The Development of Analogical Reasoning in Deaf Children and Their Parents’ Communication Mode

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The purpose of this article is to analyze the results of a study of the development of analogical reasoning in deaf children coming from two different linguistic environments (deaf children of deaf parents—sign language, deaf children of hearing parents—spoken language) and in hearing children, as well as to compare two groups of deaf children to a group of hearing children. In order to estimate the development of children’s analogical reasoning, especially the development of their understanding of different logical relations, two age groups were singled out in each population of children: younger (9- and 10-year-olds) and older (12- and 13-year-olds). In this way it is possible to assess the influence of early and consistent sign-language communication on the development of the conceptual system in deaf children and to establish whether early and consistent sign-language communication with deaf children affects their mental development to the same extent as early and consistent spoken-language communication with hearing children.

As Goswami (1991) notes, the essence of analogy is “reasoning about relations, in particular about relational similarity, so that a correspondence is established between one set of relations and another” (p. 1). The classical definition interprets analogy as “an equality of proportions . . . involving at least 4 terms . . . when the second is related to the first as the fourth is to the third” (cited in Goswami, 1991, p. 2). An example of such analogy, called the classical analogy, is the following task of verbal analogy, ill : healthy :: poor : ____.

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relations (leather : shoe :: wool : cardigan), relations that are called relations of second/higher order. Hence, inference of relational similarity as typical formal operational reasoning can emerge only in early adolescence.

A different viewpoint regarding analogical reasoning development is represented by Jurkowski (1961, 1967), who assumes that mental operations in early adolescence become independent of the content of analogy tasks. The content of the analogy tasks is understood as the category of logical relations on which these tasks are based. As studies show, analogical reasoning and the rate of its development vary depending on the category of relations contained in the pairs of particular analogies; this suggests that the extent to which mental operations depend on the category of logical relations on which these operations are performed, decreases with age. Children of younger school age (9–10 years) reason correctly when the premises concern the opposite relation (east :: west :: day :: ____ ) or the class-membership relation (carp :: fish :: stork :: ____ ), but they are unable to infer when the premises concern the causality relation (knowledge :: learn :: tiredness :: ____ ). The difference that analogy content makes decreases with age and hardly appears in children of older school age (13–14 years).

The preschool children's failures in the classical analogy tasks could be the result of applying relations that are not familiar to them in these tasks. As the study by Goswami and Brown (1990b) shows, 4-year-old children successfully solved tasks of pictorial analogies that contained physical-causal relations, e.g. cake :: cut cake :: apple :: ____ , choosing the appropriate picture from the series of different pictures (cut apple, cut bread, bruised apple, ball, banana). When solving control-causal reasoning tasks that consisted of the pictures of causally transformed objects, such as cut cake, cut apple, and cut bread, these children often found the causal agent responsible for the transformation of the mentioned objects among the series of pictures of possible agents, such as knife, water, and sun. These control tasks examined children's knowledge about the relations used in analogies. The results suggest that children of preschool age are able to recognize the higher-order relations as long as the analogies presented to them are based on relations that are part of their knowledge.

Additional support for Goswami’s (1991, 1996) claims about the importance of relational familiarity in solving the analogy tasks comes from studies by Alexander and her colleagues (1987, 1989). In their studies, 4-year-old children successfully solved geometric analogy tasks based on relations of color, shape, and size (large red circle :: small red circle :: large blue square :: ____ ), searching out the appropriate figure in a set. Goswami (1989) conducted a similar study with the use of geometric analogy tasks that contained proportion relations, such as half circle : half rectangle :: quarter circle :: ____ . Children aged 4 years used the strategy based on relational similarity, searching out the appropriate element of a figure in a set.

Sternberg and Nigro (1980) found that when solving verbal analogy tasks, children aged 9 and 12 years often use associations as “a substitute for full reasoning by analogy,” because in the task narrow : wide :: question : (trial, statement, answer, ask), the word question is highly associated with the term answer. So, in some situations, the solutions associated with the C term can be correct. In contrast, 15-year-old children use strategies based on relational similarity rather than on associations with the C term. On this basis, researchers singled out two levels of verbal-analogy solutions that correspond to Piagetian stages of concrete and formal operations. Moreover, Goldman and her colleagues (1982) conclude that 8-year-olds solving verbal-analogy tasks have difficulties in inferring the relation between the A and B terms. These difficulties can reflect a general lack of attention to the mentioned analogy terms. Hence, the children tend to choose or to generate D terms that are strongly associated with the C term.

As a study by Goswami and Brown (1990a) shows, children aged 4 years, solving first the control thematic tasks that were composed of the analogy C term (dog : ____ ) and the alternative solutions (doghouse, bone, cat, other dog), chose the first two answers as the associations with the C term. Next these children, solving the pictorial analogy tasks based on thematic relations (bird :: nest :: dog :: ____ ) and given the same alternative solutions, pointed mostly to solutions that copied the relation occurring between the A and B terms (doghouse). This implies that children are aware of the existence and necessity of the relational
similarity principle, so they possess a competence in analogical reasoning that is independent of associative mechanisms. Furthermore, an important aspect of their study is that the pictorial analogy tasks were based on familiar relations. This can indicate that the ability to recognize the similarity between the relations is determined by the familiarity of the relations on which the analogy tasks are based.

The ability to recognize the higher-order relations emerges early in a child’s development, and in Goswami’s (1991, 1996) opinion one cannot claim that this ability develops, as Piaget suggests. This ability emerges in the early development period when the difficulty level of tasks is reduced by the application of relations that are familiar to young children. As Goswami (1991) claims, what develops is the metacognitive skill that is related to the ability to consciously and purposefully use the higher-order relations when solving tasks, irrespective of task content.

The studies of the mental development of deaf children involved the use of exclusively nonverbal cognitive tasks because results obtained on the basis of verbal cognitive tasks would not reflect their general mental development (Furth, 1964). As studies show (Furth, 1964, 1966, 1971b, 1991; Furth & Youniss, 1975; Ottem, 1980), deaf children of younger school age (6–11 years), that is, the age at which the period of concrete operations occurs, do not differ from their hearing peers in their ability to understand and use the nonverbal part-whole relation, the concepts of sameness and symmetry, the numerical concepts, the principles of double alternation, the principles of relational transitivity, the spatial relations, or the principles of classification of figures. In contrast, deaf children of older school age (12–18 years), the age at which the period of formal operations occurs, are able—like their hearing peers—to understand and use the concept of probability and the simple logical-symbolic expressions. Furthermore, the quantitative and qualitative differences between deaf and hearing children are found in some spheres of logical thinking, such as understanding and using the concept of opposition, the principles of weight and liquid conservation, and complex logical-symbolic expressions. The fact that there is quantitative and qualitative similarity between these children in many spheres of logical thinking means, in Furth’s (1971b, 1991) opinion, that language is not the preliminary condition for the development of logical structures. Most deaf children show a delay in the development of “society’s language” and do not have sufficient contact with sign language. The possible explanation is that these children construct their own verbal and nonverbal symbols (gestures and images, respectively) that influence their mental development. This suggests that biological factors play a significant role in the development of logical thinking structures in deaf children, leading through the successive stages of their development to the emergence of some forms of formal thinking.

