

# Enhancing time-connectives with 3D Immersive Virtual Reality (IVR)

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# Enhancing time-connectives with 3D Immersive Virtual Reality (IVR)

## **Abstract**

This study sought to test the most efficient representation mode with which children with hearing impairment could express a story while producing connectives indicating relations of time and of cause and effect. Using Bruner's (1973, 1986, 1990) representation stages, we tested the comparative effectiveness of VR (Virtual Reality) as a mode of representation on children's production of time-connectives with four other modes of representation: pictorial, oral, signed, and textual. 134 participants aged 4-10, 69 children with hearing impairment and 65 hearing children, divided into two age groups, pre-school and elementary school children, took part in this study. The study examined their ability to express time and cause-connectives, using the different modes of representation.

The findings demonstrate substantial differences in producing time-connectives with the various modes of representation. The leading mode of representation is 3D IVR amongst the hearing children, and signed representation and 3D IVR amongst the children with hearing impairment.

Key words: Immersive Virtual Reality, hearing impairment, representation modalities, time connectives.

## **Introduction**

### *Narrative*

Telling a story is a complex task requiring mastery of linguistic means that could connect units of text and the ability to reflect the order of events and arrange them chronologically. The skill of story discourse starts to develop around the age of two to three and improves with time, where five y/o is considered to mark the developmental boundary – the point beyond which children begin to string together events that are either temporally or causally linked. Pre-schoolers can represent events, but their use

of language to represent them is inadequate. The more limited the language, the more they will use gestures and deixis indicating spatial organization without reference to sequencing. They do not anchor their story in a consistent point of time, but rather mix past and present unsystematically. In contrast, at the age of five or six, children can already construct a story plot drawn from pictures they are shown, while most of the stories they construct show clear signs of temporal organization. The level of language competency and the level of perception of the organization of the narrative make it possible to link the events according to sequence and this is expressed in the consistent use of grammatical tense. Consistent use of a verb tense gives the story uniformity of the time of occurrence, as does the use of time connectives (Berman, 1996; Berman & Slobin, 1994; Karmiloff-Smith, 1979). The organization of the text requires the acknowledge location, time and cause between events and situations.

The current study focused on temporal sequence and time and cause connectives within a story narrative in order to examine whether the mode of representation has an impact on the expression of time and cause connectives among children with hearing impairment and hearing children.

Children with hearing impairment acquire typical story structure according to the same basic development as hearing children, and their stories contain the universal elements of a narrative. However, they have noticeable difficulty in producing an organized narrative. They tell short, incomplete stories that are less organized than those of hearing children. In most cases, their stories are very simple and unsophisticated (Becker, Bürgerhoff, & Kaul, 2006; Pakulski & Kaderavek, 2001; Paul, 1998; Walker, Munro, & Rickards, 1998). Yoshinaga-Itano (1986) notes that the narrative of children with hearing impairment usually lacks a core. There is little description, if any, of the characters and the surroundings, and the connecting events are mostly omitted or excluded. In addition to the difficulties that children display in these essential elements, the hero of the story is not clear and the actions, results and reactions of the characters are poorly developed. Klecan-Aker & Blondeau (1990) examined the ability to tell a written story among children with severely hearing impairment aged 10-18 and found that they used fewer words and sentences than their hearing peers. Ravid, Most, & Cohen (2001), examined how children with hearing

impairment aged 6-7 tell a story based on a series of pictures and a scenario in comparison with hearing peers. All the children were studying in regular educational settings with individual integration, and communicated only orally. Significant differences between the groups were found in terms of the linguistic structures of the narratives and scenarios and slight differences in terms of coherence, with the hearing children performing better than the hearing impaired in these areas. There were also more significant differences in the production of narrative than in the production of scenarios, a finding which indicates a difference in the degree of difficulty in the production of these two kinds of discourse.

#### *Time and cause-connectives*

The ability to tell a story is quite complex and requires the narrator to have mastery of at least three kinds of knowledge: linguistic, textual and narrative. This study addressed the narrative knowledge – including knowledge about the semantic relationships between the sentences in the story and about the language forms that signal those relationships, with particular focus on time and cause connectives (*after, at first, because* etc.). Time appears in almost every sentence, and so there are many connectives relating to time. In comparison with other categories of connectives, the time connectives are less interchangeable, and consequently, one must know the exact meaning and usage of each one (Berent, 2003).

