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Analogical Problem Solving in Children With Verbal and Nonverbal Learning Disabilities

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Analogical reasoning—perceiving similarities in different situations and the transfer of such information—facilitates learning and understanding. However, children with learning disabilities (LD) typically demonstrate deficits in such information processing strategies. In this study, we investigated the analogical problem-solving differences between children with verbal learning disabilities (VLD), nonverbal learning disabilities (NLD), or non-LD. Results indicated better recall of component stories by children without disabilities but no significant differences between the NLD and VLD participants. However, the success rate for target problem solving was much lower for the NLD group than for the VLD and non-LD groups. The poor performance of the NLD children may be attributed to some of their characteristic weaknesses, critical for analogical problem solving. Yet the VLD group was significantly weaker in recall than the non-LD group, but this did not hamper their analogical problem-solving abilities. These findings confirm that analogical thinking requires more than memory.

Keywords: *verbal learning disabilities; nonverbal learning disabilities; analogical problem solving*

Analogical reasoning—the processing and transfer of knowledge acquired in one situation or context to another (Chen, 2002)—is both common and integral to inductive reasoning and problem solving in everyday, real-world situations (Wedman, Wedman, & Folger, 1999). By identifying the similarities in different situations, reasoning by analogy offers a powerful mechanism that facilitates thinking and explanations, understanding, inference making, learning new abstractions, and creating conceptual change, especially in our world of "perpetual novelty" (Gentner & Holyoak, 1997; Goswami, 1992). Analogical problem-solving techniques enable conceptual category organization, which, in turn, facilitates learning of an even more general category or schema. Successful analogical problem solving provides a better understanding of a class of problems not previously known, thus increasing the probability of successfully solving other types of future problems and even decreasing the time required for solving them (Gholson, Eymard, Morgan, & Kamhi, 1987; Gick & Holyoak, 1980, 1983).

Problem-analogy research has focused on identification of several key component stages in analogical problem solving (Anolli, Antonietti, Crisafulli, & Cantoia, 2001; Gick, 1985; Gick & Holyoak, 1980; Hsu & Wedman, 1994; Wedman, Wedman, & Folger, 1996; Yang & Wedman, 1993). In the first stage, the individual facing a target problem must access a plausible and useful source analog from memory and then employ comprehension skills to construct mental representations of the story analogy and of the target problem (e.g., Chen & Daehler, 1992; Gick & Holyoak, 1980; Holyoak, 1984; Holyoak & Gordon, 1984; Hsu & Wedman, 1994). In this stage, source relevance must be noted to enable consequent activation for target problem solving (Anolli et al., 2001; Wedman, Wedman, & Folger, 1996). The second stage of analogical problem solving comprises mapping, where the individual finds correspondences between the source and the target (e.g., Chen, 1996; Chen & Daehler, 1992; Chen, Yanowitz, & Daehler, 1995; Gick & Holyoak, 1980, 1983; Holyoak, Junn, & Billman, 1994; Hsu & Wedman, 1994; Wedman et al., 1996). In the third stage, the person must extend this mapping between the original source and the target to another source problem in order to retrieve or reconstruct prior knowledge (from the original source) for an appropriate solution of a new target problem (Brown & Kane, 1988; Holyoak et al., 1994; Gick & Holyoak, 1980;

Wedman et al., 1996). These stages are neither conclusive nor necessarily sequential.

Solving problems by analogy requires certain higher order cognitive capabilities such as finding relevancy (Yang & Wedman, 1993), mapping (Yang & Wedman, 1993), text comparison (Anderson, Greeno, Kline, & Neves, 1981), understanding causality (Halford, 1993; Siegler, 1989), making inferences (Brown, 1982), inductive reasoning (Brown, 1982), generalization ability (Brown, 1982; Gick, 1986), the ability to make abstractions and understand paradigms using abstract schema activation (e.g., Chen & Daehler, 1992; Holyoak, 1984; Holyoak & Gordon, 1984; Gick & Holyoak, 1980; Hsu & Wedman, 1994; Novick, 1990; Wedman et al., 1999; Yang & Wedman, 1993), and information transfer and problem-solving skills (Brown, 1982; Wedman et al., 1999; Yang & Wedman, 1993). Working-memory processes are also involved in each and every stage of problem analogy. Starting with retrieving information from memory and the construction of mental representations of the story analogy and of the target problem, and followed by a manipulation of current relevant information to reach a solution, working-memory processes thus involve the generation and manipulation of mental images created on the basis of verbal description (e.g., Cornoldi, Dalla Vecchia, & Tressoldi, 1995; Cornoldi, Rigoni, Tressoldi, & Vio, 1999).

