Enhancing the Induction Skill of Deaf and Hard-of-Hearing Children with Virtual Reality Technology

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Many researchers have found that for reasoning and reaching a reasoned conclusion, particularly when the process of induction is required, deaf and hard-of-hearing children have unusual difficulty. The purpose of this study was to investigate whether the practice of rotating virtual reality (VR) three-dimensional (3D) objects will have a positive effect on the ability of deaf and hard-of-hearing children to use inductive processes when dealing with shapes. Three groups were involved in the study: (1) experimental group, which included 21 deaf and hard-of-hearing children, who played a VR 3D game; (2) control group I, which included 23 deaf and hard-of-hearing children, who played a similar two-dimensional (2D) game (not VR game); and (3) control group II of 16 hearing children for whom no intervention was introduced. The results clearly indicate that practicing with VR 3D spatial rotations significantly improved inductive thinking used by the experimental group for shapes as compared with the first control group, who did not significantly improve their performance. Also, prior to the VR 3D experience, the deaf and hard-of-hearing children attained lower scores in inductive abilities than the children with normal hearing, (control group II). The results for the experimental group, after the VR 3D experience, improved to the extent that there was no noticeable difference between them and the children with normal hearing.

How much do the deficiencies of the auditory sense in the deaf and hard of hearing affect their cognitive and intellectual skills? Different theories have attempted to delineate the cognitive development and functioning of the deaf and hard of hearing. Martin and Jonas (1991) and Zwiebel (1991), for example, reported that normal hearing subjects and deaf and hard-of-hearing subjects do not differ significantly in their cognitive functioning, although the levels of development vary between different age groups. This is true when a language stimulus presented is within the language experience of the deaf and hard-of-hearing children and when they have appropriate opportunities to experience it. As Piaget (1964) has said, the delayed emergence of some cognitive abilities in deaf children is due to their lack of experience and their language difficulties, not to their cognitive functioning level.

Many researchers (e.g., Friedman, 1985; Hilleyeist & Epstein, 1991; Rittenhouse, Morreau, & Iran-Nejad, 1981) have suggested that educators should be concerned about *abstract thinking* of deaf and hard-of-hearing children. Myklebust (1964) claimed that deaf children have lower levels of abstract thinking qualities than do normal hearing children due to difficulties with inductive and deductive processes. Friedman (1985) examined sorting skills among normal hearing and deaf and hard-of-hearing children at kindergarten age. The sorting tasks varied in required level of abstraction and of language knowledge. At the cognitive task level (sorting by shape and color) and at the basic abstraction level (e.g., the grouping together of different dogs or of different chairs), no significant differences were found between the normal hearing children and the deaf and hard of hearing. At the higher levels of abstraction (groupings of animals and furniture), however, the performances of the deaf and hard-of-hearing children

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were worse than those of the normally hearing children. Finally, Hillyeist and Epstein (1991) reported that most of their deaf and hard-of-hearing subjects found it difficult to solve abstract mathematical exercises due to a difficulty in abstract thinking.

The current research deals with *inductive processes* among deaf and hard-of-hearing children. Trochim (1996) defined the inductive method as "bottom up"—a process that goes through the stages of making specific observations, creating testable hypotheses that lead to generalization, and creating generalized conclusions. Glanz (1989) reports on "induction of laws," a process in which induction leads to the inference of common rules that dictate the order of components within a given system. It is possible to identify the rule by formulating it verbally, by adding components to the system continuously, or both-formulating and adding components. This research, based on Glanz's definition of induction, examines the ability of deaf and hard-of-hearing children in the induction of structures of shapes. Here, a series of shapes is provided and the child's goal is to suggest the next shape in the series after inferring the given law.

Researchers (e.g., Hilleyeist & Epstein, 1991) have found that arriving at a reasoned conclusion is a process in which deaf and hard-of-hearing children have some difficulties. Such "conclusive thinking" can be of three kinds: (1) induction: reasoning from specific observations toward a broader generalized conclusion, (2) deduction: reasoning from a generalization toward specific instances, and (3) using analogy: as A is to B, so is the relationship of C to D. Millar (1989), for example, claimed that learning sciences requires the use of conclusions based upon inductive thinking, and, therefore, the power of imagination is required for scientific thinking. Daniels (1984) and others have also linked perceptual imaging to the process of inductive thought.