In English there are many time-connectives such as: after, as, as soon as, before, by the time, once, since, until, when, whenever, while, finally, first, second, in the end, later. In many sentences one can change the order of the elements of the sentence without changing its meaning. For example, the sentence “The taxi left before you came out.” means the same as “After the taxi left you came out.” Or “By the time you came out, the taxi had already left.” It is important to note that many children with hearing impairment have difficulty understanding the parallels in these kinds of sentences, and do not understand which event happened first (Berent, 2003).

Connectives expressing cause and effect are common and relatively limited in number. It is, of course, important to distinguish between the cause and the result. So the list of signal words is divided into two:

Words signifying cause: *as, because, so that, since, etc.*

Words signifying effect: *so, for this reason, hence, in consequence, therefore, thus, due to, etc.*

Cognitive development also underlies the ability to relate to cause connectives and it expands at the end of the pre-school period, and mainly in the early years of school. For five to six year olds, cause connectives are few and relate mainly to their immediate surroundings such as: “The child fell down because the owl pushed him over,” while among seven to eight year olds, one starts seeing psychological cause connectives referring to the motivation for an action such as: “He wanted to climb onto the rock in order to catch him.” The older they get, their ability to use cause connectors to motivate the entire plot rises, as they determine the goal pushing the characters to plan and perform a series of actions on which the whole story is based (Shen & Berman, 1997).

Because of the language gaps, children with hearing impairment utter few connectives, including those of time and cause. Aldersley (2003) notes this difficulty and suggests a number of reasons. First, children have to understand the differences between logical relationships in conceptual meaning. Similarly, they must understand the general meaning of each connective. In addition, they must understand the syntax that constrains the use of each kind of connective. Finally, they must understand the nuances of the prevalent meanings and usage of a certain connective as opposed to another one within a specific semantic field.

### *Representation modalities*

As far as the literature goes, studies that examined children’s expression of time and cause connectives in storytelling mostly used pictures describing the events of a story along a time continuum. The current study sought to examine the effectiveness of other modes of representation.

Bruner (1973, 1986, 1990) enumerates three representational systems which serve as important means of mediation between the child’s knowledge of the world and the linguistic representation of this knowledge, which appear to the child along a developmental continuum:

*The system of enactive representation* – In their first years, children represent objects by means of immediate sensory perception, while involving motor or other responses in taking control of the environment (e.g., riding a bicycle or tying a knot). This system reflects the child's experience and method of investigating an event while actually carrying out the activity, or making a close simulation thereof.

*The system of iconic representation* – This system demands the use of mental representations, which represent certain objects or events, and is based on frontal images such as pictures, models, or sketches. This system is important for acquiring the ability to distance oneself from enactive representation and to move closer to symbolic representation.

*The system of symbolic representation* – This system uses symbols as information codes, and allows for the arbitrary representation of reality via written or spoken language.

The current study sought to discover the most effective representation mode with which children with hearing impairment and hearing children could express time connectives. This study also compared 3D representation with four commonly used representation modes—pictorial, textual, signed, and spoken, in order to seek the most effective representation mode for expressing time connectives.

## **Participants**

134 participants took part in this study, 69 children with hearing impairment and 65 hearing children. The age of the participants ranged from four to ten years old—pre-school and elementary school children (Table 1). All participants in the study were defined as cognitively normative.

Table 1: Distribution of participants according to gender and age

		Hearing children ( <i>N</i> =65)		Children with hearing impairment ( <i>N</i> =69)		Total	
		<i>N</i>	%	<i>N</i>	%	<i>N</i>	%
Gender	Boys	37	56.9	36	52.2	73	54.5
	Girls	28	43.1	33	47.8	61	45.5
Educational setting	Preschool	42	64.6	42	60.9	84	
	School	23	35.4	27	39.1	62	

### Research tools

Six research tools were used in the current study to examine the most effective mode of representation in better producing time-connectives: Mandler & Johnson's Story Grammar (1977), pictorial representations, written representations, aural representations, signed representations and Immersive 3D VR.