The essence of children's ability to solve problems by analogy is the capacity to recognize and use similarities between story units. Story analogies facilitate problem solving when they have shared story schemata (identical characteristics) between the source and the target problem; thus, the analogists can more easily recognize, map, and transfer these schemata to solve the particular problem. Shared schemata may include the problem's initial state, goals, available resources and constraints, solution plan, and actual or anticipated outcome of the plan (Gick & Holyoak, 1983).

Regarding the onset of analogical reasoning during child development, Goswami (1992, 2001) and Goswami and Brown (1989, 1990) have posited a hypothesis of relational primacy, proposing that the capacity for analogical reasoning is fundamentally available from infancy, yet analogical performance increases with age and with the accretion of knowledge about relevant relations in the world. In a series of studies, Goswami concluded that children may be able to recognize relational similarities at any point in development; however, this ability correlates with the child's current conceptual knowledge. Recognizing similarities should not constitute an extra cognitive load if the analogous relations are already part of the child's conceptual knowledge (Goswami, 1992, 2001). Chen (1996) bolstered Goswami's (1992) position regarding early onset of the ability to recognize relational similarity, by finding no age differences (among an age range of 5–8 years) in children's ability to tap various types of similarities during analogical problem solving.

Another area of inquiry has focused on how children recognize the analogical correspondences between the source and the target and how they use the source solution to solve the target problem. Chen (1996) identified three types of source- and target-problem similarities: superficial, structural, and procedural. Superficial similarity (the degree to which protagonists, goal objects, and story themes are similar) is the initial step in the analogy transfer because it bridges between the source and the target problem. Superficial similarity enhances the child's recognition of the similarity between the new problem and the one experienced in the past. Structural similarity refers to the causal relations among the key problem elements, namely, whether the solution action was causally linked both to the solution goal and to a successful outcome. Transfer of a complete structural similarity has been found to be crucial for young children to draw analogies between source and target problems (Chen & Daehler, 1992). Procedural similarity, the specific operational features shared by source and target solutions, seems to facilitate the process of applying a learned solution by enabling children to implement the source solution after the analogy is drawn (Chen, 1996). Furthermore, in studies that gave two source stories with same solution scheme (in comparison to only one source) and that gave more than one example of a solution, children were more likely to use the analogy to solve the target problem (Chen & Daehler, 1989; Gick & Holyoak, 1980). "The same verbal statements . . . that had failed to influence transfer from a single analog proved highly beneficial when paired with two" (Gick & Holyoak, 1983, p. 31).

Children with learning disabilities (LD) typically demonstrate inefficient information processing skills, which have been pinpointed as a possible underlying cause of their cognitive-academic and social-emotional difficulties (Kavale & Forness, 1996; Kolligian & Sternberg, 1987). Researchers have suggested two major subgroups of children with LD, those with verbal learning disabilities (VLD) and those with nonverbal learning disabilities (NLD; Johnson & Myklebust, 1967; Rourke, 1988; Rourke & Tsatsanis, 1996). Children with VLD are characterized by poor reading and spelling skills, auditory processing difficulties, and other disorders that affect the reception, expression, and processing of verbal and written language (Johnson, 1995; Kamhi & Catts, 2002; Palombo, 1996). These problems, specifically problems in phonological word processing, create a bottleneck that limits the flow of information to higher levels of processing (e.g., Hulme & Snowling, 1992; Ransby & Swanson, 2003; Shankweiler et al., 1995).

In contrast, children with NLD have difficulty with tasks that are novel and complex, such as higher order academic skills (Forrest, 2004; Harnadek & Rourke, 1994; Matte & Bolaski, 1998; McDonough-Ryan et al., 2002; Rourke, 1995). These children often demonstrate weaknesses in synthesizing and integrating information as well as difficulties in areas that require problem solving, complex concept formation, and executive function skills such as task adherence, planning, response inhibition, working memory, and cognitive flexibility (Bender & Golden, 1990; Fisher, DeLuca, & Rourke, 1997; Forrest, 2004; Harnadek & Rourke, 1994; Little, 1993; Ozoles & Rourke, 1988; Rourke, 1989, 1995; Van der Vlugt, 1989, 1991). Indeed, they exhibit particular difficulties with organization, planning, and tasks requiring sequencing (Tanguay, 2001). In addition, children with NLD find it hard to internalize feedback, learn from past experience, deal with ambiguous and nonroutinized situations, and understand cause-effect relationships (e.g., Fisher et al., 1997; Harnadek & Rourke, 1994; Matte & Bolaski, 1998; Rourke, 1995). These children's academic difficulties have been attributed to a deficit in creative thinking abilities such as abstract thinking, idea generation, and elaborate reasoning (Matte & Bolaski, 1998). Furthermore, children with NLD appear to be unable to organize a narrative to differentiate between main points and supporting details or between relevant and irrelevant information (Palombo, 1996; Rourke, 1995). Their difficulties in working memory appear specifically when they are asked to elaborate and manipulate visuospatial material, even when stimuli are presented verbally (e.g., Cornoldi et al., 1999; Cornoldi, Rigoni, Venneri, & Vecchi, 2000; Liddell & Rassmussen, 2005; Mammarella & Cornoldi, 2005).

