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Solving the Raven Progressive Matrices by adults with intellectual disability with/without Down syndrome: Different cognitive patterns as indicated by eye-movements☆

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ABSTRACT

Raven matrices are used for assessing fluid intelligence and the intellectual level of groups with low intelligence. Our study addresses qualitative analysis of information processing in Raven matrices performance among individuals with intellectual disability with that of their typically developed (TD) counterparts. Twenty-three adults with non-specific intellectual disability (NSID), 15 adults with Down syndrome (DS) and 35 children with TD matched for mental age, participated. Participants solved the Raven's Colored Progressive Matrices and five items from the Raven Standard Progressive Matrices while having their eye movements monitored. The overall percent of correct answers was significantly higher for the TD group compared to two ID group. Comparison of the eye movement pattern of each group indicated that the TD group spent more time on the matrices before shifting to the options, than the two ID groups. The TD group made significantly less switches from one rejoins to another, than the ID groups. 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. There were no differences in eye scanning between participants with NSID and those with DS.

The Raven Progressive Matrices (RPM) tests were designed to assess the ability to form comparisons, deduce relationships, correlates, and reason by analogy (Raven, Raven, & Court, 1996). They are considered an analytic intelligence test which refers to the ability to reason and deal with novelty, without relying on an explicit base of declarative knowledge (Snow, Kyllonen, & Marshalek, 1984). This form of intelligence is labelled fluid intelligence, in contrast to crystallized intelligence which is based on declarative acquired knowledge (Cattell, 1963). The Raven test is comprised of three forms: the Colored Progressive Matrices (CPM), the Simpler Standard Progressive Matrices (SPM) and the Advanced Progressive Matrices (APM). Since the targeted population of the current study is individuals with intellectual disability (ID), only the CPM and the SPM were used.

The requirement of the items in set A and AB in the CPM is comprised of shape completion, comparison, and Gestalt perception as expressed by whole-part relations (Raven et al., 1996). Sets B of the CPM and C, D, E of the SPM are comprised of analogical reasoning which has long been viewed as a core component of intelligence (Sternberg, 1977). In general, researchers agree that the processes of binding and mapping used in analogical reasoning require the activation of Working Memory (WM) that is, the ability to form and manipulate mental representations of relations between objects and events

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(Baddeley, Emslie, Kolodny, & Duncan, 1998; Morrison, Holyoak, & Truong, 2001; Waltz, Lau, Grewal, & Holyoak, 2000), which in turn depends on developmental changes in the prefrontal cortex.

The RPM test is used worldwide among populations with ID in order to assess fluid intelligence levels and for matching between groups with and without ID (Carretti, Belacchi, & Cornoldi, 2010; Facon & Facon-Bollengier, 1997, 1999; Numminen, Lehto, & Ruoppila, 2001). Our study goes beyond quantitative analysis and as far as we know, is the first to address qualitative analysis of information processing when solving the test using an eye tracking technique in this population.

1. Cognitive profile of individuals with ID

Individuals with a low cognitive level constitute a heterogeneous group with regard to IQ level, aetiology 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 WM including the Central Executive, and the two slave systems phonological loop and visuo-spatial sketch (Carretti et al., 2010; Numminen, Service, & Ruoppila, 2002; Schuchardt, Gebhardt, & Mäehler, 2010). The above limitations and the belief that individuals with mild and moderate ID cannot go beyond a concrete level of reasoning (Jensen, 1970) prevent psychologists and educators from exposing these individuals to abstract cognitive problems.