Recently, in order to explain the influence of genetic and environmental factors on deaf children’s mental development, two groups of deaf children were singled out within the population of these children: a group of deaf children of deaf parents (DCDP) and a group of deaf children of hearing parents (DCHP). It is assumed that DCDP have early and consistent contact with sign language, while DCHP have contact solely with spoken language if their hearing parents do not communicate with them in sign language (Braden, 1994; Meadow, 1980). As studies show (Braden, 1987; Brill, 1974; Conrad & Weiskrantz, 1981; Courtin, 1997, 2000a, 2000b; Courtin & Melot, 1998; Dolman, 1983; Sisco & Anderson, 1980; Zwiebel, 1987), early and consistent sign-language communication enables deaf children to develop the verbal and nonverbal symbolic system that is a tool leading to their mental development, especially to the development of a complex conceptual system. This factor also contributes to the sophisticated improvement of deaf children’s cognitive abilities in the domains of categorical thinking (Courtin, 1997), spatial thinking (Conrad & Weiskrantz, 1981; Sisco & Anderson, 1980), nonverbal cause-effect reasoning (Sisco & Anderson, 1980), and understanding mental states (Courtin, 2000b; Courtin & Melot, 1998), as well as to the emergence of cognitive flexibility in their thinking (Courtin, 1997, 2000a). So DCDP can surpass hearing children of hearing parents (HCHP) having early and consistent contact with spoken language in this respect. In contrast, DCHP, because of late and insufficient contact with sign language, are delayed in the development of some
nonverbal spheres of logical thinking such as abstract spatial reasoning (Braden, 1987; Conrad & Weiskrantz, 1981) and understanding the principles of liquid conservation (Dolman, 1983). On the other hand, DCDP—in contrast to DCHP—have the genetically determined deafness that is not accompanied by other additional handicaps (e.g., partial deficits, a mild mental retardation); this indicates that the interaction of biological and environmental factors affects the general cognitive development in these children (Akamatsu, Musselman, & Zwiebel, 2000; Kusche, Greenberg, & Garfield, 1983). Moreover, sign language is treated as verbal language (Farris, 1994; Hoemann, 1991; Klima & Bellugi, 1979; Marschark, 1993; Marschark, Siple, Lillo-Martin, Campbell, & Everhart, 1997) because this language is a full-fledged linguistic system that possesses complex syntactic, lexical, and morphological structures and allows the possibility of operating with abstract expressions, logical connections, and well-organized sentences. Hence, it would be possible to examine the verbal spheres of logical thinking in deaf children while maintaining strict methodological procedures.

The development of analogical reasoning in deaf children was studied by Panasiuk (1990) and Sharpe (1985). The study by Panasiuk (1990) shows that deaf children aged 10, 12, and 14 years do not equal their hearing peers in respect to understanding and using different logical relations (opposite, class membership, and part-whole) in three spheres of analogical reasoning (verbal, numerical, and spatial). Panasiuk claims that hearing impairment makes spoken-language communication impossible and thus promotes the development of concretely imaged mental operations in deaf children. In contrast, a study by Sharpe (1985) shows that deaf adolescents (entirely DCHP) aged 14–19 years do not understand higher-order relations in tasks of verbal and geometric analogies as well as age-matched hearing adolescents do. In Sharpe’s opinion, the primary communication mode, reflected through the use of spoken language or sign language, is a prerequisite to the development of higher complex cognitive processes but not facility in any languages and it accounts for deaf and hearing adolescents’ different performances on the mentioned tasks. Hearing children’s oral-aural mode of communication provides the sensory experience that facilitates the perception of contrast more effectively than does the gestural-visual mode of communication of deaf children. Such a perception of contrast involves an analysis of spoken utterances that contain a contrast at several levels, so it leads to complex cognition and hierarchic cognitive development, unlike the perception of contrast involving an analysis of signed utterances.

Assumptions and Hypotheses

As mentioned earlier, deaf adolescents who did not have early and consistent contact with sign language obtained worse results in tasks of analogies than did hearing adolescents. According to Sharpe (1985), these outcomes can be evidence of the ineffectiveness of gestural-visual communication mode that is used by deaf people. One can assume that overlooking deaf adolescents who have early and consistent contact with sign language has led her to formulate the above-mentioned conclusion. Therefore one should reconsider the possibility that a gestural-visual communication mode and an oral-aural communication mode might facilitate to an equal degree the perception of contrast necessary to complex cognition, if deaf children (sign language) as well as hearing children (spoken language) have consistent contact with linguistic systems suitable for them from birth. Yet one should emphasize that deaf children’s gestural-visual communication mode provides them with a somewhat other sensory experience than hearing children’s oral-aural communication mode; this does not necessarily have to mean that a gestural-visual communication mode is inferior to an oral-aural communication mode. One also should assume that signs, which cannot be treated as substitutes for words but as their equivalents, enable the information containing the contents of different levels of abstractness to be conveyed, so they allow deaf children to enrich their cognitive experiences.

According to the above assumptions, the following hypotheses that will be verified empirically were formulated:

Hypothesis 1. The ability of deaf children to understand the analogical relations expressed verbally and nonverbally is comparable to the ability of
hearing children; early and consistent sign-language communication determines the emergence of this ability in deaf children at the same time as in hearing children who have early and consistent exposure to spoken language.

The following detailed hypotheses were drawn from the general hypothesis above:

Hypothesis 2. Deaf children with early and consistent exposure to sign language understand the different relations expressed in sign language in a similar way as hearing children (with early and consistent exposure to spoken language) who understand the relations expressed in spoken language.

Hypothesis 3. The education of deaf children with early and consistent exposure to sign language in an artificial sign system or in spoken language contributes to the emergence of the ability to understand numerical relations somewhat later than in hearing children with early and consistent exposure to spoken language.

Hypothesis 4. Early and consistent exposure to the grammatical structures of sign language—in contrast to early and consistent exposure to the grammar of spoken language—determines the differences between deaf and hearing children in the recognition of spatial relations, to the disadvantage of hearing children.

To verify these hypotheses, an analysis of a specific independent variable—the communication mode (sign language, spoken language)—was performed. The dependent variable, which according to the above assumptions the independent variable can influence, was the level of analogical reasoning in deaf children, in particular the level of their understanding of logical relations expressed verbally and nonverbally.

Method

Subjects
A total of 104 children took part in the study. All children were of an intellectual norm. Children who had an additional handicap from birth were eliminated from the study. When selecting children for the study, the following factors influencing the level of cognitive development were taken into consideration:

- Age—Children aged 9–10 years (the younger age group) and 12–13 years (the older age group) were tested. The age of each group reflected the characteristic periods of thinking development described by Piaget: younger group—stage of concrete operations, older group—stage of formal operations.
- Linguistic environment—The following groups of children were tested: (a) DCDP having early and consistent contact with sign language; (b) DCHP having contact with spoken language; (c) HCHP having early and consistent contact with spoken language.

The information on the deaf subjects’ linguistic environment was provided by teachers and school psychologists. Neither of the hearing parents of deaf children had contact with sign language until the child began to attend preschool (by age 6). The hearing parents did not communicate with their deaf children in sign language, and deaf parents used sign language in interaction with their deaf children. Some DCHP had deaf siblings (4 children in the younger group and 2 children in the older group). The DCDP who did not have early and consistent contact with sign language were eliminated from the study because the purpose of study was to evaluate the influence of early and consistent sign-language communication on the cognitive development of deaf children. These children were unable to use sign language or they communicated by means of some signs. This was confirmed by teachers who also mentioned that the children’s deaf parents did not communicate with them in sign language. All the deaf children attended schools where teachers used either an artificial sign system or spoken language. In the audiological respect, all children with hearing impairment had severe and profound prelingual deafness (above 80 dB in the better ear). The information about the degree of hearing loss came from school records. The data concerning the groups of children are presented in Table 1.

The study was conducted at elementary schools and secondary schools for deaf children in Warsaw, Cracow, Lodz, Wroclaw, Lublin, Wejherowo, and
Otowoć, and also at elementary schools and secondary schools for hearing children in Warsaw.

Materials

Three series of analogy tasks based on verbal, numerical, and spatial relations were selected for the study. The particular series of tasks were given in the same order for all the subjects: (a) a series of verbal analogy tasks, (b) a series of numerical analogy tasks, and (c) a series of figural-geometric analogy tasks.

The time to solve the particular tasks was limited to 90 sec, and the measurement of reaction time was eliminated, so none of the series of tasks required speed in solving them.

In order to eliminate the possibility of learning, all the analogy tasks were given in an established order according to the sequence principle. In each series, the tasks of analogies based on the same category of logical relations were presented separately.