To the best of our knowledge, despite its importance and the extensive study that has already been conducted on these children's difficulties in information processing, analogical problem solving has not yet received adequate empirical attention in children with LD. In the current study comparing children with VLD, with NLD, and without LD, we hypothesized that LD would impact analogical problem solving and that differential effects of NLD and VLD would emerge. Considering the requisite high-order academic skills needed for problem solving, we predicted that analogical problem success for the VLD group would resemble that of the non-LD group and that the NLD group would show the weakest performance.

Method

Participants

The study population consisted of 65 (40 LD and 25 non-LD) third-grade boys from nine elementary schools in middle-class neighborhoods in central Israel from both LD and mainstream classes. The participants' ages ranged from 8 years 2 months to 8 years 8 months. The mean age for the LD students was 8 years 9 months ($SD = 5$ months). The mean age for the non-LD comparison group was 8 years 7 months ($SD = 4$ months). The t-test results showed no significant age differences between the groups, $t(43) = 1.41$, $p > 0.05$. All participants were from middle-class families and had resided in Israel for at least 4 years, which allowed them adequate knowledge of Hebrew. None of the participants demonstrated extreme behavior, attentional difficulties, or severe neurological problems. Parental consent was obtained for each participant.

LD group. In line with the Israeli Law of Special Education (Ministry of Education, Culture, and Sports, 1996), the 40 students with LD were assessed in their schools, diagnosed by the school district psychological services, and identified by an interdisciplinary placement committee as in need of remedial help or special education services. The diagnostic assessment included instruments such as the *Wechsler Intelligence Scale for Children–Third Edition* (Wechsler, 1976), *Bender-Gestalt Test* (Koppitz, 1975), figure drawings (Koppitz, 1968), *Kaufman Assessment Battery for Children* (Kaufman & Kaufman, 1983a, 1983b), and achievement tests in one or more learning processes (i.e., reading, writing, mathematical calculation, or mathematical reasoning), as well as additional tests where necessary. Children's IQ scores were not available to the research team, owing to Israeli regulations for privacy protection. However, by definition, for an LD diagnosis, these IQ scores were in the normal range (Ministry of Education, Culture, and Sports, 1996). Students received an LD diagnosis based on the criteria in Israel for LD classification (in line with the *Diagnostic and Statistical Manual of Mental Disorders–Text Revision* [4th ed.]; American Psychiatric Association, 2000), which includes (a) achievement test scores at least 2 years below grade level and (b) average or above-average intelligence with a marked deficit in academic achievement.

Division into VLD and NLD subgroups. The LD children were divided into two subgroups of 20 (see Dimitrovsky, Spector, Levy-Schiff, & Vakil, 1998) based on children's standard scores on the Hebrew versions (Vakil & Blachstein, 1993) of the Rey (1964) *Auditory Verbal Learning Test* (AVLT) and the Benton (1974) *Visual Retention Test* (BVRT); see procedure below. Twenty students who had standard scores above 0 on the Rey AVLT and below 0 on the BVRT were classified as VLD. Twenty students who had standard scores below 0 on the Rey AVLT and above 0 on the BVRT were classified as NLD. Fifteen students who scored below 0 on both measures and 15 students who scored above 0 on both measures were excluded from the study. To validate the classification into NLD and VLD groups, we also examined the two groups' academic grades based on school records from the previous academic year in two subjects: reading and mathematics. In line with expected differences, the children with NLD significantly outperformed their VLD peers on reading (NLD: $M = 65.0$, $SD = 10.8$; VLD: $M = 51.05$, $SD = 9.75$) $F(1, 38) = 4.39$, $p < .05$, and the children with VLD significantly outperformed their NLD peers on mathematics (NLD: $M = 50.5$, $SD = 11.39$; VLD: $M = 68.1$, $SD = 14.13$), $F(1, 38) = 4.42$, $p < .05$. The VLD group ($n = 20$) ranged in age from 8 years 3 months to 8 years 7 months (M = 8 years 5 months, $SD = 3.5$ months). The NLD group ($n = 20$) ranged in age from 8 years 3 months to 8 years 8 months (M = 8 years 5.5 months, $SD = 4$ months).