Although it may seem that deaf and hard-of-hearing persons are similar to normal hearing people in the structure of their thoughts and in their cognitive capabilities, auditory and language deficiencies may lead to lower verbal functioning and an overall lack of appropriate experience. The consequences can be difficulties in conclusive thinking and in reaching reasoned conclusions using inductive processing (Friedman, 1985; Hilleyeist & Epstein, 1991).

This research examined the influence among deaf and hard-of-hearing children of practicing with spatial rotation, using virtual reality (VR) equipment in an inductive processing paradigm, leading to reasoned conclusions about the expected next structure in the presentation of a series of structures. This study suggests a connection between virtual rotation and development of inductive thinking with regard to structure. The process that one uses for visually imaging an object mentally by rotation ("mental imaging") is important for thinking, memory, spatial visual capabilities, performing transformations, and creative problem solving (Kaufmann, 1985; Kosslyn, 1980; Shepard & Metzler, 1971). Imaging may be a linking factor between induction of relations among objects and the perceptual rotation of these objects from various positions in space. To our best knowledge, no literature directly links the effects of rotation and the success of induction.

Until now, only one work dealt with the link between spatial rotation and VR technology. This research examined normal hearing children. Merickel (1994) assumed that children's cognitive abilities could be enhanced by having them develop, displace, transform, and interact with 2D and 3D computer-generated models. He examined the cognitive factors related to the capabilities of 23 children ages 8–11 to solve spatial problems at computerized workstations or VR. Results of the project showed that spatially related problem-solving abilities of children are influenced by training in visualization and mental manipulation of 2D figures and displacement (by rotation) and transformation (by mirroring) of mental images of 3D objects. That is, a connection was found between the capability of children to perform spatial tasks in a VR environment and the cognitive skills of creation, operation, and exploitation of mental imaging. The conclusion was that the technology known as virtual reality is highly promising and deserves extensive development as an instructional and training tool for cognitive skills.

The current research extended those findings and hypothesized that practicing spatial rotations with 3D VR games will improve the induction of structure by deaf and hard-of-hearing children. The nature of VR, we suggested, allows the user to become an active part of the environment. Also, VR's ability to convert the abstract into the concrete, by providing perspectives on processes that are impossible in the 2D (Pantelidis, 1995), offers an advantage for inducing the continuing series of shapes in a structural paradigm. We propose that positive transfer will occur from 3D VR rotation practice to structural induction skills, by means of mental imaging.

In recent years, there has been active intervention in the cognitive capabilities of deaf children to improve their intellectual functioning. Many believe that deaf children have the same intellectual potential as normal hearing children. They may fulfill this potential if the environment, the instructions, and the available materials are adequate and motivate learning. Moreover, researchers emphasize the importance of the intervention programs (Gruler & Richard, 1990; Huberty & Koller, 1984; Martin, 1991). These researchers and others have shown that it is possible to improve thinking and inductive processes through adequate exercises and training.

The uniqueness of our research is its exploitation of the innovative and attractive technology of VR to improve structural inductive processes of deaf and hard-of-hearing children. Our research used a virtual game that exercises, among other things, the ability to make three-dimensional spatial rotations. Such spatial rotation is defined as a cognitive activity, applied when imaging a situation as seen through the eyes of another person viewing it from a different location (Piaget, 1971). Many researchers (Dwyer, 1983; Emmorey, Kosslyn, & Bellugi, 1993; Talbot & Haude, 1993) have examined the aptitude for spatial rotation among deaf and hard-of-hearing children. These studies and others examined the link between the children's knowledge and experience in sign language and their skill in the rotation tests. Rotation is an activity used in sign language-the deliverer of the message marks his or her signs from his or her direction and the scene is therefore fully presented from that point of view. The receiver of the message, on the other hand, standing opposite to him or her must make a mental "switch" so that he or she can image and understand it. A listener receiving an oral message does not face a similar problem, regardless of spatial position relative to the speaker (Emmorey, 1993). Based on these points, researchers assumed that deaf or hard-of-hearing persons who communicate using sign language will do better in rotation tests than others.