#### *Mandler & Johnson's Story Grammar*

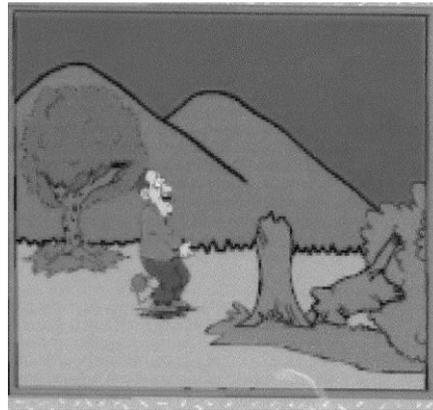
This index relates to six sub-scales and this study used section six which measure the types of connectives between episodes. According to this subscale, a general score is given for the plot according to the following key: zero for a plot consisting of episodes with no connection between them. One point for a plot with semantic links between the episodes (simple connectives: *then and, later*). Two points for a plot with causal connectives between the episodes (cause and effect). The validity of this subscale as measured by the level of inter-rater consensus was .92.

#### *Pictorial representation*

Six scenarios were chosen with temporal sequence and a cause and effect relationship. Three scenarios were defined as easy that included a known and easy to understand occurrence with four pictures, and the other three scenarios were defined as sophisticate that included a less known occurrence with four-five pictures. The extent of the complexity was determined by the expected cognitive knowledge at

kindergarten and school age, and was tested in a pilot study. It was confirmed that each child knew the particular elements used in each script. This study was organized according to Script Theory, developed by Schank & Abelson (1977). It included six scripts adapted to the different modes of representation, creating a total of 30 scripts. They were presented to the children in colorful cartoon drawings, four to five pictures for each scenario. For a sample, see illustration 1.

Illustration 1. Pictorial representation- Uprooting a tree



*Written representation*

A written version was developed for the pictorial scenarios. One or two lines were written for each picture, giving a brief description of what is shown in the picture. For example, the process of uprooting a tree "A man is standing near a tall tree", "The man is chopping the tree with an axe", "A man is standing near a falling tree" etc. We did not make use of any time-related or cause and effect words (connectives) which might hint at temporal sequence or causality, such as *before*, *after*, *then*, etc.

*Aural representation*

The written text was read to the children aloud as clear as possible.

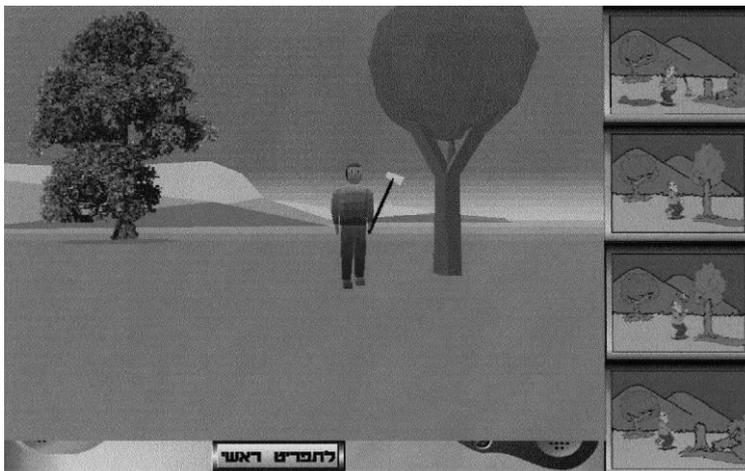
*Signed representation*

The text was translated by a sign language translator into signed language. The text was then signed on video for the participants to watch.

*Immersive 3D VR with Head Mounted Display*

The scenarios which were drawn in pictures were processed into three-dimensional and immersive simulations. The virtual representations were both visual and auditory. Illustration shows a sample screen from the virtual worlds.

Illustration 2. Virtual representation- Felling a tree



The initial three representation-modes (pictorial, written, auditory/signed) were chosen because they were the most commonly used in the educational system, as well as in IQ tests—especially the pictorial representation (Such as the Kaufman Assessment Battery for Children K-ABC, 1983; Wechsler WISC-R Intelligence Scale for Children, 1974).