2. Cognitive profile of individuals with Down syndrome

Down syndrome is the most common genetic cause of ID (Rodger, 1987). Varying degrees of ID are the most consistent feature of DS (Vicari, Bellucci, & Carlesimo, 2006). Individuals with DS exhibit a peculiar neuropsychological profile with some abilities more preserved and others more impaired. Their cognitive profile is characterized by a remarkable deficit in language abilities that usually exceeds impairments in visual–spatial abilities (Vicari et al., 2006). Since the RPM involve visual–spatial perception and WM skills, we will depict the profile of individuals with DS in these domains. Bellugi, Biharle, Jernigan, Tranuner, and Doherty (1990) found that when participants with William Syndrome (WS) draw a house, they often lack cohesion or Gestalt organization. They often had difficulties maintaining the overall configuration of drawings and focused on internal details (i.e., a typical drawing may include windows, a door, and a roof but lacks an overall organization of correct spatial relationships), whereas participants with DS tended to exhibit the opposite pattern (a typical drawing may be very simplified but will show a broad organization of proper Gestalt relationships between elements). Wang and Bellugi (1994) compared a digit and Corsi span between individuals with DS and with WS and found that those with WS performed better in the verbal short-term memory task but, at the same time, had lower scores in the visuo-spatial short-term memory task. This affords indirect evidence for a relative advantage for participants with DS in visuo-spatial rather than in the verbal span. Vicari, Bellucci, and Carlesimo (2005) compared participants with DS, WS and typically developed (TD) children matched for mental age in a visual object and spatial span test. People with DS exhibited reduced performance in both tests. However, the deficits in individuals with DS were compensated when their scores were adjusted for perceptual levels. After covarying for performance level on the visual perceptual tasks, performance of the participants with DS and the TD children no longer differed in WM tasks. These results suggest that the WM is not uniformly compromised in DS. Vicari et al. (2006) found that individuals with DS usually perform consistently with their mental age in this domain. However, there are contradicting results. Lifshitz and Rand (1999) found a significant difference in the initial scores between the groups with and without DS in visuo-spatial tests, such as the Reversal Test (Edfeldt, 1954), and the Children Test (Finch, 1953). Visu-Petra, Benga, Tincas and Miclea (2007) also found impairment in visuo-spatial skills among participants with DS compared to TD controls. In contrast, Edgin, Bruce, Pennington and Mervis (2010) found that participants with DS performed better in spatial immediate memory then participants with WS, but no between-syndrome differences in spatial WM. In a recent study Facon and Nuchadee (2010) examined whether differences in the item difficulty of the Raven's Colored Progressive Matrices (RCPM) (Raven, Court, & Raven, 1998) would be found between individuals with DS compared to participants with non-specific ID (NSID) and TD children with the same cognitive level. Their goal stem from the fact that even if its content seems homogenous, factors analysis that was conducted by Carlson and Jensen (1980) have indicated three types of items: (a) simple pattern completion, (b) pattern completion through identity and closure, (c) closure and abstract reasoning by analogy. Results show that item difficulties are clearly the same among the three groups, including those with DS. According to Facon and Nuchadee, the results are in line with the similar structure hypothesis (Hodapp & Burack, 2006; Hodapp & Zigler, 1997) even in populations with different genetic syndromes. However, caution should be used, since in their study all the three groups were matched according to the RCPM and exhibited the same raw score. Facon and Nuchadee state that the Raven contains relatively homogeneous sets of items. Therefore there is no reason, after the matching of groups on the test's raw score, for differential functioning as a result of a different aetiology or IQ level.

In conclusion, most studies indicate that participants with DS exhibit relative preservation of visuo-spatial skills, although there are contradicting results. Studies are varied regarding the type of tests, the task difficulty and methodology and it is therefore difficult to draw definite conclusions.

3. Analogical reasoning in populations with ID

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 WM; 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) and individuals with learning disability (LD) versus TD individuals with the same CA. The performance of individuals with ID was inferior to the other groups across the meta-cognitive questionnaire and analogical reasoning. When covariation of the IQ was carried out, the performance of the ID group was identical to that of TD individuals. Correlations between the two cognitive measures were found in the groups with ID and LD but not among TD participants. 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.

Henry and MacLean (2003) focused on the relation between analogical reasoning and the different components of the WM (in Baddeley & Della Sala's, 1996, model). They examined the relationships between WM and expressive vocabulary and arithmetic reasoning among children with ID (CA = 11–12) versus TD children with the same MA and TD children 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 TD participants with the same CA, arithmetic reasoning ability was predicted by visual memory and to a lesser extent by phonological memory. For TD participants with the same MA, arithmetic reasoning was also best predicted by the central executive, with an additional contribution of phonological memory. These results suggest that different WM resources are used by children of varying ages and ability levels when carrying out the same cognitive tasks.

Other studies that used analogical reasoning in populations with ID examined the efficacy of training in imparting this cognitive task. McConaghy & Kirby (1986, 1987) carried out two experiments in which they examined the performance of participants with borderline level ID (IQ = 70–85) versus TD participants 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 TD participants. 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.