Talbot and Haude (1993), for example, tested three different groups based on their experience in sign language. A group of normal hearing subjects who do not use sign language, a group of normal hearing subjects that have some experience ($M = 0.8$ years) in sign language, and a combined group of hearing and nonhearing subjects that have an average of 6.1 years of experience in sign language. They found that experience in sign language was related to success in the rotation tests. The more experienced the subjects are in sign language, the higher the result achieved in the rotation tests. Parasnis, Samar, Bettger, and Sathe (1996), Dwyer (1983), and others found similar results. Dwyer compared 60 hearing children to 60 deaf children, all 6–10 years old and reported that deaf signers have a higher rate of success in rotation tasks. Parasnis et al. compared 12 deaf children not exposed to sign language with 12 matched hearing controls. They found that the groups did not differ in their performance on the visual spatial skill tests used in that research. We conclude, therefore, that level of success is a factor of the amount of experience in sign language but not of hearing loss.

One of the most important objectives, when educating deaf and hard-of-hearing children, is to give them good thinking tools for facing independent life, and one of the most simulative, innovative, and attractive tools for enhancing thinking available today is VR technology. Pantelidis (1995) defines VR as a multimedia interactive environment that is computer-based and allows the user to assimilate and become an active partner in the virtual world. This technology is able to present information in three-dimensional formats in real time. It allows the user to become an active part of the environment and to benefit from interactive communication without using words. VR is able to convert the abstract into concrete by giving perspectives on processes that are impossible in the real world (Darrow, 1995; Durlach & Mavor, 1995; Osberg, 1995; Pantelidis, 1995).

The hypothesis of this study was that prior to practicing spatial rotations, a distinct difference will distinguish the deaf and hard-of-hearing children and normal hearing children in their inductive thinking about

Table 1 Mean grade level, hearing loss level, and gender

		Grade		Hearing loss (dB)		Gender	
Group	*n*	*M*	*SD*	*M*	*SD*	Boys	Girls
Experimental	21	3.00	.84	89.29	21.33	9	12
Control 1	23	3.60	1.35	87.95	18.30	12	11
Control 2	16	3.83	.83	—	—	8	8
Total	60	3.42		88.62		29	31

structure. This assumption was based on the various studies that claimed that deaf children have difficulty in inductive processes and that this type of thinking can be improved by practice (Friedman, 1985; Hilleyeist & Epstein, 1991). We expected that , after their practice with VR, the scores of the deaf and hard-of-hearing children (experimental group) on tasks involving inductive thought related to structure will be similar to the scores of normal hearing children.

Method

Participants

The participants in this study were 44 deaf and hard-of-hearing children ages 8–11 (average age = 9.3). The hearing loss in the better ear of the children ranged from 50 dB to 120 dB with mean loss of 88.62 dB (see Table 1). They had no additional handicaps. The children came from integrated classes in the two schools in the Tel-Aviv district under the supervision of the ministry of education. In these schools the deaf and hard-of-hearing children are taught primarily in small segregated classes, but also participate in general school activities. In some cases, they take some of the classes with normal hearing children of their age. After taking into consideration the children's background data, we placed them in one of two groups—the experimental group and a control group. The two groups were matched for age, gender, degree of hearing loss, cause of deafness, and equivalent prior experience with computer (see Table 1).

We selected an additional group of 16 normal hearing children (children to whom we had easy accessibility), in order to establish whether, in general, hearing impaired children achieve lower results than normal hearing children in inductive skills. The ages of the hearing children ranged between 8–10 (average age = 8:8).

The sample of 60 children, therefore, included the following three groups: 21 deaf and hard-of-hearing children who served as the experimental group, 23 deaf and hard-of-hearing children who served as the control group, and 16 hearing children who served as a second control group.

Procedure

Each participant in the experimental group was given 15 minutes once a week over a period of 3 months to play interactively and unguided a VR 3D Tetris game, involving the rotation of objects in space (a child at this age finds it hard to play a VR game for more than 20 minutes). Children in the deaf and hard-of-hearing control group played with a regular 2D Tetris game involving rotation for the same period of time. The children in the normal hearing control group were given no rotation tasks.