The presentation of each series of analogy tasks was preceded by instructions consistent with the content of each series of tasks; the content of the instruction was conveyed to deaf children in conventional sign language and to hearing children in spoken language. Additional explanations were given as needed.

Tasks of verbal analogies. The verbal analogies were drawn from the series of verbal analogy tasks used by Jurkowski (1967), Pietrulewicz (1983), and Panasiuk (1990, 1995). The tasks of verbal analogies were based on three categories of relations that in Jurkowski's (1967) opinion have a privileged place in cognitive psychology: opposite, part-whole, and causality. These categories of relations were taken into consideration because the purpose of the study was to examine whether deaf children of older school age—that is, the age at which the period of formal operations occurs, or in other words the period in which mental operations become independent of the category of logical relations—are able to understand logical relations regardless of type. An understanding of relations irrespective of type is evidence of attaining the level of formal thinking.

The verbal analogy tasks were inventive tasks, that is, they required children to generate the missing term that would complete the analogy.

The verbal analogy tasks were presented to the deaf children in sign language and to the hearing children first in spoken language, then in written language. To establish a list of verbal analogy tasks, words and signs belonging to the same categories were selected: (a) grammatical categories (words and signs corresponding to them from groups of nouns, verbs, adjectives, or adverbs); (b) lexical frequency categories (words and signs occurring in use equally frequently); (c) lexical-semantic categories (the meanings of words and signs almost corresponding with each other). Such an action
is consistent with Jurkowski’s (1990) recommendation that the content of the native-language words and of the foreign-language words correspond. The words and signs matched in this way were the analogy terms.

To present the trial tasks of verbal analogies (egg : hen :: milk : ____ and summer : rain :: winter : ____), the following instruction was given: “Read attentively three successive words. The first two words make a pair with each other. Compare them to each other. Then you have a third word to which you will select the fourth word. You must complete it so as to form a pair similar to the pair that is formed by the first two words.” To give the verbal analogy tasks to deaf children, words—being the analogy terms—were substituted by signs, and the instruction was modified.

The series of verbal analogy tasks numbered 24 trials; each logical relation was contained in 8 trials. The list of verbal analogy tasks is included in Appendix 1. These tasks are grouped according to specific logical relation and are marked with successive numbers.

In order to estimate the solutions of verbal analogy tasks, the principles of singling out the correct and incorrect solutions were applied. These principles were formulated by Jurkowski (1967). In reference to the tasks concerning the part-whole relation, attention was directed to whether the whole given in solution was approximate to the whole in the first pair of analogy. With regard to the opposite relation, attention was directed to the mixing of two relations that are not identical in a logical respect: opposite and negation. With reference to the causality relation, attention was directed to whether the effect was of direct (not indirect) character. Furthermore, the answers had to be correct in respect to form: they had to have the appropriate case, tense, number (singular or plural), and mood. According to Jurkowski (1967), when estimating the solutions, researchers should omit hearing children’s spelling mistakes, because the purpose of the study is to examine the ability to reason analogically, not the ability to write.

Taking these categories of relations into consideration aimed to examine whether older deaf children can understand the logical relations irrespective of their category.

The numerical analogy tasks were selective tasks, that is, they required children to mark the answer that would complete the analogy.

For first numerical analogy task, the following instruction was given: “Look attentively at three rows of numbers. The first two rows make a pair with each other. Compare them to each other. Next you have the third row of numbers, to which you must select such a row of numbers from the rows given in parentheses so as to form a pair similar to the pair that is formed by the first two rows of numbers.”

The series of numerical analogy tasks contained 18 trials; each logical relation numbered 6 trials. This series presented the various mathematical functions. The set of numerical analogy tasks is included in Appendix 2. The tasks are marked with the successive numbers and with the symbols related to a certain relation (a—opposite, b—class membership, c—part-whole).

Tasks of figural-geometric analogies. The series of figural-geometric analogy tasks was constructed by Panasiuk (1990, 1995), who used this series for the studies of analogical reasoning in deaf and hearing children. This series took only two relations into consideration: opposite and part-whole, because according to Panasiuk (1995) “it was difficult to establish a graphic picture of logical connection for the class membership relation” (p. 133).

The figural-geometric analogy tasks were selective tasks, that is, they required the children to choose one figure from among four different figures in order to complete the second pair of the analogy according to the particular logical relation.

For the first figural-geometric analogy task, the following instruction was given: “Look attentively at three figures. The first two figures make a pair with each other. Compare them to each other. Now look at the third figure, to which you should select such a figure from four figures given in parentheses so as to form a pair similar to the pair which is formed by the first two figures.”
The series of figural-geometric analogy tasks had 12 trials, 6 trials for each logical relation. The set of figural-geometric analogy tasks is included in Appendix 3. The tasks are marked with the successive numbers and with the symbols related to a certain relation (a—opposite, b—part-whole).

Procedure

The study was conducted in school rooms in conditions favoring attention to the tasks. The study was of an individual character, that is, only two persons (experimenter and subject) took part in the experiment, which consisted of one session. The deaf and hearing children were examined by a deaf researcher (the first author). This researcher is able to communicate with hearing persons, reading the utterances from their lips. By age 3 he had become deaf, so he can correctly pronounce the words and sentences in Polish, in which he is fluent. Furthermore, the hearing educators helped him convey the instructions concerning the analogy tasks when hearing children did not understand these instructions.

The session started by getting in touch with the subject. In order to contact the subject, conversations were initiated by asking questions concerning what he/she was interested in, whether he/she liked to learn, what subjects at school he/she liked, and so forth. Furthermore, DCDP were asked questions about whether their parents used sign language, and it was observed whether they could use this language fluently. This aimed to eliminate from the study those DCDP who did not have early and consistent contact with sign language.

Each subject was informed that he/she would solve interesting tasks. Next, after conveying the instructions and additional explanations, three series of analogy tasks were given in the established order. The actions performed by the subject were observed; in the series of verbal analogy tasks, the actions consisted of generating the term that would complete the analogy; in the series of nonverbal analogy tasks, the actions consisted in marking the chosen answer. While solving the verbal analogy tasks, hearing children first gave the answers in spoken language, then wrote down these answers on the card themselves (their answers in both languages corresponded with each other); deaf children gave the answers in sign language, and deaf children’s answers were written down by the experimenter. After the session, the child’s outcomes were noted on the sheet of record of results. The session with younger children lasted 45 to 60 min., and with older children, 30 to 45 min.

Results

The Development of Verbal Analogical Reasoning

The present section is related to deaf and hearing children’s understanding of verbal relations at different levels of difficulty (opposite, part-whole, and causality).

The opposite relation. The easiest relation for almost all the groups was the opposite relation, which was characterized by the highest mean scores.

Table 2  The means and standard deviations in tasks of verbal analogies based on the opposite relation

<table>
<thead>
<tr>
<th></th>
<th>DCDP</th>
<th>DCHP</th>
<th>HCHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger</td>
<td>5.250</td>
<td>0.854</td>
<td>2.1250</td>
</tr>
<tr>
<td>Older</td>
<td>6.1250</td>
<td>0.881</td>
<td>5.8750</td>
</tr>
<tr>
<td></td>
<td>0.881</td>
<td>6.9500</td>
<td>1.097</td>
</tr>
</tbody>
</table>

M—arithmetic mean; SD—standard deviation.

