissie, A. F., & Bors, D. A. (2006). Eye-movement analysis demonstrates strategic influences on intelligence. *Intelligence, 34*, 261–272.

Waltz, J. A., Lau, A., Grewal, S., & Holyoak, K. J. (2000). The role in working memory in analogical reasoning. *Memory and Cognition, 28*, 1205–1212.

Wolfensberger, W. (1972). *The principle of normalization in human services*. Toronto: National Institute on Mental Retardation.

Wolfensberger, W. (2002). Social role valorization and, or versus, "empowerment". *Mental Retardation, 42*, 252–258.

Wolverton, G. S., & Zola, D. A. (1983). The temporal character of visual information extraction during reading. In K. Rayner (Ed.), *Eye movements in reading: Perceptual and language processes* (pp. 41–51). New York: Academic Press.

Zeaman, D., & House, B. (1969). A review of attention theory. In N. Rellis (Ed.), *Handbook of mental deficiency, psychological theory and research* (2nd ed., pp. 63–120). Hillsdale, NJ: Erlbaum.