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Learning With a Missing Sense: What Can We Learn From the Interaction of a Deaf Child With a Turtle?

This case study reports on the progress of Navon, a 13-year-old boy with prelingual deafness, over a 3-month period following exposure to Logo, a computer programming language that visualizes specific programming commands by means of a virtual drawing tool called the Turtle. Despite an almost complete lack of skills in spoken and sign language, Navon made impressive progress in his programming skills, including acquisition of a notable active written vocabulary, which he learned to apply in a purposeful, rule-based manner. His achievements are discussed with reference to commonly held assumptions about the relationship between language and thought, in general, and the prerequisite of proper spoken language skills for the acquisition of reading and writing, in particular. Highlighted are the central principles responsible for Navon's unexpected cognitive and linguistic development, including the way it affected his social relations with peers and teachers.

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The way in which language contributes to thought, in general, and learning, in particular, has occupied the minds of philosophers and educators from ancient Greece to the present day. Notwithstanding considerable disagreement about the exact nature of this relationship (for a review, see Carruthers, 2002), there seems to be a consensus that being without language impedes the ability of individuals to learn and think, in a rather essential way.

Particularly for the acquisition of cognitive skills such as reading and writing, failure to properly internalize and access the coded language—that is, spoken language—is assumed to have far-reaching consequences (National Reading Panel, 2000). The basis for this conclusion is the argument that the meaning of written words is mediated by phonology, that is, by abstract phonological representations of spoken words stored in the reader's permanent lexicon (Frost, 1998; Ramus, Pidgeon, & Frith, 2003). Some researchers (e.g., Hu & Catts, 1998; Perfetti & Zhang, 1995) claim that this to hold true even for logographic orthographies, such as Mandarin Chinese, in which the basic units of writing—the Chinese characters—are only vaguely related to the phonology of spoken words, if at all. On the other hand, some scholars tend to agree that obtaining access to the meaning of

written words may be possible without phonological mediation, based on direct associations between orthographic representations and specific concepts in permanent memory. However, given that the emergence of such orthographic knowledge is hypothesized to be contingent on the existence of proper phonological decoding skills (Share, 1995, 1999, 2004), it is believed that lack of phonological competence necessarily dooms individuals to remain illiterate.

Assumptions about how the relationship between language and thought affects learning have particular relevance for individuals with prelingual deafness, since spoken language is difficult to acquire without proper hearing abilities. However, despite such hearing deficits, some individuals may eventually succeed in becoming competent speakers if they receive adequate treatment: early diagnosis, proper determination of hearing loss, optimal adjustment of hearing aids, enrollment in quality intervention programs, parental support, etc. (Carney & Moeller, 1998). Deaf children who are not exposed to competent sign language models during the critical period of language acquisition in childhood may find themselves growing up without attaining true proficiency in sign language, as well (Emmorey, Bellugi, Friederici, & Horn, 1995; Mayberry, 2007; Mayberry & Eichen, 1991). In other words, such individuals are at risk of failing to become competent in any language at all. The deaf boy portrayed in the case study in the present article represents an extreme example in this regard.

This rather pessimistic portrait of the linguistic abilities of individuals who are prelingually deaf dovetails with evidence indicating that the intellectual abilities of this population are less than those of their hearing counterparts (Marschark, 2006; Remine, Brown, Care, & Rickards, 2007). For example, scientific evidence suggests that the reading achievement levels of deaf and hard of hearing high school graduates plateau, on average, at the fourth-grade level (Gallaudet Research Institute, 2003; Holt, 1993; Monreal & Hernández, 2005; Pintner & Patterson, 1916; Traxler, 2000; Wauters, Van Bon, & Telling, 2006; Wolk & Allen, 1984). Given that written words are assumed to refer to spoken words rather than ideas (Frost, 1998)—at least in orthographies implemented according to alphabetic principles—it makes intuitive sense to attribute such reading comprehension deficits directly to poor mastery of spoken language and a lack of sensitivity to its phonetic structure (Padden & Hanson, 2000; Perfetti & Sandak, 2000). Likewise, it seems defensible to draw a direct causal link between the poor language skills of prelingually deafened individuals and their ability to learn new skills in a more general sense. Such depressed potential for learning should manifest in particular in individuals who, due to prelingual deafness and additional disfavoring conditions, have failed to internalize both the spoken and signed forms of language. However, as I demonstrate in the following case study, such research-based or intuitive conclusions must be viewed with caution so that deaf educators can see beyond a child's deafness and recognize the potential for learning that deaf children bring to class.