### **Procedure**

The hearing participants and the participants with hearing impairment were divided into two age groups: kindergarten and elementary school-age children. We examined their ability to tell a story using the different modes of representation, in particular the production of time-connectives, after arranging episodes of a scenario in which a temporal order exists. Each participant received four scrambled episodes of a single scenario and was tested with three-five modes of representation (written mode was given only to elementary school-age children, signed mode was given only to children with hearing impairment). The participants arranged the episodes of the scenario, and then were asked to tell the story according to the time sequence they had created. For example, the baking a cake scenario was divided into four different episodes: the first

episode showed the need to put the materials into a bowl. The second showed the need to flatten the dough, then, the need to put the cake in the oven, and finally the outcome should be a baked cake. This scenario has an unchangeable temporal order.

As mentioned above, this study was organized according to Script Theory, developed by Schank & Abelson (1977). The ability to produce time connectives was measured by the number of time connectives used in the story.

In order to avoid the familiarity with the story lines in the different modes of representations, the children received different scripts for each mode of representation. The scripts were validated by experts and were found to have a similar level of difficulty.

The experts' validation was conducted in two steps. In the first phase, 20 hearing children with no language or cognitive difficulties participated. The tested children were between 12-14 y/o. They were much older than the research participants that were 4-10 y/o, in order to insure that the level of difficulty in arranging the pictures referred to the temporal ability and not to any other difficulty. On the second phase, ten additional adults participated in the validation process. The participants were asked to arrange the pictures of the scenario that were put in front of them in a random order. Since there was a chance that the participant would arrange the pictures in the correct order just by chance, we presented to each participant a blank picture and asked: "What would happen now? Or what would be the next picture." Thus, the participant was asked to predict the next episode in the story. All the participants succeeded in the first 6 scenarios. Since there was no agreement on the seventh we had omitted it from the research.

The scripts were then distributed among the research children randomly. The scripts that we have developed in VR had the same number of clues as the story lines in the other modes of representation. The only difference was the three-dimensionality and obviously the immersive and interactive aspects that characterize 3D IVR.

Each participant was tested in all modes of representations. The scripts and the order of modes of representations were different for each participant. For example, a child was tested with script A with pictorial representation, then with script C with written representation, following with script B with 3D representation and finally script D

with aural representation. Another child was tested with script C with 3D representation, then with script A with aural representation and so forth. This way we avoided the issue of familiarity with the story lines in the different modes of representation and the effect of the research tool was neutralized.

### Virtual worlds

The main screen consisted of an entry into six virtual worlds – three for the younger group, and three for the older group. An entry screen for each virtual world was developed. On each entry screen there was a picture which stood for a scenario, as well as the title of the story. On the right pane of the VR world, separate pictures appeared, each one representing a scene from the scenario (Illustration 1).

The pictures were not arranged in logical order. If placed in the proper sequence, they created a story which had temporal sequence. Clicking on a picture took the user into the virtual world of a specific scene. The user could then manipulate by clicking on few the objects of the scene in an immersive 3D audio-visual environment. The manipulation was unique since the immersion in the 3D virtual worlds demanded a very active role. For example, in the baking episode, the participants could break the eggs, spill or pour the milk, etc. The multiple possibilities of manipulation within a scenario are a unique feature of VR and therefore are considered to be highly interactive.

Illustration 1. One of the episodes in a virtual world depicting the process of uprooting a tree.



In order to test the child's narrative ability and expression of time-connectives, we developed a screen on which the participant could arrange the episodes of the scenario in sequence and then tell the story created.

In order to test the child's ability to arrange the pictures in the proper order, we developed a screen for arranging a scenario (Illustration 2). It was made up of four to five green squares. On each square there was a number, and small red circles for the visual identification of numbers for children who were not yet able to identify digits. Four pictures belonging to the scenario appeared on the bottom of the screen. The child had to drag the pictures with the mouse, and arrange them according to the correct time sequence onto the green squares. The participant was then asked to tell the story that s/he had created. On finishing, the child would press the red operating key (Illustration 3), and would then watch the movie s/he had created, according to the temporal order s/he had dictated.

Illustration 2. One of the screens for arranging a scenario.