Table 3  The values of t test and the levels of significance of differences between the mean scores of (a) particular environmental groups at both levels of age, and (b) age groups (younger and older) in each population

<table>
<thead>
<tr>
<th>A comparison of younger environmental groups</th>
<th>A comparison of older environmental groups</th>
<th>A comparison of age groups (younger and older) in population</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCDP-DCHP, t(20) = 5.77, p &lt; 0.05</td>
<td>DCDP-DCHP, t(30) = 0.80, ns</td>
<td>DCDP, t(30) = 2.85, p &lt; 0.05</td>
</tr>
<tr>
<td>DCDP-HCHP, t(34) = 2.04, p &lt; 0.05</td>
<td>DCDP-HCHP, t(34) = 2.44, p &lt; 0.05</td>
<td>DCHP, t(21) = 6.89, p &lt; 0.05</td>
</tr>
<tr>
<td>DCHP-HCHP, t(25) = 6.90, p &lt; 0.05</td>
<td>DCHP-HCHP, t(34) = 3.18, p &lt; 0.05</td>
<td>HCHP, t(38) = 3.14, p &lt; 0.05</td>
</tr>
</tbody>
</table>

t—a value of function of student’s test; p—a level of significance.
With the exception of the comparison of older groups of DCDP and DCHP, the only significant differences were found in the mean scores with regard to understanding the opposite relation. In the population of DCHP, the increase in children’s understanding of the opposite relation is larger than in the others (DCDP and HCHP). In each population, there is a significant difference between age groups, younger and older, in terms of their understanding of the opposite relation. A general ANOVA three-way model with repeated measures in one factor has been applied to explore the interactions between group membership, age, and task. Because the interaction of three factors had been significant, $F(14, 686) = 3.79, p < 0.0001$, the analysis was followed by separate ANOVAs for particular tasks, with posthoc LSD tests. For the verbal opposite relation, the ANOVA showed a significant effect of age, $F(1, 98) = 65.82, p < 0.0001$; a significant effect of group, $F(2, 98) = 38.30, p < 0.0001$; and a significant interaction between age and group, $F(2, 98) = 15.33, p < 0.0001$. Posthoc LSD tests showed that in both DCHP groups the scores are low. All younger groups had lower scores in comparison with older ones. The scores of the younger DCDP group are not significantly different from the younger HCHP group, while in the older DCDP group the scores are a little lower.

The qualitative analysis. When solving task 22 (sell : buy :: rest : ____), hearing children completed the analogy by giving the words work, make, run, and labor. In contrast, deaf children coming from two linguistic environments tended to complete this analogy by giving one term (work). Hearing children are able to go beyond the schematic connections and operate on a wider range of terms. A comparison of the wrong solutions given by all the groups of children in many tasks allows one to conclude that there are no qualitative differences between them. When solving trial 22 (sell : buy :: rest : ____), subjects gave terms of associative or situational character, such as lie, laze, and not work. In contrast, the inappropriate solutions given by younger DCHP constitute a separate category of errors. Almost all the tasks were completed by giving the terms that have no content relationship with any term of the analogy. In task 1 (well : badly :: nicely : ____), the following terms appeared: mess, wise, clothes, and writing.

The part-whole relation. The part-whole relation is a somewhat more difficult relation from the previous connection; the evidence is the lower mean score in each group.

With regard to their understanding of the part-whole relation, significant differences occur between the following groups: younger groups of DCDP and HCHP; younger groups of DCHP and HCHP; older groups of DCDP and DCHP; and older groups of DCHP and HCHP. No significant differences are found in the other comparisons. The developmental trend in the populations of DCDP and DCHP is greater than in the population of HCHP. Yet, the increase of results between age groups, younger and older, attains a significant level in each population. For

Table 4 The means and standard deviations in tasks of verbal analogies based on the part-whole relation

<table>
<thead>
<tr>
<th>Age group</th>
<th>DCDP M SD</th>
<th>DCHP M SD</th>
<th>HCHP M SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>2.625 0.957</td>
<td>1.937 1.609</td>
<td>4.700 1.894</td>
</tr>
<tr>
<td>Older</td>
<td>6.375 1.627</td>
<td>4.937 1.178</td>
<td>6.300 1.559</td>
</tr>
</tbody>
</table>

M—arithmetic mean; SD—standard deviation.

Table 5 The values of $t$ test and the levels of significance of differences between the mean scores of: a) particular environmental groups at both levels of age; b) age groups (younger and older) in each population

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>DCDP-DCHP, $t(24) = 1.46, ns$</td>
<td>DCDP-DCHP, $t(30) = 2.86, p &lt; 0.05$</td>
<td>DCDP-DCHP, $t(24) = 7.96, p &lt; 0.05$</td>
</tr>
<tr>
<td>DCDP-HCHP, $t(25) = 4.27, p &lt; 0.05$</td>
<td>DCDP-HCHP, $t(34) = 0.14, ns$</td>
<td>DCDP-HCHP, $t(34) = 2.89, p &lt; 0.05$</td>
</tr>
<tr>
<td>DCHP-HCHP, $t(34) = 4.65, p &lt; 0.05$</td>
<td>DCHP-HCHP, $t(34) = 2.89, p &lt; 0.05$</td>
<td>HCHP, $t(38) = 2.91, p &lt; 0.05$</td>
</tr>
</tbody>
</table>

$t$—a value of function of student’s test; $p$—a level of significance.

The qualitative analysis. When solving task 22 (sell : buy :: rest : ____), hearing children completed the analogy by giving the words work, make, run, and labor. In contrast, deaf children coming from two linguistic environments tended to complete this analogy by giving one term (work). Hearing children are able to go beyond the schematic connections and operate on a wider range of terms. A comparison of the wrong solutions given by all the groups of children in many tasks allows one to conclude that there are no qualitative differences between them. When solving trial 22 (sell : buy :: rest : ____), subjects gave terms of associative or situational character, such as lie, laze, and not work. In contrast, the inappropriate solutions given by younger DCHP constitute a separate category of errors. Almost all the tasks were completed by giving the terms that have no content relationship with any term of the analogy. In task 1 (well : badly :: nicely : ____), the following terms appeared: mess, wise, clothes, and writing.

The part-whole relation. The part-whole relation is a somewhat more difficult relation from the previous connection; the evidence is the lower mean score in each group.

With regard to their understanding of the part-whole relation, significant differences occur between the following groups: younger groups of DCDP and HCHP; younger groups of DCHP and HCHP; older groups of DCDP and DCHP; and older groups of DCHP and HCHP. No significant differences are found in the other comparisons. The developmental trend in the populations of DCDP and DCHP is greater than in the population of HCHP. Yet, the increase of results between age groups, younger and older, attains a significant level in each population. For
Table 6  The means and standard deviations in tasks of verbal analogies based on the causality relation

<table>
<thead>
<tr>
<th>Age group</th>
<th>DCDP M</th>
<th>DCHP M</th>
<th>HCHP M</th>
<th>DCDP SD</th>
<th>DCHP SD</th>
<th>HCHP SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>3.6250</td>
<td>0.9375</td>
<td>0.924</td>
<td>2.6000</td>
<td>1.666</td>
<td>5.2500</td>
</tr>
<tr>
<td>Older</td>
<td>5.625</td>
<td>1.786</td>
<td>1.578</td>
<td>5.2500</td>
<td>1.772</td>
<td>5.2000</td>
</tr>
</tbody>
</table>

M—arithmetic mean; SD—standard deviation.

The verbal part-whole relation, the ANOVA showed a significant effect of age, $F(1, 98) = 85.70, p < 0.0001$; a significant effect of group, $F(2, 98) = 16.30, p < 0.0001$; and a significant interaction of factors, $F(2, 98) = 4.65, p < 0.02$. The results of LSD tests suggest that all differences are significant, except the non-significant difference between younger groups of DCDP and DCHP.

The qualitative analysis. When solving task 23 (wool : sheep :: feathers : ____), younger DCDP tended to complete the analogy by giving concrete concepts such as hen, duck, peacock, goose, and pigeon, whereas younger HCHP tended to give the general concept bird. These proportions (37.5% and 65% using the concept bird) are equalized in older children (68.75% and 65%). In reference to task 17 (drawers : desk :: pockets : ____), one can observe a different tendency. DCDP from both age groups (18.75% and 37.5%) gave the general name clothes more frequently than HCHP (5% and 20%) who in turn gave more names of certain kinds of clothes: jacket, trousers, coat, and blouse. Furthermore, in task 14 (corridors : school :: streets : ____), one can notice associative terms, such as cars, courtyard, houses, shops, and street-lamps. In trial 8 (minute : hour :: centimeter : ____), distance terms such as kilometer, decimeter, millimeter were given by children. These errors occurred most frequently in younger children and more frequently in the deaf than in the hearing.