Hessels-Schlatter (2002) and Lifshitz et al. (2005) examined the efficacy of the dynamic assessment approach in improving analogical reasoning problem solving among participants with ID. However, not all participants solved all tasks and reached the maximum scores even after teaching with a dynamic assessment procedure.

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. We have recently examined the process of thinking while solving analogical problems in a population with ID using an eye-tracking technique (Vakil, Lifshitz, Weiss, & Arzouan, 2011).

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 create 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, Lombard, Farren, Flusser, Balsamo, & Fowler, 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 TD participants with the compatible 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, presence or absence of one of the stimuli). The search time was shorter in both groups 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 (the latency) among those with ID was longer than among the TD, and they focused their gaze on the central region of the picture longer than the TD subjects. 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 controls. 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 TD individuals. While the above studies focused on visual perceptual tasks, in our previous study (Vakil et al., 2011) we used the eye tracker technique when solving complex tasks such as analogical reasoning.

Eighteen adults with ID and 20 TD children matched for cognitive level participated in this study. Participants solved the Conceptual and Perceptual Analogical Modifiability Test (CPAM, Tzuriel & Galinka, 2000) while having their eye movements monitored. As predicted, the overall percent of correct answers was significantly higher for the TD group than for the ID group. Eye tracking measures yielded similarities and differences in information processing between the two groups: both groups spent more time on the matrices representing a perceptual analogy than on the matrices representing a conceptual analogy. Furthermore, in both groups more switches were made within the perceptual than within the conceptual analogies. Both groups spent an equal time on the perceptual analogies, whereas the ID group spent more time than the TD group on the conceptual analogies. Thus, the easier analogies (conceptual) differentiated better than the more difficult analogies (perceptual) between the groups when time on a region of interest was measured. However, when the number of switches was measured, the ID group made more switches than the TD group on the perceptual but not on the conceptual analogies. 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 as a reflection of two different types of strategies, constructive matching and response elimination (Bethell-Fox et al., 1984; Vigneau, Caissie, & Bors, 2006). The current study employed an eye tracking array while solving intelligence tests such as the RCPM and the RSPM test (Raven et al., 1998).

The main goal of the present research was to examine information processing and strategy use as expressed by eye movement patterns in the RSPM test performance among adults (aged 21–50) with ID with/without Down syndrome versus TD children with the same mental age. The analyses of eye movements, as reflecting the strategy used, has two obvious advantages. The first is that it is quantifiable and the second is that it does not depend on the subjective report of the participant.

4. Method

4.1. Participants

The sample was comprised of 81 participants divided to three groups: adults with ID with non-specific aetiology (NSID), adults with DS, and children with TD with matched mental age. The Peabody Picture Vocabulary Scale (Dunn & Dunn, 1997) was administered in order to match the mental age between the three groups.

The mean raw scores for the ID, DS, and TD groups were 7.07 (SD = 1.67), 7.14 (SD = 2.36), and 9.09 (SD = 4.42), respectively. The groups did not differ significantly on the PPVT score $F(2,77) = 3.84$, $p > .05$.

Participants with ID: This group was composed of 32 persons with ID aged from 18 to 50 years (M = 32.77; SD = 10.28).
Participants with DS: This group was composed of 16 persons with ID aged from 21 to 45 years (M = 31.06; SD = 6.82).

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 18 and 50 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.

4.1.1. Participants with TD

The group was composed of 35 children aged from 6 to 11 (M = 7.87; SD = 1.83) who were recruited from 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.

4.2. Eye tracking

4.2.1. 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.

4.2.2. Response recording

Participants viewed 36 question items of the Raven 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.

4.3. Procedure

The study was carried out in two stages. In the first stage the PPVT (Dunn & Dunn, 1997) 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.

4.3.1. The experiment

The Raven Matrices was administered in the Eye Tracker laboratory. We administered set AB and B from the RCPM. In addition we administered the first five items from set C, D, and E from the RPM.

Prior to seating near the eye tracker, a two-stage training phase (Vigneau et al., 2006) was carried out:

(a) The participants were introduced to the original printed version of the Raven test. Standard instructions were given by the experimenter and the participants completed the first five items of the part A of colored version as practice items. These items were not included in the test.
(b) The participants were then seated on a chair with their face approximately 45 cm from the eye tracker system. The standard Raven instructions were given again by the experimenter and the participants completed sets AB, B (RCAM) and five items from sets C, D, E 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 five 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 five practice items, the participants completed the test: 12 items of part AB, 12 items of part B, the first five items of parts C, D and E.