Control group. The control group consisted of 25 children without LD from parallel third-grade, regular education classes in the same schools, who, according to their teachers' reports, showed no learning, behavioral, or attentional difficulties.

Instruments and Procedures for Subgroup Classification

Rey AVLT. The Rey AVLT (Rey, 1964) is a widely used diagnostic tool that measures various memory components including immediate and delayed recall, learning rate, recognition, proactive and retroactive interference, primacy, and recency effects (Lezak, 1995; Query & Megran, 1983; Ryan, Rosenberg, & Mittenberg, 1984; Weins, Mcminn, & Crossen, 1988). The Hebrew version of the Rey AVLT (Vakil & Blachstein, 1993) was administered.

We followed the standard administration of the Rey AVLT as described by Lezak (1995), which includes 15 common words (List A) presented orally, at the rate of 1 word per second, in five consecutive presentations (Trials 1–5). After each of these trials, the participants were asked to recall freely, in any order, as many words as possible. In Trial 6, participants were asked to freely recall as many of the words as possible from List B (15 new words introduced to proactively interfere with the first 15 words presented in List A). Trial 7 consisted of a free recall of List A, without rereading List A. Trial 8 was the same as Trial 7 but after a 20-minute delay. Dimitrovsky et al. (1998) placed participants' trial scores into six categories: immediate memory, best learning, proactive interference, retroactive interference, delayed recall, recognition, and temporal order. We transformed these scores to standard scores and subjected them to the factor-analytic procedure used by Vakil and Blachstein (1993). Three major factors emerged by using a principal-component analysis to determine the number of factors retained by Kaiser's eigenvalue greater than 1.0 rule and by rotating the emerged factors orthogonally using an Equamax procedure, which together explained 77.5% of the variance: (a) storage, including temporal order, best learning, and recognition (35% of the explained variance); (b) retention, in spite of time or stimulus interference, including delayed recall and retroactive interference (25.8% of the explained variance); and (c) short-term verbal memory, including proactive interference and immediate memory (16.7% of the explained variance).

Dimitrovsky et al. (1998) used retention as the measure of verbal learning and memory and included retroactive interference (Trial 7 without Trial 6) and delayed recall (Trial 8 without Trial 5). There were four considerations for their decision: (a) Unlike storage and short term verbal memory, retention was either first or second in all three analyses; (b) the structural model for the combined sample was most similar to the previously found model (Vakil & Blachstein, 1993); (c) conceptually, this retention more clearly reflected consistency of verbal learning and perception (Anderson, 1985) than storage and short-term verbal memory; and (d) there was no significant relationship between BVRT scores and retention. Based on these considerations and to allow comparison to comparable studies (Dimitrovsky et al., 1998), we used retention as our measure of verbal learning and memory in this study. Thus, to classify the subgroups of VLD and NLD, test scores for the Rey AVLT were based on the average scores for retention—that is, the average of the scores for retroactive interference and delayed recall, which were transformed to standard scores.

BVRT. The BVRT (Benton, 1974) was the second measure used to assess subgroups of children with LD. This visual perception and memory test consists of three parallel sets of 10 cards with geometric designs. The BVRT is a visual-spatial memory test involving design reproduction that assesses both visual perception and visual-constructive abilities. Out of the four possible BVRT procedures, in this study, participants were tested on Administrations A and D. In Administration A, each design is exposed for 10 seconds, after which the student is asked to reproduce the design from memory. In Administration D, each design is exposed for 10 seconds, and after a 15-second delay, the student is asked to reproduce the design from memory. The administration and scoring for both tests was standard (Lezak, 1995). Thus, to classify the subgroups of VLD and NLD, test scores for the BVRT were based on the average of number of correct answers given in both Administrations A and D, which were transformed to standard scores.

Study Task Materials and Procedures: Analogy-Based Problem-Solving Task

Due to the difficulty inherent in solving analogy-based problems for all children, we implemented several facilitating mechanisms when designing the target task. First, we based the target problem-solving task on two source stories that were structurally similar (each story had a protagonist, goal, obstacle, and solution). Second, we elicited the recall of key aspects of each of the two stories. Third, we explicitly asked the participants to refer to the similarities between the two source stories. A pilot study that administered the task on 10 non-LD children and 10 children with LD showed that children in both groups were able to solve the problem.