The Case of Navon

The present case study reports the achievements of Navon (a Hebrew pseudonym meaning "bright"), a prelingually deaf 13-year-old boy living in Israel. I became acquainted with Navon while participating in an educational project launched by a private donor whose aim was to promote learning among deaf children with particularly weak academic achievement. The main idea behind the project was to assign a tutor to each candidate for 3 months with the goal of helping the student with homework or involving him or her in other skill-fostering activities (e.g., playing memory games, making picture puzzles). The selection criteria for tutors were (a) experience working with deaf children, (b) knowledge of Israeli Sign Language or Signed Hebrew, and (c) an academic background in education or related areas. At the time the project was implemented, I was a student in counseling and special education at the University of Haifa writing my master's thesis, which was titled *The Cognition of the Deaf Child* (Miller, 1986). I had already been working for several years as social coordinator at Shema Haifa, a center for the rehabilitation of hard of hearing and deaf children in northern Israel. I was fluent in Signed Hebrew and reasonably conversant in Israeli Sign Language. On the basis of these qualifications, I was chosen to tutor Navon. During the 3 months in question, we met two afternoons a week for about 2 hours.

The description of Navon provided in the present article, including the development he went through from the moment we first met, is partly based on materials taken from his personal school file, as well as information provided by his principal, teachers, school counselor, and parents. The majority of it, however, reflects the summary of authentic observations I put in writing during the period I worked with him. The notes were taken at each meeting and included a general description of Navon's actions and progress on a specific day, as well as more detailed descriptions of events of particular interest that I observed while working with him. I took most of the notes

while physically observing Navon in action, but some were added in recollection.

The aim of my note taking was to document Navon's behavior and progress in order to help me set adequate objectives for working with him in subsequent meetings. A secondary goal was to gather materials that would help me prepare a final report to the donor financing the project. The case of Navon as presented in the present study is based on a selected sample of notes which I categorized as being relevant for outlining his development in response to his encounter with the Logo computer programming environment. Its presentation is implemented according to a mixed case study, narrative approach (Polkinghorne, 1995), whereas the interpretation of its significance reflects a process/outcome-based orientation.

The notes on which I based the case study were taken approximately 20 years ago. It was at this time—after using them in writing up a final progress report to the private donor—that I put the notebook in which the notes were written into a binder and forgot their existence. Recently, while clearing my office of materials successfully accumulated over the last three decades but never used, I found the notebook, which had been buried for so many years under a pile of other documents. While reading the notes I had made so long ago, I felt a sense of fascination. Having accrued two decades of research experience in the field of deaf cognition in which emphasis was put on reading and writing, I found a very different meaning in these notes from when I first wrote them down. As I demonstrate in the present article, their relevance for understanding the way deafness affects the intellectual abilities of prelingually deafened individuals in the absence of proper treatment remains highly relevant even today. The same is true with respect to the message these notes carry regarding the direction intervention should take if it is to provide individuals with prelingual deafness with the opportunity to develop their cognitive skills, as well as their academic skills, in the absence of sufficient mastery of spoken language.

Navon's Background

Navon was the only child of a couple who had immigrated to Israel from Romania in the early 1980s, when he was 11 years old, about 2 years before we first met. As indicated by a verbatim report in his personal school file, he had severe to profound hearing loss in both ears. Although the exact onset was unknown, it was estimated to be prelingual in nature and was assumed to be the result of perinatal complications. Navon did not wear hearing aids. There was no information in the file suggesting the existence of additional disabilities. According to information obtained from his parents, Navon spent some time in an institution for children with disabilities in Romania before the family immigrated to Israel. His cognitive functioning and his achievements in school were described in general terms as "very weak." The file contained no additional information about Navon's intellectual potential or socioeconomic background. The background information presented below was gathered from his parents and from school personnel (principal, teachers, counselor).

Navon was exceptional in many regards. As I learned while visiting him at home some time after I started meeting with him, he and his parents lived in a two-room apartment in one of the suburbs of Haifa, a seaport in northern Israel. The apartment was sparsely furnished, but clean, and it had a friendly atmosphere. There were no books, and, as I came to learn during my visit, his mother was illiterate, while his father was semiliterate in Romanian. Both were in their 50s, relatively old for a child of Navon's age. Their competence in Hebrew was very limited and seemed to be confined to a vocabulary adequate for coping with daily needs. At the time of my visit, both parents were unemployed and relied on social welfare to make ends meet. Navon's father told me that he used to work as a plumber for the municipality of Haifa, but was forced to quit this job because of chronic health problems.

Strikingly, the communication between Navon and his parents appeared to lack the use of oral or sign language. In fact, during my visit the interaction between them was entirely based on other types of nonverbal behavior, such as pointing, gestures, and facial expressions. The lack of reliance on a conventional communication system notwithstanding, Navon's parents seemed to have a very warm relationship with their deaf son, which they manifested repeatedly during my visit through physical behavior such as touching and hugging, and through caring glances. There was no doubt that the boy had loving parents.

Navon attended a school that by and large served a population with multiple disabilities (physical/sensory disabilities combined with moderate mental handicaps and specific behavioral problems), although he himself was not diagnosed to have other disabilities besides deafness. His chronological age should have positioned him at least at the sixth-grade level, but because of his extremely poor language and academic skills, the school administration put him in a class with hearing-impaired fourth graders. His teacher claimed that even fourth grade was too advanced for him and that he would have been better served by

learning at a more basic grade level where pupils were taught reading and writing.