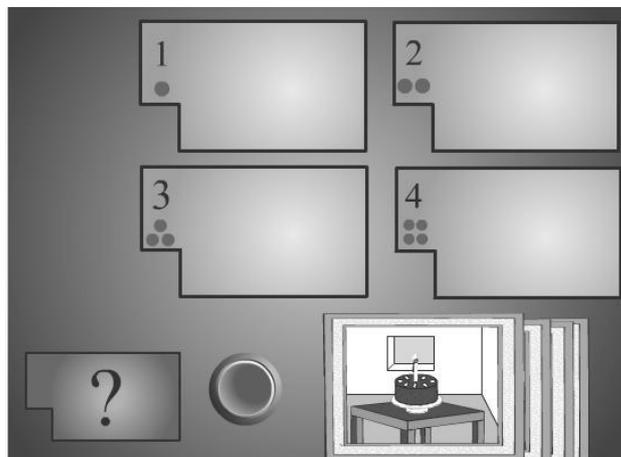


Illustration 3: A participant in a virtual world



## Results

This study was designed to compare and test the effectiveness of a 3D immersive virtual representation mode with other 2D and audio-visual representation modes—pictorial, aural, signed, and written. The study was designed to discover the most effective mode of representation for children to express time-connectives.

To test the differences between the hearing children and children with hearing impairment in expressing time-connectives when describing the stories presented to them through different modes, the frequency scores were calculated for the appearance of connectives in the transcribed scenario expressed by the children. The scores were calculated according to the number of times the connectives appeared based on the *Story-Grammar's index* developed by Mandler & Johnson (1977).

### *Pictorial, aural and virtual representation*

Pre-school and elementary school hearing children and children with hearing impairment were tested for the following three representation modalities – pictorial, aural and 3D virtual reality. A 2 X 2 Manova analysis (groups X educational setting) showed a significant difference between the group of hearing children and children with hearing impairment,  $F(3,120)= 45.06, p<.001$ . The averages and standard deviation of both research groups and the results of the differences analyses conducted to compare between them separately for each mode are presented in table 3.

Table 3. Averages and standard deviations of temporal and causal connectives among hearing children as opposed to hearing impaired children according to modality (pictorial, spoken, and 3D virtual).

Representation indices	Hearing children (N=65)		Children with hearing impairment (N=69)		F (1, 122)
	M	SD	M	SD	
Pictorial	6.08	2.53	1.75	1.39	124.16 ***
Spoken	5.02	2.58	1.80	1.52	61.39 ***
3D virtual	6.14	2.12	3.08	2.10	55.28 ***

\*\*\* p<.001

For the differences analyses conducted on each index separately, there were significant differences in the number of time and cause connectives between the groups in all three representation modes (pictorial, aural and virtual), while the difference in pictorial representation was greater than for the other two modes, for virtual representation the gap has diminished. According to the averages presented in table 3, we can see that for each of the representation modes, the number of time and cause connectives among the hearing participants was significantly greater than for the children with hearing impairment group.

A significant difference was also found between pre-schoolers and school children,  $F(3,120)= 3.52, p<.05$ . In table 4 we can see that there were significant differences between the settings for pictorial and oral representation. The averages show that the number of time and cause connectives in the two indices for which there was a significant difference is greater among preschoolers than among the schoolchildren.

Table 4: Averages and standard deviations of time and causal connectives for pictorial, spoken, and 3D virtual representation among pre-schoolers as opposed to elementary school children

Representation indices	Pre-school (N=84)		E-School (N=50)		F (1, 122)
	M	SD	M	SD	
Pictorial	4.38	3.37	3.33	2.10	4.79 *
Spoken	3.85	2.89	2.83	2.14	4.65 *
3D virtual	4.63	2.92	4.71	2.01	.55