Table 7  The values of $t$ test and the levels of significance of differences between the mean scores of: a) particular environmental groups at both levels of age; b) age groups (younger and older) in each population

<table>
<thead>
<tr>
<th>A comparison of younger environmental groups</th>
<th>A comparison of older environmental groups</th>
<th>A comparison of age groups environmental groups (younger and older) in population</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCDP-DCHP, $t(24) = 5.99, p &lt; 0.05$</td>
<td>DCDP-DCHP, $t(30) = 3.15, p &lt; 0.05$</td>
<td>DCDP, $t(30) = 3.28, p &lt; 0.05$</td>
</tr>
<tr>
<td>DCDP-HCHP, $t(34) = 1.89, ns$</td>
<td>DCDP-HCHP, $t(34) = 0.52, ns$</td>
<td>DCHP, $t(24) = 0.03, p &lt; 0.05$</td>
</tr>
<tr>
<td>DCHP-HCHP, $t(26) = 3.79, p &lt; 0.05$</td>
<td>DCHP-HCHP, $t(34) = 2.76, p &lt; 0.05$</td>
<td>HCHP, $t(38) = 4.88, p &lt; 0.05$</td>
</tr>
</tbody>
</table>

$t$—a value of function of student’s test; $p$—a level of significance.

The causality relation. The most difficult relation expressed verbally is the causality relation, which was characterized by the lowest mean scores.

With regard to their understanding of the causality relation, significant differences are observed between younger groups of DCDP and DCHP, younger groups of DCHP and HCHP, older groups of DCDP and DCHP, and older groups of DCHP and HCHP. The other comparisons did not show significant differences. The increase in their understanding of the causality relation in the population of DCDP is somewhat less than in the other populations (DCHP and HCHP); the increase of scores is significant in each population. For the verbal causality relation, the ANOVA showed a significant effect of age, $F(1, 98) = 61.12, p < 0.0001$, and a significant effect of group, $F(2, 98) = 17.63, p < 0.0001$. No significant interaction, $F(2, 98) = 0.63, ns$, was found. All younger groups had lower scores when compared to older ones, and the DCHP groups had lower scores in comparison to other groups.

The qualitative analysis. In task 6 (frosts : ice :: rain : ____), which required children to recognize a direct causal relationship between atmospheric phenomena, DCDP gave the terms such as flood, mud, and puddles, and HCHP gave only this last label. Trial 12 (bomb : ruins :: thunderbolt : ____), which concerns acoustic phenomena, was much easier for groups of DCDP than for groups of HCHP. In DCDP, one can observe solutions that refer to visually perceived phenomena (destructions, fire, flame, and overturned tree), and in HCHP one can observe only the first three words. Moreover, in task 6 (frosts : ice :: rain : ____), one can notice associative responses such as water, storm, wetly, and thunderbolt. When solving trial 9 (inattention : accident :: lack of food : ____), instead of
the required term hunger, terms such as death and illness appeared. Here the effect is of an indirect character. These errors are characteristic for each group, yet most errors appear in younger children, more often in DCHP than in DCDP and HCHP.

The Development of Numerical Analogical Reasoning

The next set of trials given to children was a series of numerical analogy tasks that represented three categories of logical relations: class membership, opposite and part-whole.

The class membership relation. The easiest connection is the class membership relation, and the mean scores in this relation have the highest values.

With regard to their understanding of the class membership relation, a significant difference appears solely between younger groups of DCHP and HCHP; no significant differences in the other comparisons of environmental groups at both levels of age are found. A larger increase in terms of their understanding of the class membership relation is observed in the population of DCHP, and in the others a smaller one. In contrast, the increase of scores is significant only in the population of DCHP. For the numerical class membership relation, the ANOVA showed a significant effect of age, F(1, 98) = 11.69, p < 0.001; a significant effect of group, F(2, 98) = 3.82, p < 0.05; and a nonsignificant interaction of factors, F(2, 98) = 2.70, p < 0.08. The LSD tests show that only the younger DCHP group has significantly lower scores in comparison to other younger ones.

The qualitative analysis. The mathematical functions in all the numerical analogy tasks based on the class membership relation are the same and take the form: (n + n + n + n) : (4m) :: (m + m + m) : (3m). The children had to infer the multiplication of some identical elements by their number from the addition of these elements. The most frequent error, typical for all the groups, was a kind of repetition of the analogy’s B term. In task 2, (8 + 8) : (8 · 2) :: (2 + 2 + 2 + 2) : (____), the row of numbers (2 · 8) was mostly given.

The opposite relation. A somewhat more difficult relation from the previous connection is the opposite relation, which is characterized by lower mean scores.

The differences between scores of younger groups of DCDP and DCHP and younger groups of DCHP and HCHP are significant, and the differences between scores of the other groups do not show a significant level. The increase in their understanding of the opposite relation—greater in the environmental groups of DCDP and DCHP, smaller in the population of HCHP—is significant only in the first two groups. For the numerical opposite relation, the ANOVA showed a significant effect of age, F(1, 98) = 11.51, p < 0.001; a significant effect of group, F(2, 98) = 3.49, p < 0.05; and a nonsignificant interaction of factors, F(2, 98) = 1.85, p < 0.2. The LSD tests show that only the younger DCHP group has significantly lower scores in comparison to other younger ones.

Table 9 The values of t test and the levels of significance of differences between the mean scores of: a) particular environmental groups at both levels of age; b) age groups (younger and older) in each population

<table>
<thead>
<tr>
<th></th>
<th>A comparison of younger environmental groups</th>
<th>A comparison of older environmental groups</th>
<th>A comparison of age groups (younger and older) in population</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCDP-DCHP</td>
<td>t(23) = 1.87, ns</td>
<td>DCDP-DCHP, t(30) = 0.90, ns</td>
<td>DCDP, t(20) = 1.71, ns</td>
</tr>
<tr>
<td>DCDP-HCHP</td>
<td>t(34) = 0.40, ns</td>
<td>DCDP-HCHP, t(29) = 0.53, ns</td>
<td>DCHP, t(17) = 2.65, p &lt; 0.05</td>
</tr>
<tr>
<td>DCHP-HCHP</td>
<td>t(23) = 2.21, p &lt; 0.05</td>
<td>DCHP-HCHP, t(34) = 0.30, ns</td>
<td>HCHP, t(38) = 1.04, ns</td>
</tr>
</tbody>
</table>

* t—a value of function of student’s test; p—a level of significance.
The qualitative analysis. The mathematical functions in most numerical analogy tasks based on the opposite relation have the following schema: \((n, n + 2, n + 4) : (n + 4, n + 2, n) \rightarrow (m, m + 1, m + 2) : (m + 2, m + 1, m)\). These tasks required children to infer the diminishing sequence from the growing sequence. The most frequent error, typical for all the groups, was to infer the growing sequence from the growing sequence. In task 8, \((3, 6, 9) : (18, 15, 12) \rightarrow (6, 9, 12) \rightarrow (____)\), two rows of numbers \((15, 18, 21)\) and \((4, 7, 10)\) appeared.

The part-whole relation. The most difficult connection, the part-whole relation, is characterized also by the lowest mean indicators.

With the exception of the comparison of older groups of DCHP and HCHP, no significant differences in the understanding of the part-whole relation were found in the comparisons. The increase in populations of DCDP and HCHP in their understanding of the part-whole relation is larger than in the population of DCHP; this increase is significant only in the first two groups. For the numerical part-whole relation, the ANOVA showed a significant effect of age, \(F(1, 98) = 23.96, p < 0.0001\); a significant effect of group, \(F(2, 98) = 3.25, p < 0.05\); and a nonsignificant interaction of factors, \(F(2, 98) = 1.19, p > 0.4\). As the LSD analysis shows, the older DCHP group has lower scores in comparison with other older ones.