Unlike at home, Navon was not an accepted child in school. His principal and teachers characterized him as apathetic, as someone who generally showed no understanding of the subject matter being taught and with whom they were unable to communicate. They stated that his academic achievements were somewhat better in arithmetic, and that he seemed to have grasped the basic principles of calculation. All emphasized that Navon did not use oral language at all; nor did he read lips. Although he was entitled to participate in an oral habilitation program once a week, his speech therapist claimed that he often did not show up. Moreover, she complained that the few times she did work with him, he proved entirely apathetic to her efforts. Navon also seemed to have very rudimentary control of manual communication. According to the school counselor, Navon was a rejected child in class as well as during recess, when he often was teased by chronological age–matched pupils for only being in the fourth grade. However, the counselor stressed that despite being unpopular, Navon was not violent.

My First Encounter With Navon

My first meeting with Navon took place in a quiet room at the Shema rehabilitation center in Haifa that I had equipped with various games I intended to use to establish an initial relationship. My first impression of Navon was that he was truly apathetic, just as his principal and teachers had described him to me. But he also appeared to be scared and, above all, to lack self-confidence. He persistently avoided eye contact, and all my attempts to communicate with him or encourage him to participate in playful activities failed miserably. It seemed that all he wanted was for me to leave him alone and let him go home. The only times Navon actually exhibited some sign of cooperation was when I offered him something to drink and some sweets.

The same disregard for my attempts at communication and involvement in specific activities was typical of our second meeting. I felt deeply frustrated at this point of not knowing how to get through to Navon, and conclusions similar to those I heard from his teachers started crossing my mind. Thus, the day of our third meeting, I was tinkering with the idea of giving him up as I came to meet him. However, on this particular day—because of his encounter with a "Turtle"—Navon became involved in a process that served as the basis of an impressive development.

Acquaintance With a Turtle

The Turtle in question was not, of course, a typical (real) turtle, but a virtual turtle on a computer display. It was an integral feature of Logo, a sophisticated programming language. (The version of Logo that Navon worked with was Terrapin Logo. For more information on Terrapin Logo, see http://www.terrapinlogo.com.) Seymour Papert and a team of researchers at the Massachusetts Institute of Technology had developed Logo to allow students to investigate arithmetic and mathematical principles by providing them with immediate graphic feedback of these principals' essence (Papert, 1980). The Turtle—as it was named by its developers—is a small triangle on the computer screen whose behavior (movements) is programmable by means of specific Logo commands. A virtual pen attached to the belly of the Turtle graphically illustrates (draws) the effect of the commands it receives from its programmer. For example, the following sequence of commands, when entered into the input box, will prompt the Turtle to draw a square that is 50 Turtle steps long on each side:

```
Forward 50 Right 90
Forward 50 Right 90
Forward 50 Right 90
Forward 50 Right 90
{ENTER}
```

By the 1980s, Logo had become a highly popular educational tool and was installed by recommendation of the Ministry of Education on personal computers in computerized classrooms all over Israel. At the time I started working with Navon, I myself had become an enthusiastic Logo programmer.

When I met with Navon the third time, I therefore decided to take him to the computer room where I intended to do some programming in Logo. Given the accumulated frustration I felt from our previous sessions, the impetus for pointing to him to sit next to me in front of a computer was to kill time rather than to instruct him in programming Logo. But from the very first moment, Navon appeared mesmerized by what I was doing to make the Turtle move and draw figures on the computer screen. Noticing his interest, I intuitively asked him by gestures if he would like to try it himself. Surprisingly, he agreed without hesitation. It was from this moment that our weekly meeting turned into a captivating learning experience, one that fundamentally changed him as a person and forced me to reconsider many of my assumptions about the essence of the relationship between language and thought.

The process Navon went through while learning to navigate the Turtle on the computer screen, although fascinating, was extremely complex, and the obstacles on his way to become a

Logo programmer were numerous. Yet the ultimate barrier to success was, undoubtedly, his strikingly poor linguistic skills. It was at this point in our relationship that I was confronted with the fact that he was a child with only minimal control of sign language. Even more forceful was the realization of the extent to which he lacked spoken language. In short, I could use neither speech nor sign as a scaffold for teaching him the principles of Logo programming. However, as I was forced to instantly realize, this linguistic barrier notwithstanding, Navon could assimilate new, complex concepts and skills—many of them requiring abstract thinking—surprisingly fast. In many regards, he quickly became independent of my assistance in using them with impressive creativity. However, as our first few meetings had hinted, progress would not always come easily.

Understanding the Concept of the Turtle

As I stated in the preceding section, in the Logo programming environment the programmable little triangle on the computer screen represents a virtual turtle. Although this idea is normally grasped relatively effortlessly by children with intact hearing, making it understandable to Navon was a major problem. The principal reason for this was that neither his spoken nor his sign language knowledge was sufficiently developed to sustain an explanation. Like Navon's failure to understand the accompanying explanations, the drawing of a turtle on a piece of cardboard for demonstration also proved insufficient for creating true insight regarding the representative nature of the triangle. Understanding finally emerged following my repeated pointing from the turtle on the cardboard to the triangle on the computer display, which included sticking the former on the latter. From this moment on, Navon produced the sign "turtle"—a sign he probably picked up from me—whenever he referred to the triangle (Turtle).