p<.05

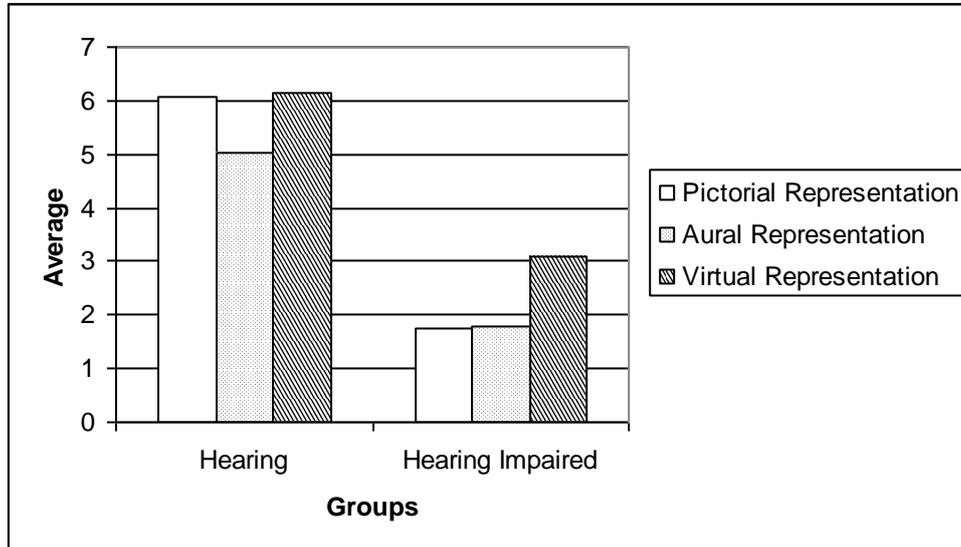
The MANOVA analysis showed significant interaction of groups by educational setting,  $F(3,120)= 7.48$ ,  $p<.001$ . The difference analyses conducted for each separate modality showed significant interaction for pictorial representation,  $F(1,122)= 7.72$ ,  $p<.001$  and for 3D virtual representation,  $F(1,122)= 20.25$ ,  $p<.001$ , but not for oral representation,  $F(1,122)= 3.85$ ,  $p>.05$ .

The gap between the pre-school participants with hearing impairment and hearing participants was greater than between the two groups of school children. This finding was most prominent for 3D virtual representation. Similarly, within the hearing group, the number of time and cause connectives is lower among the school children than for the preschoolers, while within the children with hearing impairment group it was the opposite – the older the children, the more connectives they used.

From these findings, we see that there are differences between the various representation modes and the number of time and cause connectives appearing in the participants' descriptions of the scenarios. And in fact, in a 2 X 2 X 3 difference analysis (groups X setting X modality), there was a significant difference between three modes: pictorial, oral and 3D virtual,  $F(2,244)= 24.52$ ;  $p<.001$ , with the highest number of connectives in the 3D virtual representation  $M= 4.66$ ;  $SD= 2.60$ , followed by pictorial,  $M= 3.98$ ;  $SD= 2.98$  and lastly oral,  $M= 3.46$ ;  $SD= 2.66$ . A comparative pair analysis revealed significant differences for all three modes.

The difference analysis also showed significant interaction of groups X modes,  $F(2,244)= 7.16$ ;  $p<.001$ . Graph 1 presents this interaction.

Graph 1: Average frequency of appearance of time and cause connectives for pictorial, aural and 3D virtual representation for the hearing group vs. the group with hearing impairment



Graph 1 indicates that in the hearing impaired group, the difference between 3D virtual representation, which has the highest number of time and cause connectives, and the two other modes – pictorial and oral – is particularly noticeable. The pair's comparison analysis only revealed a significant difference between the virtual mode and the pictorial and oral ones. In contrast, in the hearing group, it appears that the number of time and cause connectives in virtual and pictorial representation is greater than in oral representation. Indeed, in the pair's comparison analyses, there was a difference between the number of connectives in oral representation and the other two modes.

#### *Textual representation*

In addition to the pictorial, aural and 3D virtual modes, the hearing school children and the children with hearing impairment were also exposed to textual representation. Here too, the number of time and cause connectives was calculated. In order to test for differences between the hearing children and the children with hearing impairment in this modality, a one-way MANOVA analysis was conducted. The analysis revealed

a significant difference between the two research groups,  $F(4,42)= 16.39$ ;  $p<.001$ . The difference analyses were conducted for each index separately. No significant difference in reference to the written representation was found,  $F(1,45)= 3.65$ ;  $p>.05$ . In a 2 X 4 difference analysis (groups X modalities), there was a significant difference between the four modes,  $F(3,135)= 57.55$ ;  $p<.001$ . The highest number of time and cause connectives was found in the 3D virtual representation,  $M=4.68$ ;  $SD=2.07$ , then pictorial,  $M=3.28$ ;  $SD=2.08$ , followed by aural,  $M=2.77$ ;  $SD=2.11$ , and finally textual  $M=1.17$ ;  $SD=2.67$ . In the pairs comparison analyses no significant differences were found in any of the four modalities.