### Table 10

The means and standard deviations in tasks of numerical analogies based on the opposite relation

<table>
<thead>
<tr>
<th>Age group</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>4.5000</td>
<td>0.894</td>
<td>3.5625</td>
<td>1.457</td>
<td>4.5000</td>
<td>0.888</td>
</tr>
<tr>
<td>Older</td>
<td>5.1250</td>
<td>0.802</td>
<td>4.7500</td>
<td>0.575</td>
<td>4.7500</td>
<td>1.249</td>
</tr>
</tbody>
</table>

M—arithmetic mean; SD—standard deviation.

### Table 11

The values of \(t\) test and the levels of significance of differences between the mean scores of (a) particular environmental groups at both levels of age, and (b) age groups (younger and older) in each population

<table>
<thead>
<tr>
<th>A comparison of younger environmental groups</th>
<th>A comparison of older environmental groups</th>
<th>A comparison of age groups (younger and older) in population</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCDP-DCHP, (t(25) = 2.20, p &lt; 0.05)</td>
<td>DCDP-DCHP, (t(29) = 1.52, ns)</td>
<td>DCDP, (t(30) = 2.09, p &lt; 0.05)</td>
</tr>
<tr>
<td>DCDP-HCHP, (t(34) = 0.00, ns)</td>
<td>DCDP-HCHP, (t(29) = 1.09, ns)</td>
<td>DCHP, (t(20) = 3.05, p &lt; 0.05)</td>
</tr>
<tr>
<td>DCHP-HCHP, (t(28) = 2.26, p &lt; 0.05)</td>
<td>DCHP-HCHP, (t(24) = 0.00, ns)</td>
<td>HCHP, (t(38) = 0.73, ns)</td>
</tr>
</tbody>
</table>

\(t\)—a value of function of student’s test; \(p\)—a level of significance.
identity and take a 180° rotation of figures into consideration. The most frequent error, which occurs mostly in both groups of HCHP and younger group of DCHP, was the maintenance of the analogy’s C term. When solving task 3, the answer (number 2) was given, which does not take the 180° rotation into consideration. The chosen figure, a diamond with a particular element on the left, is not rotated 180° in relation to the identical figure in the C term.

The part-whole relation. A more difficult connection is the part-whole relation, and mean indicators in this relation have lower values.

The differences in the understanding of the part-whole relation between the scores of particular environmental groups at both levels of age do not show a significant level. The increase of scores in understanding the part-whole relation in the population of DCDP is larger than in the other populations (DCHP and HCHP); this increase is significant only in the populations of DCDP and HCHP. For the spatial part-whole relation, the ANOVA showed a significant effect of age; \( F(1, 98) = 20.47, p < 0.0001 \); a nonsignificant effect of group; \( F(2, 98) = 1.63, p < 0.2 \); and a nonsignificant interaction of factors, \( F(2, 98) = 1.01, p < 0.4 \). The LSD tests show that the younger groups have lower scores.

The qualitative analysis. All the figural-geometric analogy tasks based on the part-whole relation require a precise analysis and synthesis of the appearance of elements of particular figures. The most frequent error, typical for all the groups, was the transfer of opposite relation. This kind of error is observed in task 9 (number 1). Here the figure chosen as the analogy completion is rotated 180° in relation to the identical figure in the C term. The number of errors decreases with increasing age.

**Discussion**

The aim of the present study was to verify the hypotheses about the almost equivalent influence of early and consistent sign-language communication on the development of verbal and nonverbal thought processes in deaf children. Hence, the empirical data selected during the conducted study allow not only the evaluation of the level of mental development of deaf children coming from two different linguistic environments, but also the comparison of these children to hearing children.

The results of this study support the general hypothesis that early and consistent sign-language communication determines the emergence of similar abilities to understand the logical relations expressed verbally and nonverbally in deaf children at the same time as in hearing children with early and consistent exposure to spoken language. The quantitative and qualitative similarity in performance between DCDP and HCHP can mean that children from both populations possess a similar complex conceptual system, which is required to solve the analogy tasks that have a complicated logical structure. This system has been shaped on the basis of a verbal and nonverbal symbolic system. If DCDP, like HCHP, are able to recognize the analogy between similar logical relations, one should expect that from early childhood the analogy

| Table 12  The means and standard deviations in tasks of numerical analogies based on the part-whole relation |
|----------------|----------------|----------------|
|                | DCDP           | DCHP           | HCHP           |
|                | M   | SD  | M   | SD  | M   | SD  |
| Age group      |     |     |     |     |     |     |
| Younger        | 2.6875 | 1.446 | 2.3750 | 1.257 | 2.7500 | 1.831 |
| Older          | 4.5625 | 1.894 | 3.2500 | 1.914 | 4.7500 | 1.369 |
| M—arithmetic mean; SD—standard deviation. |

| Table 13  The values of \( t \) test and the levels of significance of differences between the mean scores of (a) particular environmental groups at both levels of age and (b) age groups (younger and older) in each population |
|----------------|----------------|----------------|----------------|
| A comparison of younger environmental groups | A comparison of older environmental groups | A comparison of age groups (younger and older) in population |
| DCDP-DCHP, \( t(30) = 0.65, \) ns          | DCDP-DCHP, \( t(30) = 1.95, \) ns          | DCDP, \( t(30) = 3.15, p < 0.05 \)          |
| DCDP-HCHP, \( t(34) = 0.11, \) ns          | DCDP-HCHP, \( t(34) = 0.34, \) ns          | DCHP, \( t(30) = 1.53, \) ns          |
| DCHP-HCHP, \( t(34) = 0.69, \) ns          | DCHP-HCHP, \( t(34) = 2.74, p < 0.05 \)          | HCHP, \( t(38) = 3.91, p < 0.05 \)          |
| \( t \)—a value of function of student’s test; \( p \)—a level of significance. |
plays a role in their cognitive development, on condition that these children have a consistent contact with a suitable linguistic system from birth. Sign-language communication, like spoken-language communication, is an effective tool leading to the emergence of similar cognitive abilities in the appropriate time; this is confirmed by the results of studies carried out by Braden (1987), Brill (1974), Courtin (1997, 2000a, 2000b; Courtin & Melot, 1998), Sisco and Anderson (1980), and Zwiebel (1987). Yet the precise quantitative and qualitative analysis of performances in the different tasks has revealed some differences between DCDP and HCHP, for which there are many possible explanations.

One of the three detailed hypotheses, which suggested that deaf children with early and consistent exposure to sign language understand the different relations expressed in sign language in a similar way as hearing children (with early and consistent exposure to spoken language) who understand the relations expressed in spoken language, is partially confirmed by the results of this study, because significant differences were revealed in the series of verbal analogy tasks based on the opposite relation. As Furth (1966, 1971a) notices, the education of deaf children consists only in repeating the specific actions or expressions of a concrete character; it can lead to the impoverishment of their linguistic and nonlinguistic experiences. It seems that not taking into consideration the opposing terms of abstract character (signs, words) in the didactic process can result in the concreteness of deaf children’s thinking regardless of whether they have early and consistent contact with sign language.

Yet, the series of verbal analogy tasks based on the part-whole relation has revealed some interesting information. It refers especially to younger DCDP who—compared to younger HCHP—obtained worse results in many verbal analogy tasks containing the part-whole relation. The explanations for their failures perhaps are such factors as the inappropriate acquisition of the contents of some concepts or the difficulties in the multisensory association of information coming from the setting. The fact that the poor performance of younger DCDP is due to the restricted transmission of information concerning the perceptual (color, shape, size, and element) and functional (application) properties of perceived objects relates to the teachers’ use of ineffective communicative systems. In the Polish educational system, the education of deaf children takes place mostly either in spoken language or in

### Table 14

<table>
<thead>
<tr>
<th>Age group</th>
<th>DCDP M (SD)</th>
<th>DCHP M (SD)</th>
<th>HCHP M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>5.8125 (0.539)</td>
<td>5.4375 (0.811)</td>
<td>5.3000 (1.081)</td>
</tr>
<tr>
<td>Older</td>
<td>5.9375 (0.241)</td>
<td>5.9375 (0.241)</td>
<td>5.5000 (1.000)</td>
</tr>
</tbody>
</table>

M—arithmetic mean; SD—standard deviation.