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.

5. Results

As described above, participants were presented with 39 slides from the RCPM and RSM. Some of the slides could not be analyzed because of technical problems in rerecording the eye movements (e.g., due to head movements). In the case that more than three slides have to be removed that particular participant was eliminated from the analyses.

5.1. Correct answers

One-way ANOVA was conducted in order to analyze the percent of analogies correctly solved by the three groups (Typical Development – TD, Non-specific Intellectual Disability – NSID, and Down syndrome – DS). The groups were significantly different from each other, $F(2,70) = 18.37$, $p < 001$. Follow up analysis using Tukey-HSD reviled that the overall percent of correct answers was significantly higher ($p < .005$) for the TD group ($M = 63.92$, $SD = 23.17$) compared to that of the NSID group ($M = 33.40$, $SD = 16.24$) and the DS group ($M = 40.50$, $SD = 14.57$). Follow up analysis using Tukey-HSD indicated significant differences ($p < .001$; $p < .01$) between the TD group versus those with ID and DS respectively, but no ID and DS ($p > .05$) groups differences.

5.2. 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 matrices consist of three or nine sub-regions and the answers options consist of four or six sub-regions. To enable the analyses of all slides, the results were corrected and analyzed proportionally to the number of matrices (i.e., 3 or 9) and the number of answer options (4 or 6).

1. Average time on slide

   First, the average time (in seconds) on slide was analyzed. The difference between the groups was marginally different, $F(2,70) = 2.93$, $p = .06$. The source of the difference is between the TD group, that on average, spent less time on the slides ($M = 262.72$, $SD = 52.16$) compared to the NSID group ($M = 340.46$, $SD = 184.76$) which in tern did not differ from the DS group ($M = 313.93$, $SD = 108.06$).
2. Proportional time on the correct answer (out of all options) – correct versus incorrect responses

   Because the number of options was not equal for all slides (some were four and some were six) the proportional amount of time on the correct answer was divided accordingly, such that the score of 1 would be chance. Mixed ANOVA was conducted in order to analyze the proportional time on the correct answer of the three groups (TD, NSID, and DS) as a function of the correctness of their response (correct vs. incorrect). The former is a between subject factor and the latter is a within subject factor. The Group main effect was marginally different, $F(2,66) = 2.66$, $p = .08$. The Correctness main effect, as well as the interaction Group by Correctness reached significance, $F(1,66) = 512.28$, $p < .001$, and $F(2,66) = 3.44$, $p < .05$, respectively. As can be seen in Fig. 1, all groups spent more time than chance on the correct answer when responded correctly, but below chance when responded incorrectly. The interaction stems from the fact that the difference between the correct and incorrect answers was steeper for the NSID group compare to the other groups.
3. Time on matrix as a ratio of the overall slide time – correct versus incorrect responses

   Groups did not significantly differ overall on the proportional time on matrix, $F(2,68) = 75$, $p > .05$. Overall, the proportional amount of time spent on the matrices was not significantly different whether the answer was eventually correct or incorrect, $F(1,68) = 2.68$, $p > .05$. However, the Group by Correctness interaction reached significance, $F(2,68) = 3.77$, $p < .05$. Simple analyses, comparing two of the groups each time revealed that the source of the interaction is that while the TD group spent more time on the matrices when the answer was incorrect as compared to correct, the NSID and DS groups spent about equal time on the matrices regardless the correctness of their answer (see Fig. 2).
4. Amount of time spent on the matrices until first move to the options – correct versus incorrect responses.

   Both main effects, Group, $F(2,68) = 10.83$, $p < .001$, and Correctness, $F(1,68) = 8.16$, $p < .01$, reached significance, but not the interaction between them, $F(2,68) = 2.34$, $p > .05$. Follow up analysis using Tukey-HSD revealed that the TD group spent significantly ($p < .05$) more time than the other two groups on the matrices before moving to the options. As can be seen in Fig. 3, overall, more time was spent when the answers were incorrect.
5. Overall number of switches across all regions of interest in the matrix and the answer options – correct versus incorrect responses