The experimental and control groups were evaluated before and after the experiment using Cattell and Cattell's (1965) subtest of "Structural Sequences" (for a sample, see Figure 1). This was done in order to establish whether practicing rotation exercises with VR has an effect on the structural inductive processing of the participants. The subtest has 12 items; each contains a series of three shapes that differ from each other according to a discernable pattern. The subject has to infer the pattern by induction and choose the missing fourth shape out of five possible choices. For each correct answer, the child receives 1 point. The range of possible scores is from 0 to 12. Cattell and Cattell report a reliability score or over .80 with groups of students.

Instructions to the test were given orally in conjunction with sign language, to ensure that all children fully understood the requirements. The normal hearing children took the test only once.

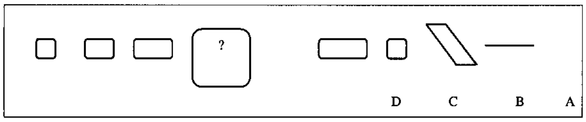

Figure 1 A sample of Cattell & Cattell's (1965) subtest of Structural Sequences.

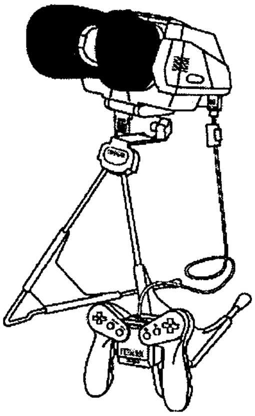

Figure 2 Virtual Boy-Nintendo 1995.

The VR hardware (Figure 2) used in this research was a virtual reality interactive game, with a unique system able to create a dramatic three-dimensional world. The VR program (Figure 3) included three similar games (Tetris, Puzzle, Center-Fill), with the objective, in all three, to fill a large 3D cube with small blocks of different shapes. The child had to place dropping blocks into the right spaces. In order to accumulate a high score, the child had to act both accurately and quickly.

The optimal solution was reached by a combination of selecting the most appropriate shapes and rotating them as required. The participant had to complete the blank locations on the "board" according to an induced rule that he or she had inferred and fit the appropriate shape in the blank locations. Control group 1 practiced using a "routine" Tetris-style 2D game (not VR game).

Results

The rationale of this study assumed that prior to practicing with spatial rotations, a distinct difference would be found between deaf and hard-of-hearing children and normal hearing children in their inductive thinking of spatial structure. After their practice in the VR mode, we expected that the experimental group would improve to the point where no distinct difference would exist between them and the group of normal hearing children. The grades of the deaf and hard-of-hearing children in the experimental group would be similar to the grades of the normal hearing children. To test this hypothesis, we conducted a one-way analysis of variance (ANOVA) for the Index of Structural Induction (ISI) in a before and after paradigm.

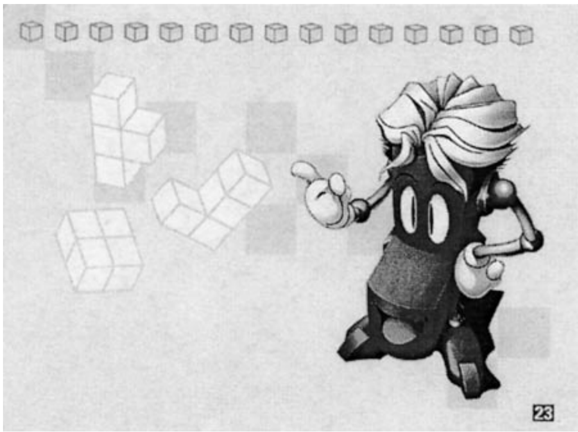

Figure 3 3D virtual reality rotation.

Table 2 exhibits the ISI scores for the three groups—the experimental group, the control group of the deaf and hard of hearing, and, finally, the control group of the normal hearing. In addition, the table exhibits the results of the ANOVA. Figure 4 graphically presents the results before the intervention, and Figure 5 presents the results after the intervention.