### *Signed representation*

Signed representation was also tested among the group with hearing impairment. A one-way difference analysis was conducted to see if there were differences between the pre-schoolers and the elementary school children. A difference was found between the two settings,  $F(4,54)=6.55$ ;  $p<.001$ . However, in the difference analyses conducted for each index separately, there was no significant difference between the two groups for signed representation,  $F(1,57)= 1.19$ ;  $p>.05$ .

These findings suggest that even though the pictorial mode is the most widely used for perceiving, expressing and examining temporal sequence, we should look for other new ways with which to express and evaluate temporal sequencing, so that children will be able to better fulfill their cognitive and academic potential.

### **Discussion**

In the research literature, one can find that hearing loss affects a number of areas, but the greatest gap between a hearing child and the child with hearing impairment is evident in the area of linguistic competence. Auditory deprivation critically affects the development of language, especially at a young age (Moore, 2001). In this study we examined the expression of time and cause-connectives among hearing children and children with hearing impairment using different representation modes.

We found significant differences between the hearing and hearing-impaired groups with regard to the number of time and cause-connectives for all representation modes,

where for each one, the number of connectives was higher for the hearing group than for the group with hearing impairment. This finding is compatible with the findings of earlier studies on language, which found significant linguistic delays among children with hearing impairment expressed, among other things, in a lack of linguistic sequencing and connectivity. Berent (2003) notes that many children with hearing impairment have difficulty understanding the parallel between clauses in sentences with time-connectives, and do not understand which event occurred first. This is one of the reasons why children with hearing impairment hardly use time-connectives. Another reason is linked to the overall linguistic deprivation of children with hearing impairment. Aldersley (2003) also notes that the children have difficulty understanding the differences between logical relationships in conceptual meaning, the general meaning of each connective, the syntax constraining the use of each connective, and the nuances of meaning governing the choice and use of a particular connective over another for a specific semantic context.

We have found support in earlier studies we have conducted to the other significant finding of this study that the gap between the hearing and the hearing-impaired children diminishes when they use the 3D virtual representation. A similar finding was evident in a cognitive task of perceiving a time sequence among hearing children (Eden & Passig, 2007) and among children with hearing impairment (Eden, 2008).

Using 3D virtual representation in this study too, all the participants managed to express more time and cause-connectives. This result was more prominent among the children with hearing impairment, since with 3D virtual representation the gap between the hearing children and children with hearing impairment diminished significantly. For textual representation, there was no difference between the groups, due probably to the low abilities of all the participant in this study for textual representation. It is possible that some children use time and cause-connectives such as *then* and *afterwards* somewhat mechanically, but since we compared the different representation modes and reached a clear and considerable generalization, this is not significant. This would have equally affected all the modes for that child, and so it would not have affected the results for the different modes.

Among the hearing children, virtual representation came first, followed by pictorial (the opposite for preschoolers), and then aural representation—some way behind, and finally textual representation far behind that. So far, we have not found a study that examined time and cause-connectives using virtual reality, and so we cannot relate to our findings in the context of any existing findings. We can, however, explain and support the findings with reference to the advantages of virtual reality – that is to say, to the sense of immersion, the high level of interactivity and the active learning process.