   Group was the only effect reached significance, $F(1,68) = 5.90$, $p < .005$. Correctness and Group by Correctness did not reach significance, $F(1,68) = 1.02$, $p > .05$ and $F(2,68) = 1.67$, $p > .05$, respectively. Follow up analysis using Tukey-HSD reviled that overall the TD group made significantly ($p < .05$) less switches than the other two groups (see Fig. 4).
6. Proportional number of switches between matrix and options – correct versus incorrect responses

   Although main effect of Group did not reach significance, $F(2,68) = 1.29$, $p > .05$, main effect of Correctness, $F(1,68) = 4.89$, $p < .05$, and the interaction Group by Correctness reached significance, $F(2,68) = 3.64$, $p < .05$. In order to detect the source of the interaction two One Way ANOVAs with Tukey-HSD as follow up procedure, were conducted. In the

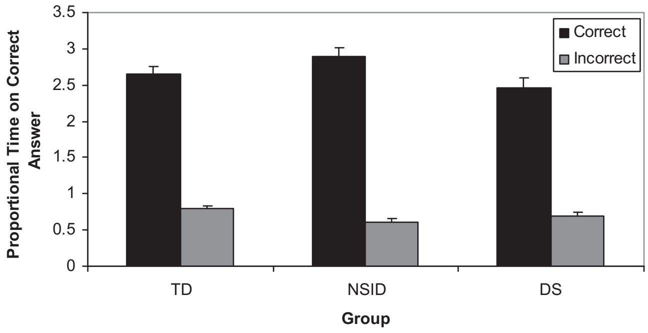

Fig. 1. Proportional time on the correct answer (out of all options) – correct versus incorrect responses.

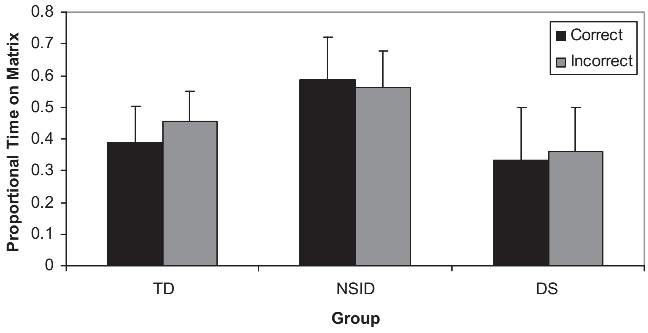

Fig. 2. Time on matrix as a ratio of the overall time on slide – correct versus incorrect responses.

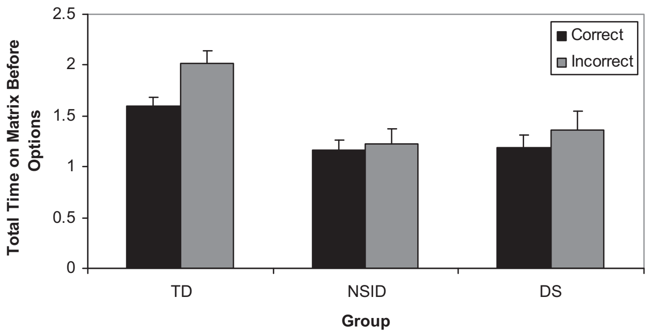

Fig. 3. Amount of time spent on the matrices until first move to the options – correct versus incorrect responses.

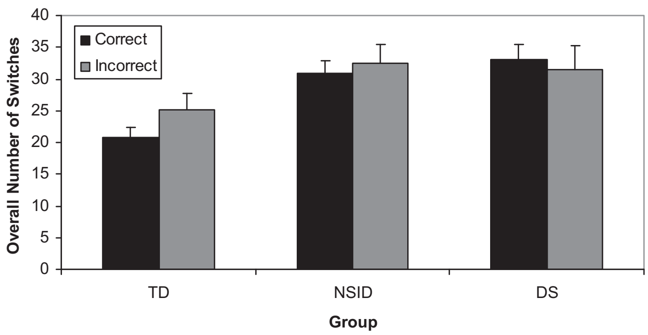

Fig. 4. Overall number of switches across all regions of interest in the matrix and the answer options – correct versus incorrect responses.