After Navon grasped the concept of the Turtle, I started acquainting him with its basic characteristics, such as its ability to move forward and backward, to turn right and left, and to document (draw), with the virtual "pen" attached to its virtual belly, the product of its movements on the computer display. For this purpose, I attached a real pen to the belly region of the turtle drawn on the cardboard and then guided the turtle over a blank sheet of paper so that it drew a square. This time, Navon exhibited comprehension of my demonstration almost immediately—which encouraged me to go on teaching him the first Logo commands that would allow him to start working with the Turtle.

Dealing With the First Logo Commands

The first Logo command I introduced to Navon was "Forward," which, in conjunction with a number representing turtle steps, causes the Turtle to make a forward movement on the computer screen. For this purpose, I entered (typed) the command into the input box [Forward 50] and initiated its execution by pressing {ENTER}. I then pointed to Navon to indicate that it was now his turn. Almost instantly, I realized that this would be a real challenge for him; he seemed to have no experience with computers and, even worse, he did not know the letters of the Latin alphabet, which are used to write Logo commands. In other words, he was forced to identify and type them by comparing the letter shapes of the provided example with the shapes of the letters on the computer keyboard. This obvious obstacle notwithstanding, Navon—who had always been indifferent to whatever activity I tried to involve him in—started working with great determination and obvious enthusiasm. After several failures, he finally succeeded in typing the correct command to cause the Turtle to move forward; a smile of satisfaction appeared on his face.

The same day, I introduced Navon to more Logo commands: "Right" and "Left," which, in conjunction with a number (1–360) indicating degrees, make the Turtle turn in a specific direction. Beyond that, I barely interfered with his learning process. He now was in a position to move the Turtle all over the Logo *d*isplay window, which he did extensively, with apparent pleasure, and, more important, with rapidly growing control. Surprisingly, at the end of our third meeting, he typed the three Logo commands fluently and with great accuracy. Even more impressive, toward the end of the day he had started a seemingly systematic investigation of the impact that altering the values of the commands had on the Turtle's behavior. Probably most noteworthy, however, is that all these achievements were made without Navon and me having exchanged a single spoken word.

Navon Pushes Ahead

Encouraged by the changes in Navon's behavior I had observed during our last meeting, I looked forward impatiently to our next (fourth) meeting 2 days later. I was curious as to whether he would want to continue working with the Turtle and, even more, how much he remembered of what he had already learned. In contrast to our previous meetings, this time he came in early, with a big smile on his face. Without waiting for me to suggest something different, he headed for the computer room, taking a seat in front

of the computer on which I already had set up the Logo environment. Surprisingly, except for initially mixing up the two last letters of the "Right" command—confusion he almost instantly rectified—he spelled the previously introduced commands perfectly, and the way in which he used them evidenced clearly that he was fully aware of how they affected the Turtle. He also used keys representing control or editing functions, such as {ENTER}, {BACKSPACE}, and {DELETE}, purposefully and self-confidently. Moreover, it seemed that his ability to correctly recognize specific letters had consolidated over the past 2 days, a conclusion I drew from the observation that he now keyed in the letters of the commands faster and with astounding accuracy. Most important, Navon made it perfectly clear to me that he wanted to learn further commands.

That same day and over the next four meetings, Navon gradually mastered all the basic Logo commands that allowed him to control (program) the behavior of the Turtle: some of them affecting its movement (e.g., "Back," "Home"), others manipulating its virtual pen (e.g., "Penup," "Pendown," "Penerase," "Pencolor"), and some controlling the background of the Logo display window (e.g., "Clearscreen," "Background"). I also showed him that he could execute sequences of commands at once. For this purpose, I keyed several commands with which he was already familiar one after another into the input box (e.g., Forward 50 Right 90 Forward 20) and initiated their execution by pressing {ENTER}. While, on the one hand, this economized his work, it forced him, on the other hand, to think of his programming in a linear manner, foreseeing its impact beyond that of a specific command. Finally, he also learned how to save his work and to reload it later on. He mastered these options by carefully watching and copying my demonstration of the different steps involved in their proper implementation, using his name, Navon, as a file name. This opportunity allowed him, incidentally, to learn how to spell his name in English.

During all these meetings, I noted that Navon continued to create and examine his products with apparent interest and remarkable creativity. (For example, he experimented with angles combined with movements, drew increasingly complex figures, and worked on improving the way in which he realized his products.) In doing so he started to acquire a language, one in which orthographic representations associated with meaning without involving the dimension of sound (voice).