### Table 15

<table>
<thead>
<tr>
<th>A comparison of younger environmental groups</th>
<th>A comparison of older environmental groups</th>
<th>A comparison of age groups (younger and older) in population</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCDP-DCHP, t(30) = 1.54, ns</td>
<td>DCDP-DCHP, t(30) = 0.00, ns</td>
<td>DCDP, t(20) = 0.86, ns</td>
</tr>
<tr>
<td>DCDP-HCHP, t(25) = 1.86, ns</td>
<td>DCDP-HCHP, t(19) = 1.89, ns</td>
<td>DCHP, t(17) = 2.35, p &lt; 0.05</td>
</tr>
<tr>
<td>DCHP-HCHP, t(34) = 0.42, ns</td>
<td>DCHP-HCHP, t(19) = 1.89, ns</td>
<td>HCHP, t(38) = 0.60, ns</td>
</tr>
</tbody>
</table>

t—a value of function of student’s test; p—a level of significance.
an artificial sign system (Tomaszewski, 1999); this obstructs them in the appropriate acquisition of the contents of concepts referring not only to the various concrete objects, but also to mathematics. Mathematical concepts such as month, year, day, week, minute, hour, centimeter, and meter, contain many dimensions, so it can be necessary to possess the multidimensional semantic space in the mind in order to establish a degree of distance between these concepts (Biela, 1981; Trzebiński, 1981). As a result of being educated in ineffective communicative systems, DCDP probably possess the semantic space with a restricted number of dimensions in the early school education period; this can contribute to the poor formation of part-whole concepts in their mind.

Another possible source of the failure of younger DCDP to understand the part-whole relation is their difficulty in the multisensory association of stimuli, which is mentioned by Gałąkowski (1998) when describing Baron-Cohen’s experimental analysis of Eye-Direction Detector (EDD) and Shared-Attention Mechanism (SAM), important in nonlinguistic communication. The function of these regulative mechanisms is to form a common attention field in the communication process, to which the necessity of the use of both the visual and auditory modality channels relates. In the communication process that is of triadic character (child–parent–object), there is an interpretation phenomenon that is related to giving a meaning to the observed objects. Then, during intensive concentration on the given object (e.g., a flower), the child simultaneously associates the stimuli coming from the object with the symbolic stimuli coming from the parent. Multisensory association of information involves sniffing, touching, and seeing the object and receiving symbolic information about it, so it requires the simultaneous use of the different modalities of the senses—vision, hearing, smell, and touch. In DCDP, in contrast, owing to their deafness, the difficulties in multisensory association of stimuli emerge in the early life period. When encountering unfamiliar objects, these children can observe, yet they cannot simultaneously receive information about their perceptual and functional properties. In this connection, as Tomaszewski (2000a, 2001) notices, the process of shifting the child’s attention from the object to a person conveying the information about this object and back occurs. The delayed reception of information about objects in early childhood can lead to a restricted understanding of the part-whole relation in the early school period, but only in some spheres. It refers to some verbal analogy tasks, such as juice : plant :: blood : ____.

This task contains the biological concepts that are certainly familiar to younger DCDP, but which, linked according to the part-whole relation, give them difficulties in understanding this relation.

In contrast, the series of verbal analogy tasks based on the causality relation has not revealed significant differences between environmental groups of DCDP and HCHP at both levels of age. This could be evidence of the similarity between the cognitive structures that are responsible for the operations on the most difficult relation, the causality relation. Yet, one should point out that in the case of both populations, the process of becoming mental

<table>
<thead>
<tr>
<th>Table 16</th>
<th>The means and standard deviations in tasks of figural-geometric analogies based on the part-whole relation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age group</strong></td>
<td><strong>DCDP</strong></td>
</tr>
<tr>
<td><strong>M</strong></td>
<td><strong>SD</strong></td>
</tr>
<tr>
<td>Younger</td>
<td>2.6250</td>
</tr>
<tr>
<td>Older</td>
<td>4.5625</td>
</tr>
</tbody>
</table>

M—arithmetic mean; SD—standard deviation.

<table>
<thead>
<tr>
<th>Table 17</th>
<th>The values of t test and the levels of significance of differences between the mean scores of (a) particular environmental groups at both levels of age and (b) age groups (younger and older) in each population</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A comparison of younger environmental groups</strong></td>
<td><strong>A comparison of older environmental groups</strong></td>
</tr>
<tr>
<td><strong>(younger and older) in population</strong></td>
<td></td>
</tr>
<tr>
<td>DCDP-DCHP, t(30) = 0.14, ns</td>
<td>DCDP-DCHP, t(24) = 2.03, ns</td>
</tr>
<tr>
<td>DCDP-HCHP, t(34) = 0.62, ns</td>
<td>DCDP-HCHP, t(34) = 0.75, ns</td>
</tr>
<tr>
<td>DCHP-HCHP, t(29) = 0.82, ns</td>
<td>DCHP-HCHP, t(34) = 1.28, ns</td>
</tr>
</tbody>
</table>

t—a value of function of student’s test; p—a level of significance.
operations independent of the categories of relations on which these operations are performed occurs in early adolescence. Older DCDP and HCHP, in contrast to younger DCDP and HCHP, have shown an understanding of logical relations regardless of their category; this is evidence of attaining a formal thinking level. Furthermore, when solving the verbal analogy tasks based on the causality relation, it is necessary to coordinate the mental operations because these tasks require the recognition of the direct (not indirect) causal connection between the specific phenomena, and the knowledge about these phenomena itself is not sufficient to solve these tasks correctly. The coordination of mental operations is possible when these operations become independent of the category of logical relations (Jurkowski, 1967). This suggests that early and consistent sign-language communication can—to some extent—influence the emergence of abilities to coordinate the mental operations, as does early and consistent spoken-language communication.

With regard to deaf children who do not have early and consistent contact with sign language (that is, DCHP), they have shown a considerably lower level of understanding of the different verbal relations than do DCDP and HCHP. The lack of understanding by younger DCHP of some expressions in the analogy terms, and their difficulties in understanding particular relations, can indicate that these children have a restricted conceptual system that does not allow them to rapidly grasp the concepts of opposite, part-whole, and causality while solving the tasks. These data support the claim that deaf children’s early and consistent contact solely with spoken language deprives them of the possibility of knowing the world fully. This is because the information that reaches them by means of linguistic code is not of visual character and often is omitted by them in cognitive and linguistic processing (Tomlinson-Keasey & Kelly, 1974, 1978) if this processing takes place in their mind. Moreover, the considerably lower level of understanding of the causality relation found in older DCHP is a sign of lack of coordination of logical operations, and thus their thinking does not attain a formal operational level. The cause of their delay may not only be the lack of early and consistent sign-language communication, but also an incomplete participation in the family life and events connected with it. Talking about some events connected with the family and social life in sign language is one factor that enriches deaf children’s linguistic and nonlinguistic experience; it promotes the development of the cognitive structures responsible for the coordination of mental operations.\(^5\)

The results of the conducted study in terms of the understanding of the numerical relations are inconsistent with the second detailed hypothesis that the education of deaf children with early and consistent exposure to sign language in the artificial sign system or spoken language contributes to the emergence of the abilities to understand the numerical relations in them somewhat later than in hearing children with early and consistent exposure to spoken language. The lack of quantitative and qualitative differences between DCDP and HCHP in terms of their understanding of the different numerical relations may be evidence that a similar complex conceptual system does function in their minds. This lack of significance could result from the fact that DCDP—already in preschool and the early school period—probably learn the various arithmetic actions of reversible character, such as addition, subtraction, multiplication, and division, from their parents. Such a situation is possible because these parents use sign language in the interaction with their children and can convey basic mathematical knowledge to them by means of this language. Early learning of arithmetic actions allows children to memorize them and later leads to a widening of the knowledge about relations occurring between mathematical functions.