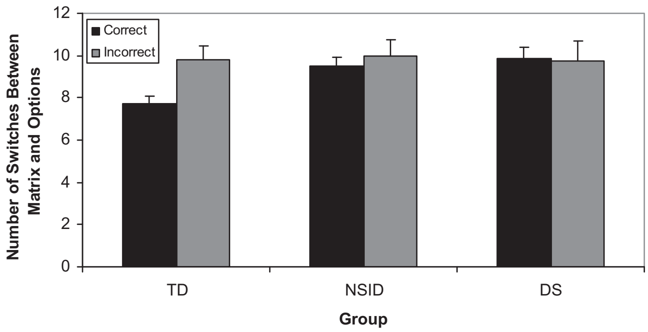

Fig. 5. Number of switches between matrix and options – correct versus incorrect responses.

first the groups were compared on the correct answers condition. The TD group made significantly, less switches than the other two groups, $F(2,68) = 7.29$, $p < .01$. The Group effect did not reach significance when compared on the incorrect answers, $F(2,68) = .03$, $p > .05$ (see Fig. 5).

6. Discussion

The primary finding is that the TD group overall spent less time processing each analogy compared to the two groups with ID, yet they outperformed both groups in solving the Raven Matrices. Apparently, all groups spent proportionally more time on the analogies which eventually were solved correctly than on those that were incorrectly solved. However, when looking at the proportional time spent on the matrices the TD group showed a different pattern than that of the ID group. When more time spent on the matrices it predicted an incorrect answer for the TD group, but for both ID groups the time spent on the matrices did not predict the correctness of their responses. This possibly reflects more efficient monitoring processes by the TD group that when encountering a difficult analogy spend more time in an attempt to solve it accurately. This is consistent with the finding that proportionally the TD group spent more time on the matrices before shifting to the options, than the two ID groups. At the same time the TD group made significantly less switches from one rejoins to another, than the ID groups. In addition, the proportional number of switches inside the matrix was higher for the TD groups compared to the other groups. Put together, the TD group spends more time on the matrices before scanning the options, also made more switches inside the matrix and the fact that overall they make less switches from one region to another. This difference in scanning pattern between the TD group and the ID groups reflects a fundamental difference in the strategy used to solve the analogies.

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. While the TD groups' scanning pattern reflects a "constructive matching" strategy the ID groups' scanning pattern reflects a "response elimination" strategy (Bethell-Fox et al., 1984; Vigneau et al., 2006).

The participants with ID made more switches than the participants with TD. 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. It was already pointed out that the TD group, but not the ID group, spent more time scanning the correct answer proportional to the other response options. That behavior might suggests that the TD group were more reflective pondering on the correct answer prior to their overt response. The ID group in contrast 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).

It is important to notice that unlike the ID groups, the TD group's eye movements were sensitive to the correctness of their answer. For example when looking at the proportional time spent on the matrices (more time on the incorrect answers) or when looking at the number of switches between matrix and options, less switches when correct answers than incorrect for the TD group. The ID groups made overall more switches and the number of switches was similar regardless of the correctness of the answer.

Finally, it is worth noticing that the eye movement pattern distinguishes nicely between the TD and ID groups. However, in most cases the eye movement pattern of the DS and the NSID was not distinguishable. Under the assumption that the eye movement pattern reflects the cognitive strategy used, it seems that the two ID groups not only were not different in the number of analogies solved but they did not differ from each other in the strategies used to solve the analogies. There are contradicting results regarding the performance of participants with DS in visual spatial tasks.

Studies report on similar performance in this domain of this aetiology (Vicari et al., 2005, 2006; Wang & Bellugi, 1994, while other report on the opposite Lifshitz & Rand, 1999; Visu-Petra et al., 2007). Our findings are in accordance of those of Vicari et al. (2006) indicating that individuals with DS performed consistently with their mental age in this domain. Our findings support the results of Facon and Nuchadee (2010) who did not found differences in performance between individuals with TD versus those with NSID and DS. In their study all the three groups were matched according to the RCPM and exhibited the same raw score. However, the matching between the three groups in our study was based on the PPVT (Dunn & Dunn, 1997). We found some advantage of the DS group on the Raven scores. However, the differences did not reach significant. But the most important finding lies in the fact that there were no differences in eye movement between participants with NSID and those with DS.

This study highlights the potential of analysis eye movements in tasks where not only the final answer but also the strategy used is important. Analysis of eye movements is even more critical in populations such as those participated in the present study, which have difficulties explicitly expressing the strategy they have used solving the task. Such findings have the potential to help clinicians develop remediation strategy to ameliorate performance.

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