The analogy-based problem-solving task presented two source stories and a target story. Stage 1 (story retelling) involved the recall of story components from the two stories presented. Stage 2 (abstract representation) involved relating to the similarities between the two stories. Stage 3 (target problem solving) required the transfer and application of the stories' shared solution to the target problem.

Stage 1: Story retelling. The procedure and scoring for the story-retelling stage derived from Chen and Daehler (1989). In each session, participants were told that they would hear two stories and could follow along on the printed copies of the stories that they would be given; they were also told that they would later be asked to try to remember as many details as possible from the stories. After hearing the first story and following its printed copy, the printed copy was removed, and participants were asked to recall as many details as they could from that story. The procedure was repeated for the second story. These two stories presented particular structural schemata for problematic situations needing a solution (i.e., the protagonist, goal, and obstacle). Although the details of the stories differed, the means for solving them was similar. Story 1 was about a hungry monkey in a cage who tried to reach the bananas outside his cage. He tried using two individual sticks within his reach, but neither stick was long enough to access the bananas. After thinking, he connected the sticks, thereby reaching and obtaining the bananas. Story 2 was about Eddie and his friends playing baseball. In the course of their game, the ball landed on a nearby roof. Eddie tried to get the baseball with his bat, but the bat was too short. After thinking, Eddie connected two bats, reached the ball, and got it down. Scoring for the recall task was indicated by the oral recall of four key story components: protagonist (monkey/Eddie), goal (bananas/ball), obstacle (cage and distance/roof and distance), and solution (connecting sticks/connecting bats). For each of the four key story components, 1 point was scored for a correct answer and 0 for an incorrect answer, with a possible total range of 0 to 4 points.

Stage 2: Abstract representation. In Stage 2, the participants were asked what the stories had in common. The participants were specifically asked, "Are these stories similar?" "How are they alike?" "Does anything similar happen in these stories?" Abstract representation was indicated when participants generated the solution principle presented in both stories (i.e., connecting two shorter items to form one longer item that can procure the desired object). Scoring was 1 when the participant expressed the solution principle and 0 when the participant did not, with a possible range of 0 to 1 points.

Stage 3: Target problem solving. In Stage 3, three of the four structural story components represented by the two source stories (protagonist, goal, and obstacle) were reintroduced to the participant in the form of an actual physical target problem needing a solution. For the target problem, the child was presented with a transparent plastic cylinder of 30-centimeter height and 5-centimeter diameter, open at one end and closed at the other, with a 10-centimeter high volume of water filling the bottom of the closed end, and a .05-centimeter bead floating on the surface of the water at the bottom of the cylinder. Also on the table and within easy reach of the child were several objects: two plastic Tinkertoy®-like rods slotted at each end (each too short to reach the bottom of the cylinder), which could easily be connected to each other; a plastic spoon attached to one of these rods through one of its slots; several large sheets of poster paper; a pair of scissors; a toy hammer; several clothespins; several rubber bands; and a scarf. Each participant was asked to retrieve the bead using the items on the table but without turning the cylinder upside down or putting his or her hand(s) in the cylinder. Scoring was 1 when the participant connected the two rods and successfully retrieved the bead and 0 when the participant did not, with a possible range of 0 to 1 points.

Results

Results for the three groups are presented in sequence for the three stages of the analogical problem-solving task.

Table 1
Means and Standard Deviations for Schemata Recalled for Story 1 and Story 2 (Stage 1)

	Group		
	Control	Nonverbal Learning Disabilities	Verbal Learning Disabilities
n	25	20	20
Story 1			
M	2.64_a	$.35_b$	$.40_b$
SD	1.66	.59	.50
Story 2			
M	2.80_a	$.20_b$	$.30_b$
SD	1.61	.41	.47

Note: Means with different subscripts differ significantly by Bonferroni multiple-comparisons test.

Table 2
Number (and %) of Participants Who Generated an Abstract Representation From the Two Stories (Stage 2)

	Group		
Generated Abstract Representation	Control	Nonverbal Learning Disabilities	Verbal Learning Disabilities
n	25	20	20
No	14 (56%)	15 (75%)	14 (70%)
Yes	11 (44%)	5 (25%)	6 (30%)

Note: Percentage values are within groups.