In retrospect, when I first started meeting with Navon he apparently was completely ignorant of the letters he now recognized fluently in typing commands that controlled the behavior of the Turtle. He also seemed at first to have no experience operating a computer. Seeing him, after so few meetings, behaving as if all these skills had always been a part of his life was indeed extraordinary, and there was no sign at all that he intended to stop there. The more he felt in control, the more he demanded to know, seeking ways to become more sophisticated. If, in the beginning, he had been satisfied by controlling the behavior of the Turtle, he now frequently manifested dissatisfaction (shaking his head, becoming impatient) because he did not think that the way in which he achieved such control was very efficient. For example, it was entirely clear from his facial expression that he considered writing exactly the same command several times not only annoying, but also ineffective. He seemed to assume intuitively that there must be more efficient ways to achieve the same result, and, in his nonverbal way, made it clear that he wanted to know them.

I therefore decided to introduce Navon to more advanced programming features of Logo. As with previous commands, he carefully studied these new options, trying to understand the potential they bore for programming the Turtle. As before, learning for him seemed to occur in a word(sign)-less world, yet his fingers continued to avidly proclaim his comprehension.

Signs of Autonomous Development

Navon clearly seemed to plan his work (drawings) before taking action to implement it in Logo. However, an issue of particular interest was whether he continued reflecting on it outside our meetings, that is, when he was not exposed to the Logo programming environment. He delivered proof that this was indeed the case shortly after I acquainted him with the "Repeat" command, which allows the execution of one or more Logo commands a predetermined number of times. For example, the following two applications of the "Repeat" command cause the *Turtle* to draw first a triangle and then a square:

```
Repeat 3 [Forward 50 Right 120]
{ENTER}
Repeat 4 [Forward 50 Right 90]
{ENTER}
```

In these two examples, the programmer can alter three performance dimensions by manipulating their numeric values, namely (a) the number of times that the command(s) in brackets are repeated, (b) the length of the Turtle's forward movement, and (c) the degree of the Turtle's turn to the right. To make the Turtle draw a

triangle or square, however, it is sufficient to manipulate the number of repetitions and the degree of Turtle rotation (two of the three dimensions). In order to acquaint Navon with the features of the "Repeat" command (at our ninth meeting), I showed him the two examples provided above, as well as some others of the same kind in which I manipulated the length of the Turtle's forward movement (by increasing or decreasing the numbers). By now highly familiar with producing sequences of Logo commands that controlled the movement of the Turtle, Navon grasped the basic idea underlying the "Repeat" command effortlessly and started investigating and practicing it, mainly drawing polygons of varying sizes and with different numbers of vertices.

At our next (10th) meeting, Navon entered the computer room with a mysterious expression on his face and insisted on showing me something. Surprisingly, he did not immediately turn to the keyboard, but, rather, took a pencil and drew a circle. Then he watched me expectantly, a behavior I erroneously interpreted as a request to show him how to program a circle, since so far I had not shown him how to do that. It came as quite a surprise to me as he determinedly turned to the computer himself and keyed in and executed the following sequence of Logo commands:

```
Repeat 180 [Forward 2 Right 2]
{ENTER}
```

He watched me as the Turtle drew a circle, and his glance showed obvious satisfaction with my astonishment. During our future meetings Navon drew many more circles, manipulating all three performance dimensions while studying the effect of the manipulations. As his control over this new skill grew, he started integrating circles creatively into his Turtle drawings.

A Multiple-Choice "Reading Comprehension" Test

As I observed Navon becoming more and more sophisticated in the way he programmed the Turtle, and doing so with increasing confidence, I began to wonder if he would be able to understand the product of a command sequence he had not programmed himself. To clarify this issue, I decided to give him a kind of a multiple-choice "reading comprehension" test. For this purpose, I prepared 10 program sequences of increasing difficulty composed of Logo commands he was already familiar with. For each sequence, I prepared four drawings representing a potential product: the correct drawing and three other drawings that resembled the correct one to a decreasing degree. (Three examples of the multiple-choice "reading comprehension" test are provided in the Appendix).

At our 11th meeting I asked Navon to sit beside me and keyed in the first program sequence, without executing it. I put the first set of drawings in front of him, then pointed to the command sequence on the computer display and immediately thereafter again to the four options. He had no problem understanding my request. He first considered the sequence, then turned his attention to the four drawings, sometimes going back and forth several times, and finally pointed to the drawing he thought to be the correct one. In 8 out of 10 instances, he was correct on the first try. The two times he erred, he choose the drawing graphically closest to the correct one and, when given a second chance, made the right choice. In other words, Navon actually was able to read in Logo.

When Turtle Commands Become Language

Our meetings so far had led Navon to essentially change in almost every aspect of his personality. Yet the most significant development in this regard was still ahead. It came when, having seen his performance on the "reading comprehension" test, I decided to introduce him to an additional feature of the Logo programming language—the writing of procedures. Defining a procedure in Logo means associating one or more Logo commands with a particular name (word) that, thereafter, generates their execution. For example, Logo allows one to give the name "Square" to a command sequence that draws a square, and the name "Circle" to a command sequence that draws a circle:

```
To Square
Repeat 4 [Forward 20 Right 90]
End.

To Circle
Repeat 360 [Forward 1 Right 1]
End.
```

Following their definition, such "names" function similarly to regular Logo commands that control the behavior of the Turtle. For example, keying the word "Square" into the input box and pressing {ENTER} causes the Turtle to draw a square, while doing the same with the word "Circle" leads it to draw a circle. Logo also allows you to embed procedures within procedures. For example, in a procedure for drawing a car, the programmer, instead of programming a circle, may use the already existing procedure name "Circle" to draw the wheels.