Observing the data in Table 2 and Figures 4 and 5, we can see that before practicing, no significant difference was found between the two groups of deaf and hard-of-hearing children (experimental and control). However, a significant difference in ISI appeared between the hearing children and both the experimental and control groups of deaf and hard-of-hearing children. After intervention, however, there was no difference between the experimental group and the hearing children. Significant differences were found in structural inductive thinking between the two control groups (deaf and hearing) and between the experimental group and the two control groups (see Table 2). After intervention, the scores achieved by the experi-

Table 2 ISI by group and time

Time	(1) Experimental HI	(2) Control HI	(3) Control hearing[a]	*F* scores	Contrasts significance
Before					
M	5.23	5.13	10.93	$F(2, 57) = 62.48$ $p < .001$	p (1,2) = ns p (1,3) < .001 p (2,3) < .001
SD	2.04	2.00	0.57		
n	21	23	16		
After					
M	11.00	5.65	10.93	$F(2, 57) = 102.04$ $p < .001$	p (1,2) < .001 p (1,3) = ns p (2,3) < .001
SD	0.77	2.08	0.57		
t	−16.1	−2.02	—		
n	21	23	16		

HI = Hearing-impaired.

[a] The normal control hearing group was tested only once. The results were entered for comparison with the "before" and "after" experimental results.

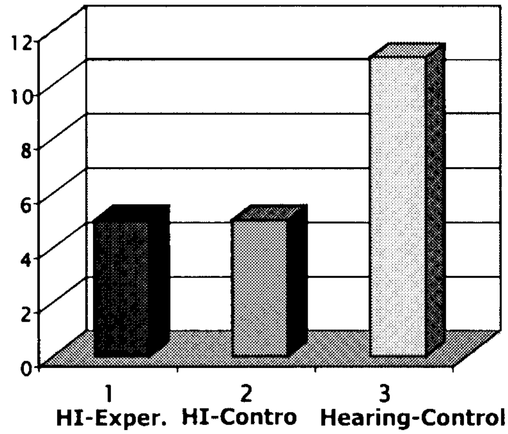

Figure 4 Structural inductive averages by group before intervention.

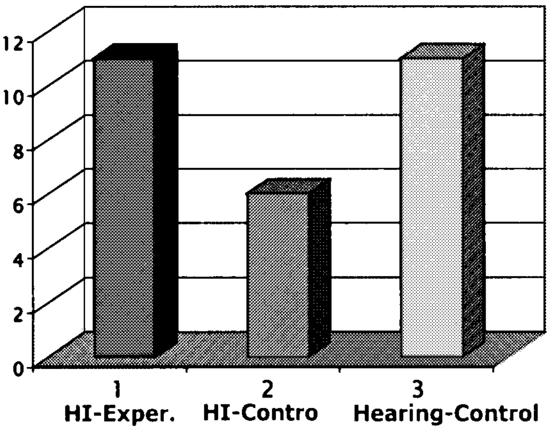

Figure 5 Structural inductive averages by group after intervention.

mental group of deaf and hard-of-hearing children reached the same level as those of normally hearing children, whereas the scores of the deaf and hard-of-hearing control group remained low.

In summary, there were three major differences in performance between the three groups. First, the hearing control group demonstrated higher performance than the deaf and hard-of-hearing children, prior to the intervention program. Second, after the intervention, the deaf and hard-of-hearing experimental group demonstrated greater performance than the deaf and hard-of-hearing control group 1. Third, the deaf and hard-of-hearing experimental group reached the same level as the hearing control group 2.

Discussion

One of the objectives when educating deaf and hard-of-hearing persons is to emphasize with them the importance of nurturing independent thinking. One question to be asked is how can educators do so in a manner that will encourage and motivate young children to be involved in an intervention program designed to improve their cognitive achievements.

This research focused on a specific field of thinking-structural induction (ISI). The underlying assumption of the research was that, while deaf and hard-of-hearing children have difficulty in inductive processing, this type of thinking can be improved. The assumption was based on various studies that had found that, although the deaf resembled the normal hearing children in most thinking-related tasks, auditory and language deficiencies lead to lower verbal functioning and to less satisfactory results in tasks requiring inductive thinking (Friedman, 1985; Hilleyeist & Epstein, 1991).