Stage 1: Story Retelling

Multivariate analysis of variance (MANOVA) was applied for the recall of the four story components (protagonist, goal, obstacle, and solution), for each of the two stories (Story 1 and Story 2), for each group of participants (control, VLD, and NLD), and for between-subject factors. The analysis revealed a significant group effect, $F(4, 122) = 18.29$, $p < .001$, $\eta^2 = .38$. Univariate analyses indicated significant differences in recall of the four core components of both stories, $F(2, 62) = 31.74$, $p < .001$, $\eta^2 = .51$ and $F(2, 62) = 44.73$, $p < .001$, $\eta^2 = .59$, for Story 1 and Story 2, respectively. Post hoc analyses (Bonferroni's $p < .05$) indicated that the pattern of group differences was identical for the two stories. Children in the non-LD group showed better memory of the core story components than did either of the two LD groups, who did not significantly differ from each other. Table 1 presents means and standard deviations for recall for each story, by participant group.

Due to the large standard deviations versus the means, specifically in the LD groups, we reanalyzed the data using *Kruskal Wallis Tests* applied separately to the overall memory scores on Story 1 and Story 2. Results indicated that the three groups significantly differed in overall memory for Story 1, $\chi^2(1) = 18.23$, $p < .001$, and for Story 2, $\chi^2(1) = 21.53$, $p < .001$. *Mann-Whitney Tests* revealed the same pattern of differences among the study groups for both stories as the ones that emerged with the parametric analyses.

Stage 2: Abstract Representation

Next, we examined whether the participant groups differed in their abstract representation of the stories. Table 2 presents the number of participants for each group who generated the correct abstract representation from the two stories. Chi-square analysis indicated that the percentage of participants who generated the correct abstract representation from the two stories was similar for all groups, $\chi^2(2) = 1.98$, $p > .05$. Indeed, all three groups revealed a low level of abstract-representation capabilities, with no group differences between the control group and the two LD groups. However, in a further within-group analysis examining differences within each group between children who were and were not able to generate the abstract representation, we found no within-group differences for either the non-LD or the VLD groups, $\chi^2 < 1$ and $\chi^2(1) = 3.20$, $p > .05$, respectively, but a significant difference did emerge for the NLD group, $\chi^2(1) = 5.00$, $p < .05$. In the group of children with NLD, the percentage of children who were able to generate the correct abstract representation was significantly lower than the percentage of those who could not.

Stage 3: Target Problem Solving

Finally, we examined whether the participant groups differed in their target problem-solving skills. Chi-square analysis indicated that the percentage of participants who solved the target problem differed among the three participant groups, $\chi^2(2) = 10.78$, $p < .01$. Table 3 presents the numbers of participants who solved the target problem in each study group. The data presented in Table 3 indicate that the percentages of participants who succeeded in solving the target problem were similar for the control and VLD groups and much lower for the NLD group.

Logistic Regressions for Predicting Target Problem Solving

Inasmuch as the two LD groups differed from the control group in memory performance (Stage 1), we

Table 3
Number (and %) of Participants Who Solved the Target Physical Problem (Stage 3)

Solved the Target Problem	Group: Control	Nonverbal Learning Disabilities	Verbal Learning Disabilities
n	25	20	20
No	13 (52%)	19 (95%)	11 (55%)
Yes	12 (48%)	1 (5%)	9 (45%)

Note: Percentage values are within groups.

Table 4
Hierarchical Logistic Regression Results for Target Problem Solving (No/Yes) as a Function of Memory and Group (Verbal Learning Disabilities/Controls)

Variables	*B*	*Wald Test* (*Z* ratio)	Odds Ratio
Step 1			
Memory: Story 1	0.01	0.001	1.01
Memory: Story 2	0.15	0.26	1.16
Step 2			
Group	0.42	0.21	1.52

Note: Group: 1 = no learning disabilities; 2 = verbal learning disabilities.

Table 5
Hierarchical Logistic Regression Results for Target Problem Solving (No/Yes) as a Function of Memory and Group (Nonverbal Learning Disabilities/Controls)

Variables	*B*	*Wald Test* (*Z* ratio)	Odds Ratio
Step 1			
Memory: Story 1	0.24	0.57	1.27
Memory: Story 2	0.29	0.89	1.34
Step 2			
Group	–2.54	3.82	0.08

Note: Group: 1 = no learning disabilities; 2 = nonverbal learning disabilities.