Procedures turn Logo into a generative programming language that allows programmers to expand its repertoire according to their needs. It was this generativity that led Navon to

a spontaneous and unique language development, one that nobody actually foresaw. Navon had no problem understanding the basic idea behind the writing of procedures, and he seemed to recognize almost immediately the extraordinary potential they had to make his work with the Turtle more efficient. Yet he found himself coping with a frustrating fact: He had no available words that he could use to name procedures he wanted to define.

To make up for this lack, he started requesting names (words) each time he defined a new procedure. He would first give the procedure a placeholding name, "XXX," then write the command sequence, then test its accuracy by running it, then—after satisfying himself as to the result—ask me to assign an adequate letter string (i.e., a name) to the product. In fact, he no longer passively learned given Logo commands, but started to develop a unique vocabulary, wholly new to him, that developed out of his own specific needs—naming the procedures he programmed to achieve specific goals.

This process of learning new words became even more enhanced as, at a later stage, I taught him to incorporate variables into his programs, which made the programs more flexible. As with procedure names, the creation of variables motivated him to acquire new words representing the dimension they manipulated (e.g., size, color). In this way, he gradually built up a growing written vocabulary that served his unique needs, a vocabulary he learned to apply with great rigor according to the rules of Logo—in a manner similar to the way young children learn to use the language of their surroundings. Again and again, he implemented the different procedures in various contexts by writing their names, and the Turtle reliably reflected the essence of their nature. All these achievements were made without Navon having acquired the names of the letters he used, nor being aware of the sound of the words he acquired.

An Optimistic Outcome

After 3 months my work tutoring Navon came to an end, and it was time to summarize the progress he had made following his experience with the Turtle, as well as to consider whether it provided some new insight regarding the impact of prelingual deafness on individuals' abilities to think and learn. The first point to stress here is Navon's impressive linguistic development. Having been a child virtually without any language competence at our first encounter, following the intervention he was equipped with a substantial vocabulary in English, a vocabulary he knew how to spell and read fluently. Yet even more important, this vocabulary seemed to serve him quite efficiently in figuring out how to realize personal programming objectives and how to solve the problems he encountered in the course of these objectives' realization. For this latter achievement, Navon had to master a system of rules and a set of concepts that determined the way the vocabulary he acquired was to be used in relation to a language—Logo. Particularly noteworthy in this regard is that he acquired a substantial part of these skills and knowledge by his own initiative in a constant attempt to increase his control over what he was doing.

Notwithstanding these extraordinary achievements, I would like to state clearly that Navon's ability to communicate with his surroundings in spoken language did not improve. He still was a speechless child without adequate vocal skills to voice the words he was able to read. Moreover, the linguistic rules he internalized while programming the Logo Turtle—although complex in their nature—were not the rules that govern spoken Hebrew, and they were definitely far less complex than the rules on which natural languages are based. On the other hand, however, it is important to emphasize that the sheer fact that he developed a substantial vocabulary in written language, which he learned to apply subject to a rule-based system, gives hope that, under appropriate conditions, he and others like him could also succeed in internalizing spoken language, including its phonological dimension.

The impressive linguistic development I observed working with Navon was accompanied by some other significant developments. About 1½ months after I began working with him, his homeroom teacher informed me that she had witnessed some notable changes in his behavior at school. According to her, Navon had become much more confident and had started to pay attention to what was going on in class—although there was no real improvement in his ability to speechread or to express himself in spoken language. His interactions with his classmates and with students of his age had become markedly less tense, and he now was often seen in their company in the courtyard during recess. The teacher further claimed that Navon loved to be in computer class, where, she said, "he plays around with some kind of a computer-assisted graphic program." (Later, during a visit to Navon's school, I learned that the computer program she was referring to was Logo.)

At the summing-up meeting I held at Navon's school after I had finished working with him, his principal and teachers all declared that he was no longer the apathetic child they had known some months before. There was consensus that he now made a real effort to engage with the subject mat-

ter taught in class, although—except in operating the computer—his academic skills did not show any notable improvement. Encouragingly, however, they noted that his signing had become much richer—an observation I made myself in the course of our meetings—probably as a result of the increased interaction he now had with other deaf students in the school. Regrettably, there was no evidence of a similar improvement in his ability to understand spoken language or to express himself in spoken words, skills which, for him, both remained seriously impoverished. From a social perspective, the principal and teachers found that Navon had become accepted or even somehow popular among his schoolmates because of his skills on the computer. Moreover, the teacher responsible for the computer class had adopted him as his "assistant." The same teacher also expressed his astonishment at "how fast Navon is at keying in words," noting, "He successfully spells so many words without making a single error."