Researchers have found that the functioning of the deaf improved following adequate learning, practicing, and training (Gruler & Richard, 1990, Martin, 1991). Many of the current intervention programs do not exploit the vast possibilities available with today's technology, especially the innovative and attractive technology of VR. The uniqueness of this project is the use it makes of a virtual game that provides practice with spatial rotation, as a method for improving structural inductive processes with deaf and hard-of-hearing children. As such, it is one of the first attempts to use VR technology to improve the cognitive skills of deaf population.

The results of this study point to a distinct difference in structural induction ability between deaf or hard-of-hearing and normal hearing children before practicing, favoring the normal hearing subjects. This finding reflects other studies that have found, similarly, that deaf and hard-of-hearing children have difficulties in the inductive processes and need assistance in this skill (Friedman, 1985; Hilleyeist & Epstein, 1991). The improvement of the structural inductive skills of the experimental group while exploiting a VR 3D game was such that no distinct difference remained between them and the normal hearing control group after the intervention. The deaf and hard-of-hearing control group, however, who had no VR training, still maintained low scores. The gap between them and the normal hearing group remained the same even after the 2D practice.

These findings show a clear priority for the VR 3D intervention over a 2D "routine" one. We may assume that these findings occurred due to the differences between the two types of exercises. Although the children in both groups played the Tetris game for similar lengths of time, the only difference between them—the 3D virtual reality game versus the 2D one—seems to have made all the difference.

A reasonable way to explain these results is through the essence of VR technology. VR technology creates a "presymbolic" communication in which the users can communicate with imaginary worlds with no use of words. This creates a world charged with sights, voices, and feelings distinct from language and syntax (Passig, 1996). The deaf and hard-of-hearing children who used this technology were able to bring out their potential with no language or auditory limitations. VR does not limit the designer in the manner in which the information is presented, or limit his movements, so the user of the technology is able to immerse within the learning environment (Pantelidis, 1995). This is the method in which the deaf where immersed in the game. They felt as if they themselves where moving the pieces, searching for the right ones, using inductive procedures and rotating them. The abstract became less vague and more concrete. Different researches in the field of VR found that this immersion upgrades the interface with the senses and improves one's understanding of abstract terms by converting them into more concrete ones (Darrow, 1995; Osberg, 1995).

One key attribute of VR is its interactivity—it allows the users to take a very active role. The increased liveliness and interactivity allows the user to become part of a virtual world. This tool is able to present information in 3D form and in real time. It is an elaboration of a reality in which a person can hear, look, touch, and bond with objects and images. This method allows the user to take an active role in the environment and not stay a passive bystander (Bricken & Byrne, 1992; Heim, 1992; Osberg, 1995; Powers & Darrow, 1994). Deaf and hard-of-hearing children require a more active involvement in learning processes than normal hearing children do (Marzam, 1998).

Another way to explain the results is in terms of transfer strategies or tendencies from one field to another in order to explain a certain problem or phenomenon (Tishman & Perkins, 1996). The results of the study point to a transfer from a rotation activity to a structural induction activity. It seems possible to link induction and rotation via mental imaging-induction skills require the use of imaging (Daniels, 1984; Millar, 1989). Also, to perform rotation, one must use imagery. To rotate an object, one needs to imagine first what will be the position of the object after the rotation (Piaget, 1971). It is possible that, due to this link between the variables, a positive transfer occurred.

A different explanation of these results is simply that this tool is a fun and motivating one. Various studies have pointed out that children using VR enjoy using it and want to learn more by using it (Bricken & Byrne, 1992; Talkmitt, 1996). The high levels of motivation of the participants resulted in their persistence with the program and their eventual success.

In summary, the results indicate that the achievements of the deaf and hard of hearing participants in the structural inductive processes using a 3D VR game has improved. Beyond this contribution, which is important in itself, the most important contribution of this research was the enhancement of this aspect of thinking so that deaf and hard-of-hearing children reached the levels of normal hearing ones. Further work in this area is warranted.

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