Table 6
Hierarchical Logistic Regression Results for Target Problem Solving (No/Yes) as a Function of Memory and Group (Verbal Learning Disabilities/Nonverbal Learning Disabilities)

Variables	*B*	*Wald Test* (*Z* ratio)	Odds Ratio
Step 1			
Memory: Story 1	0.152	0.026	1.16
Memory: Story 2	1.48	1.77	4.41
Step 2			
Group	–2.87	5.81	0.06

Note: Group: 1 = verbal learning disabilities; 2 = nonverbal learning disabilities.

performed three hierarchical logistic regressions to predict target problem solving as an outcome, with the participant groups (three separate dichotomous variables) as predictor variables, while controlling for memory levels for the two stories. Specifically, we performed three hierarchical logistic regressions, each with target problem solving (no/yes) as an outcome variable. In each regression, memory for Story 1 and Story 2 was entered in Step 1, and group was entered in Step 2. In the first regression, the group variable consisted of the VLD and control groups; in the second analysis, the group variable consisted of the NLD and control groups; and in the third analysis, the group variable consisted of the VLD and NLD groups. Tables 4, 5, and 6 show the regression coefficients, Wald statistics, and odds ratios for each of the three regressions.

The first regression, for the VLD and control groups, revealed no significant effects for memory (Step 1, $\chi^2 < 1$) or for group (Step 2, $\chi^2 < 1$). The second regression, for the NLD and control groups, revealed significant effects for memory (Step 1), $\chi^2(2) = 6.62$, $p < .05$, and for group (Step 2), $\chi^2(1) = 4.56$, $p < .05$. Inspection of the odds ratio of group indicated that the children with NLD showed poorer performance on the target problem-solving task as compared with the control group. The third regression, for the VLD and NLD groups, revealed no significant effect for memory (Step 1), $\chi^2(2) = 4.12$, $p > .05$, but a significant effect for group (Step 2), $\chi^2(1) = 9.15$, $p < .01$. Inspection of the odds ratio of group indicated that the children with NLD showed poorer performance on the target problem-solving task when compared with the children with VLD.

Discussion

Analogical thinking, which entails the transfer of knowledge from a source or base problem to a target problem by a mapping process (i.e., finding appropriate correspondences between the two analogs), requires the identification of similarities and the realization of story-shared schemata between the two analogs (Gick & Holyoak, 1983; Wedman et al., 1996). Furthermore, mapping may require the induction of schemata from a specific example (Gick & Holyoak, 1983). The relations between processing concrete examples and categorization have been experimentally supported (Schustack & Anderson, 1979).

The ability to solve problems by analogy may facilitate the successful solving of other types of problems and may shorten the time required for solving them (Gick & Holyoak, 1980, 1983; Novick, 1990). Thus, problem solving and the analysis of its requisite skills are a well-researched area of inquiry. However, the particular weaknesses of children with LD in this domain have been less investigated, as have subtypes of LD. Such an investigation into distinctions between groups with and without LD, and within different LD subtypes (VLD and NLD), was expected to illuminate both the components of problem solving (their interdependence and autonomy) and the group differences between the two LD subtypes.

Due to the difficulty many children face when solving an analogy problem (Chen, 1999), we adopted several strategies to facilitate participants' performance of the target task. We selected two structurally similar source stories, elicited participants' recall of key aspects, asked children to articulate the two source stories' similarities, and only then invited participants to solve an analogical physical problem that resembled the two source stories structurally.

The recall of specific story components (protagonist, goal, obstacle, and solution) for each of the two stories showed that the non-LD participants exhibited better memory than did either of the two LD groups, who did not significantly differ from one another. These results confirmed Humphries, Cardy, Worling, and Peets's (2004) study where children with NLD were comparable to their VLD counterparts in text-content recall.

In contrast, the success rate for solving the target physical problem was much lower for the NLD group than for the VLD and non-LD groups, who resembled one another. The results of the hierarchical logistic regressions on target problem solving showed that even when the recall variable was partialled out, the children with NLD demonstrated poorer performance than did the non-LD group. Furthermore, the children with NLD showed poorer performance than did the children with VLD.

These inconsistent findings for the different stages of the problem-solving task raise theoretical implications regarding the components and structure of analogy tasks. Sternberg (1977) suggested that solving analogies involves a number of independent component processes executed serially. His results indicated that children's mastery of analogical problem solving, particularly among children with LD, is not necessarily a hierarchical process and that the components are not necessarily cumulative or interdependent.