Theoretical and Practical Implications

The case of Navon provides both theoretical and practical insights. First, observations about his development (which is summarized in Table 1) challenge a widely held theoretical position that postulates language—in particular, spoken language—to be a prerequisite for thought and learning (see, e.g., Carruthers, 2002). In fact, Navon's impressive development gives testimony that individuals, even those with seemingly very poor ability with conventional languages (e.g., spoken language, sign language), preserve the ability to think as well as learn new skills with remarkable efficiency (see also Furth, 1966). This learning, of course, is likely to be contingent upon such individuals' expo-

Table 1
A Summary of the Skills and Concepts Navon Acquired in Working With the Turtle

Skills/knowledge	*Description of development*
Recognition of letters	Navon learned to recognize all the letters of the English alphabet.
Operation of keyboard	Navon acquired factual and procedural knowledge that allowed him to efficiently key in letters and numbers and to execute other keyboard-related functions (e.g., editing and running Logo codes, saving and reloading his work).
Concept of programming	Navon grasped that the letter strings (Logo commands) he keyed in had a unique impact on the behavior of a small triangle located on the computer display, the Turtle. He learned that controlling the Turtle's behavior means to communicate with the Turtle.
Unit of communication	Navon acquired a large number of Logo commands as the basic units of communication. He grasped that more commands mean better control over the Turtle, and he therefore insisted on expanding his command vocabulary.
Structure of communication	Navon learned that effective communication requires the proper structuring of the units of communication (Logo commands, procedure names, etc.) that control the behavior of the Turtle.
Conceptualization	When learning to define procedures, Navon grasped the idea of conceptualizing sequences of communication units in order to increase his productivity.
Generativity/creativity	Using the very same units of communication, Navon successfully created increasingly complex graphic representations of geometrical figures, drawings of items (e.g., car, house, airplane, ship), etc. He even programmed drawings of the Latin letters that made up his name.
Programming strategy	The way in which Navon realized his products in Logo reflected systematic planning; particularly after he had become acquainted with the essence of procedures and subprocedures, his programming became increasingly analytic in nature (e.g., "house = body of house, roof, door, window; tie all together").
Problem solving	Navon's ability to detect and correct problems in his Logo programs improved constantly as he moved from a primarily trial-and-error approach (e.g., random adjustment of input determining Turtle movement) to a strategic approach, that is, systematic adjustment of input relative to previous incorrect input (*greater than*, *smaller than*), including an estimation of error size.
Interpersonal communication	When we first met, Navon hardly ever initiated an act of communication. This changed dramatically after he started working with the Turtle. Particularly when he had trouble programming it properly, he frequently became very communicative, using mainly nonverbal means (e.g., gestures, mimicking) in conjunction with pointing to or rewriting improperly operating Logo program codes to make himself clear.
Improvement of status	Demonstrating his skills in Logo programming in the computer classroom significantly improved Navon's social status in school and, as a consequence, notably increased his interactions with classmates who used sign language as a means of communication. This may explain why his signing skills seemed to gradually improve.
Stagnation	In spite of rather impressive development in many domains, Navon's ability to use spoken language for communication remained extremely poor.

sure to an environment that consistently and reliably provides them with feedback on their behavior.

Second, Navon's development strongly suggests that, under certain conditions, children with prelingual deafness may be capable of internalizing spoken language as an abstract written symbolic system, without the need to address its phonological properties (see also Miller, 2006)—a dimension that is very difficult to gain access to and internalize in the case of severe hearing impairments. Indeed, working with the Turtle, Navon acquired dozens of words—Turtle commands, procedure names, and variable names—for which he developed permanent, detailed orthographic representations that allowed him to read and write them fluently. Moreover, as indicated by his surprisingly fast progress, his ability to internalize structural knowledge (syntax) that determined the adequate use of this vocabulary within the Logo programming environment proved strikingly intact, although its acquisition was definitely not phonologically mediated. These observations are in obvious disaccord with assumptions underlying currently popular reading theories; all of them stress phonological mediation as a sine qua non condition for the efficient processing of written words (Frost, 1998; National Reading Panel, 2000; Ramus et al., 2003; S. E. Shaywitz & B. A. Shaywitz, 2005; Stanovich, 2000; Troia, 2004; Vellutino, Fletcher, Snowling, & Scanlon, 2004), as well as for the acquisition of detailed orthographic representations (Share, 1995, 1999, 2004).

The fact that he was not in possession of a language neither prevented Navon from learning nor—in the course of his interactions with the Turtle—kept him from internalizing a system of abstract symbols (Logo) that represented meaning with reference to a set of conventionalized rules. In trying to understand the ultimate significance of these achievements, it is important to keep in mind that, prior to his encounter with the Turtle, his development had stagnated in many respects. Given this to be true, attributing Navon's sudden development to certain peculiarities of Logo makes sense. As I have already noted, the core features of this programming language are interactivity and generativity, as well as the provision of immediate visual feedback (the Turtle's behavior) that reliably reflects the adequacy of Logo programs (a series of commands organized [written] according to the syntax of Logo) written by the programmer for the purpose of achieving specific, meaningful objectives.