Some already suggested (Mintz & Nachmias, 1998) that computerized imaging is of very great importance in making a representation of the complex world in which we live. By means of 3D VR, we can study abstract concepts which have hitherto been inaccessible to investigation, and can translate abstract perceptions into much more understandable visual representations. One explanation is linked to the ability of this technology to make the abstract more concrete, thereby making it easier to perceive time. Mintz & Nachmias (1998) showed that a visual environment on a computer screen, which can be altered and controlled by the viewer, is likely to provide children with a tool that will help them act and gain experience intuitively when studying concepts which until now had been considered too abstract and complex. All the more so in VR, various studies in the field have already found that immersion improves the sensory interface, and improves the ability to understand abstract concepts by making them more concrete (Darrow, 1995; Osberg, 1995; Passig & Eden, 2000 a; b). Time is an abstract concept based on representational thinking. A person looking at a series of pictures of an event developing over time is supposed to understand the meaning of each point in time, to fill in the gaps from personal experience, and construct a continuum of events which develops in time. In order to do this, the ability to generate abstractions is essential (Bornens, 1990). The participants were immersed in the 3D scenario and therefore, to a certain extent, felt that they were a part of it. In this way, abstract time became a less foggy and more concrete concept.

Another explanation touches on the interactivity of VR, and on its ability to cause the participants to be especially active. There is a high level of similarity to life and of 3D immersion, which enables the participant to be part of the virtual world. It is a kind of

expansion of reality in which a person can hear, see, touch and communicate with objects and images. This method enables the participant to become an active part of the environment, and not solely a passive observer (Osberg, 1995; Harper, Hedberg, & Wright, 2000; Barab, Hay, Barnett, & Squire, 2001; and many others). It may suggest that children need a more active representation and expression mode in order to attain a higher level of abstraction.

We can say with caution that the high results indicate a positive impact of the technology of virtual reality of the language of children in general, and of children with hearing impairment in particular. Further studies on this topic will no doubt clarify this viewpoint.

It is interesting to note that for pictorial representation, which was customarily used to examine these variables, the gap between hearing and hearing impaired children was greater than for other modes. It is true that the difficulty in pictorial representation can be explained by the fact that the sequence of pictures makes a certain cognitive demand on the children, by requiring them to translate a spatial, static, visual sequence into dynamic, temporal, verbal output (Berman & Slobin, 1994) but there is also a visual sequence in virtual and signed representation, even though it is not static. Furthermore, the difficulty in pictorial representation is also expressed in the testing of the perception of temporal sequence a fact that underscores the need to test representation modes through additional studies.

We expected that with aural representation the children with hearing impairment would express even fewer time and cause connectives, and that the gap between them and the hearing children would be greater. It seems that speech reading had a positive impact nonetheless.

#### *Developmental aspect*

Another important finding of this study relates to the use of time and cause-connectives from the developmental standpoint. In a comparison between the pre-schoolers and the elementary school children, we found that, in general, the number of time and cause-connectives among the hearing group dropped in elementary school's group compared with the pre-school's group, while for the children with hearing

impairment, the reverse phenomenon was observed—the number of connectives rose with age. It is known that narrative is further developing the older a person is (Shen & Berman, 1997). Since for hearing elementary school children the narrative abilities are indeed more developed, this might be the reason why they do not need to make massive use of time and cause-connectives. On the other hand, children with hearing impairment, whose narrative abilities are simpler, still need to rely on time and cause-connectives just as the younger hearing children did.

Another explanation pertains to the educators who work with children with hearing impairment. When they focus on stories in sequence and want to emphasize the time relationships in the different episodes, they have a tendency to stress the time and cause-connectives. Thus, one could speculate that the children absorb and imitate this.

An interesting age-related finding is the large gap between the pre-schooler and the elementary school children with hearing impairment for the 3D virtual representation. We found in this study that the elementary school children with hearing impairment express many more time and cause-connectives in this modality than the pre-schoolers. Since older children find it easier to use virtual reality, we assume that the usage ease and convenience enhanced their expressive abilities. We may assume that the impact of the technology on language is more effective at the elementary school age.

## **Conclusion**

To the best of our knowledge, the literature has no record of other attempts to verify whether expressing time-connectives is dependent on the mode of expression used. Therefore, the results of this study could open a new venue for research in order to better understand the potential and pitfalls of the modes of representation we use in educating our children.

Above all, this study suggests that 3D Immersive VR technology is an important and efficient mode of representation in attaining a higher level of abstraction when compared with other modes.

If indeed further validated in future studies, we believe that these results could turn out to be breaking news for educators. We hope, nonetheless, that this initial evidence

will motivate curriculum planners to introduce VR into the curriculum and help children use their cognitive abilities in a most rewarding way.

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