Our results for memory recall showed no significant differences between the NLD and the VLD participants, yet the children with VLD were not as successful as those with NLD in analogical problem solving. Moreover, when compared with the non-LD participants, the VLD group was significantly weaker in recall, but this did not hamper their analogical problem-solving abilities. These findings raise several possible explanations. For one, the current outcomes suggest that analogical thinking requires more than a memory for details or relevant information (Chen & Daehler, 1992; Gentner & Toupin, 1986). Another way to interpret the results regarding the differences in the VLD and the NLD groups' ability to reach a real solution to the analogy-target task might relate to the problem type employed in current study. Our target problem required processing of spatial information, involving three-dimensional objects that needed to be connected together to reach another object. Possibly, this type of task may require not only spatial abilities but also the ability to maintain information in visuospatial working memory and to manipulate an object in space to reach the goal. Based on the aforementioned difficulties of the NLD children with visuospatial working memory, they may have failed the task based on the type of processing involved—that is, the need to maintain and manipulate stimuli in visuospatial working memory. Future studies would do well to explore the differences in analogical problem solving between NLD and VLD groups by comparing two different target problems, where one problem asks children to manipulate visuospatial stimuli and the other asks them to manipulate phonological stimuli based on a verbal target problem (e.g., Duyck, Vandierendonck, & De Vooght, 2003). If children's success is linked with the type of target problem, it will strengthen this alternative explanation.

The poorer performance of the NLD children may also be attributed to some of their characteristic weaknesses, which are critical for analogical problem solving, such as their difficulties in coping with novel or complex tasks (Forrest, 2004; Harnadek & Rourke, 1994; Matte & Bolaski, 1998; McDonough-Ryan et al., 2002; Rourke, 1995). These children's acknowledged deficits in differentiating between main points and supporting details or between relevant and irrelevant aspects of narratives (Palombo, 1996; Rourke, 1995) may possibly impair or altogether preclude the required abstraction for analogical problem solving. Other relevant domains of difficulty for children with NLD that may adversely affect their analogical problem-solving abilities could be their problems with organization, planning, sequencing, synthesizing and integrating information, understanding cause-effect relationships, formulating complex concepts, and creative-thinking abilities such as abstract thinking, idea generation, and elaborate reasoning (Bender & Golden, 1990; Forrest, 2004; Harnadek & Rourke, 1994; Little, 1993; Matte & Bolaski, 1998; Ozoles & Rourke, 1988; Rourke, 1989, 1995; Tanguay, 2001; Van der Vlugt, 1989, 1991).

It is interesting that significant group differences between the clinical and the nonclinical groups emerged only with regard to children's retelling and not in their capacity for abstract representation. This finding may imply that these two tasks reflect different cognitive processes. All three groups revealed similarly low scores for abstract representations, which must be drawn from similarities between the two stories. Future research should attempt to discern whether the children's difficulty focused on finding the similarities or in articulating those similarities (see Anolli et al., 2001). Providing three or four rather than two stories (see Gick & Holyoak, 1983), or providing hints such as sentence starters, may help participants better formulate their answers. Also, more directive or leading questions toward the stories' similarities could have resulted in better performance on the representation task. Yet Spencer and Weisberg (1986) found that multiple source stories did not enhance their participants' cross-context transfer. Thus, we are not certain that facilitation will arise from story multiplicity or from a concerted focus on abstract reasoning (Anolli et al., 2001).

We should mention here that despite overall low success rates for all groups, the group of children with NLD showed the largest gap between children who could generate an abstract representation and those who could not. This finding calls for further study concerning a possibly severer deficit in abstraction in this group compared with the two others. Indeed, further investigation may explain why all three of our study groups did not succeed as well as we predicted in the abstract-reasoning task, but more important than our research design are the practical pedagogical implications of this study.

Both Gick (1986) and Robertson (2001) contended that analogical problem solving can be learned and can be transferred to later tasks, particularly academic ones. Thus, based on the current outcomes showing difficulties in analogical problem, specifically in the NLD group, training and intervention should be a viable course of action, especially for this subgroup. If intervention and remediation can facilitate acquisition of the cognitive skills needed for problem solving in learners without disabilities, an even stronger case can be made for facilitation and focused activities when teaching children with LD. Goswami and Brown (1989, 1990) pointed out the potential of analogical problem solving in young children and suggested that explicit instruction and intervention should be initiated at an early age for children with LD. Children with LD, particularly of the nonverbal subtype, usually respond to direct instruction and guided practice (Foss, 1991). Furthermore, teaching cognitive strategies to children, especially to children with LD, yields a higher transfer (Clark & Voogle, 1985). Because of the benefits of problem solving and, particularly, analogical problem solving as an effective means for thinking and for developing thinking skills, children with LD may enjoy long-term and transfer benefits from directive instruction and strategy training in problem solving, especially analogical problem solving.

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