If one applies the same principles to a regular language-learning context, the spontaneous development of language is contingent, first and foremost, upon the exposure of individuals to an interactive field of experience where they acquire vocabulary and rule-based knowledge according to their unique needs and where they are capable of practicing and extending this knowledge within contexts that are relevant to them. For children with intact hearing, the existence of these conditions in their surroundings is normally taken for granted. The same, however, is seldom the case for children who suffer from a significant hearing impairment. Such children often struggle to acquire spoken language owing to possession of significantly reduced information regarding its phonological properties and within contexts that are entirely detached from their personal desires and needs, as well as from their everyday life. Navon's development following exposure to the Logo programming environment is encouraging in this regard. It provides evidence that such inadequate learning conditions can be ameliorated (see also Gaustad, 1999).

Although he was exposed to a speaking environment at home and in school, where instruction was based on a Total Communication approach, for Navon it was ultimately the massive act of reading and writing required by the programming of the Turtle that initiated a remarkable spontaneous linguistic development. This suggests that educators concerned with language acquisition in prelingually deafened individuals, in general, and these individuals' reading instruction, in particular, could truly gain from a conceptual shift in their instructional paradigm, going from "reading and writing to speech" rather than "speech to reading and writing." It is worth emphasizing that, unlike in speechreading, in reading and writing the perception of the basic language units (the graphemes of written words) is not impaired by deafness. This circumstance facilitates these language units' initial permanent internalization in the form of detailed orthographic representations, adequate for the efficient future processing of text, and provides a basis on which to build phonemic awareness. In view of the ease with which Navon learned to read and write Turtle commands, procedure names, and the like, on the one hand, and his complete failure to develop even basic speech, on the other hand, consideration of such an instructional paradigm shift seems justified.

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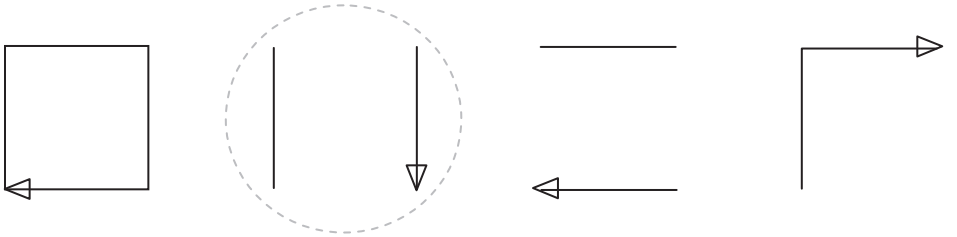
Appendix

Three Examples of Increasing Difficulty From Navon's Multiple-Choice "Reading Comprehension" Test

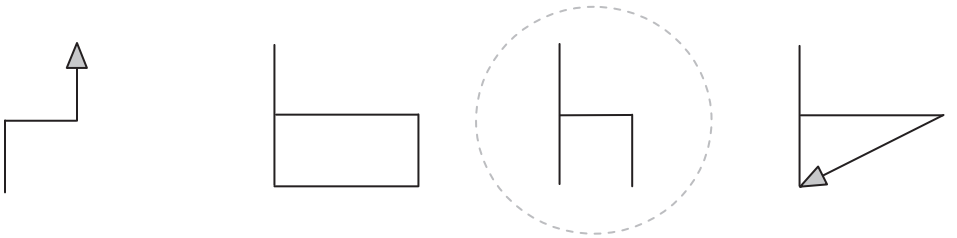
Example program 1:

Home Forward 50 Right 90 Penup Forward 50 Right 90 Pendown Forward 50



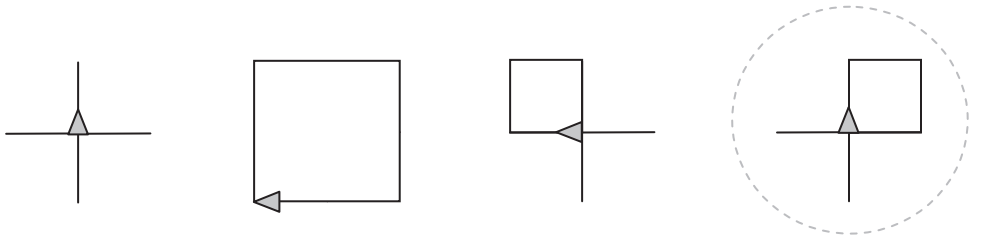
Example program 4:

Clearscreen Forward 25 Right 90 Forward 25 Left 90 Back 25 Penup Home Pendown Forward 50 Hideturtle



Example program 8:

Clearscreen Repeat 4 [Forward 25 Back 25 Right 90] Home Repeat 4 [Forward 25 Right 90]



Note. When solving example program 8, Navon first pointed to the second drawing from the right, but chose the correct one after he reexamined the program following my indication of disapproval.