The somewhat poorer performances of both age groups of DCHP in the numerical analogy tasks—compared to performances of DCDP and HCHP—should be attributed to a low level of cognitive competence, which occurs in the early period of their life and which is a consequence of hearing parents’ use of spoken language in their interaction with these children. This language does not fulfil the specific conditions of deaf children’s development because it requires the use of the auditory channel in the communication process. Deaf children can—solely in
a visual way—receive the semantic, symbolic, and spatial information that in turn they process into new information also of visual character. Young DCHP cannot receive a variety of information referring to the perceptual and functional properties of perceived objects and phenomena, and for this reason they process and produce less information; it makes them individuals of a low thinking level. Hence, it is possible that these children may not show the readiness to learn numerical concepts in school. Such an interpretation is consistent with Sisco and Anderson’s (1980) and Zwiebel’s (1987) viewpoints. Yet, it is important to note that older DCHP, in contrast to older DCDP and HCHP, correctly solved the numerical analogy tasks depending on the category of logical relations that are contained in them. This means that they are unable to coordinate the mental operations, showing thus a concrete thinking level. This also allows us to believe that their cognitive structures accountable for the operations on the most difficult relation—the part-whole relation—do not attain a higher level of functioning because of the delay in general mental development, which is found in the early period of their life. This delay is due probably to a lack of communication in sign language.

The results in terms of the children’s understanding of the spatial relations are partially consistent with the last detailed hypothesis that early and consistent exposure to the grammatical structures of sign language, in contrast to early and consistent exposure to the grammar of spoken language, determines the differences between deaf and hearing children in the recognition of spatial relations, to hearing children’s disadvantage. Although no significant superiority of DCDP to HCHP is found in terms of their understanding of the spatial relations, the differences between them are so large that one can claim about an influence of grammatical structures of sign language on the intensive development of visual-spatial abilities in deaf children. In reference to the figural-geometric analogy tasks based on the opposite relation, some improvement in their understanding of this relation is observed in DCDP from both age groups. These tasks require children to discover the principle of figure identity when taking the 180° rotation of figures into consideration, so the sophisticated improvement of DCDP with regard to their understanding of the opposite relation can be connected with the reversal interpretation, which is the skill revealed quite frequently in the processing of sign language grammar (Emmorey, Kosslyn, & Bellugi, 1993). This means that if the perceptual-spatial experience of DCDP corresponds with the content of abstract-spatial reasoning tasks, these children can show a higher level of understanding of the logical spatial relations than HCHP. Furthermore, on account of the fact that the series of figural-geometric analogy tasks was not of speed character, significant differences could not occur between the mentioned environmental groups. It is confirmed by the results of experiments conducted by American psychologists (Braden, 1987; Emmorey, Kosslyn, & Bellugi, 1993), who state that DCDP can be faster than HCHP in the visual-spatial information processing.

That there is a quantitative and qualitative similarity between the particular environmental groups—DCDP, DCHP, and HCHP—at both levels of age in their understanding of the spatial relations may confirm Furth’s (1971b, 1991) thesis about the lack of influence of language on the development of some nonverbal spheres of logical thinking in deaf children. This is all the more so because he considers the possibility that other factors play a role in the development of a conceptual system in deaf children, especially DCHP, namely that DCHP construct their own verbal and nonverbal symbols (gestures and images), which can help them to develop logical thinking. Furth’s reflections are confirmed by the results of preliminary studies conducted by Tomaszewski (2000b, 2001), who examined the influence of biological factors on the formation and development of grammatical structures of gestural language in DCHP having contact solely with spoken language in the preschool environment. In such an environment, these children constructed three- and four-gesture utterances that in the grammatical respect resembled sign language structures, so they were created according to the rules of visual-spatial grammar. Moreover, these utterances consisted not only of gestures, but also of negations, with the gestures being the lexical means of a symbolic form, that is, they were not idiosyncratic gestures. It seems that deaf child-
ren’s use of symbolic gestures can reflect their general mental development and to some extent influence the development of logical thinking, as Furth (1971b, 1991) suggests. In contrast, the understanding and use of negations by them could point to an understanding of specific social phenomena (e.g., a ban on making something, denying the facts). So communication in gestural language, possessing some elements of visual-spatial grammar, can promote both the formation of concepts (e.g., spatial concepts) and the intensive processing of visual-spatial information, and then lead to the understanding of spatial relations by DCHP in the school period.

The understanding and use of logical relations regardless of their category as a sign of formal thinking (Jurkowski, 1961, 1967) is an example of metacognitive skill that is connected with the ability to consciously and purposefully use the higher-order relations when solving the tasks irrespective of task content (Goswami, 1991). This metacognitive skill is found among older children only in the populations of DCDP and HCHP. When solving the successive analogy tasks based on the most difficult relations (verbal causality relation, numerical part-whole relation, and spatial part-whole relation), these children showed a high level of conscious use of these relations; owing to this, most analogy tasks were correctly solved. In order to understand and use the mentioned logical relations, it is necessary to possess the general knowledge as well as select the mental operations appropriate for the task content and combine them in a systematic way. Furthermore, the skill of solving the verbal and nonverbal analogy tasks that contain opposite, part-whole, causality, and class membership relations is the ability to recognize the similarity between logical relations (not the similarity between the exterior features within these tasks). The fact that this skill is observed entirely in DCDP and HCHP means that the concepts of opposite, part-whole, causality, and class membership do function in their minds, so these children do not rely on the perceptually visible features of tasks while solving them, but are using a complex conceptual system.

In contrast, DCHP from both age groups have less linguistic experience in the area of sign language. This experience consists of both the familiarity of signs as the equivalents of words and the knowledge about the relations occurring between signs, being the symbolic labels of reality elements. The lack of some part of knowledge about the relations found in DCHP definitely distinguishes them from children from other populations; it appears to be consistent with Goswami’s (1991, 1996) thesis, according to which the skill of solving the analogy tasks is determined by the familiarity of relations on which these tasks are based. As regards their nonlinguistic experience, which is most frequently connected with casual learning, it is so rich that it enables them to solve many nonverbal tasks, such as the figural-geometric analogy tasks and some numerical analogy tasks. Attention should be paid to the character of tasks presented to children. The verbal and numerical analogy tasks, in contrast to the figural-geometric analogy tasks, comprise linguistic and mathematical symbols that are socially shared symbols, and hence it is necessary to acquire them in order to achieve the possibility of functioning in the society normally. Yet, because of a low level of cognitive competence resulting from the lack of exposure to sign language in early childhood, DCHP have difficulties in acquiring these symbols; owing to this, they show a delay in the development of understanding some verbal and numerical relations and thus do not attain a formal thinking level at the appropriate time. It does not mean that the ability to coordinate mental operations is not available to these children. This ability can emerge in their development later than in the case of HCHP (Furth, 1991; Furth & Youniss, 1975). However, one should carefully interpret the outcomes obtained by DCHP in the verbal analogy tasks, because it could appear that poor linguistic abilities—rather than delays in the analogical reasoning development—are accountable for the lower results in groups of DCHP. The evidence for this is that their outcomes in the figural-geometric analogy tasks are comparable to the results of children from the other groups, indicating that these children are able to reason by analogy.

In summary, Sharpe’s (1985) claim that deaf children’s gestural-visual communication mode is inferior to hearing children’s oral-aural communication mode is not confirmed by the results of this study. One should state that not only early and consistent
sign-language communication, but also deaf children’s own activity, can affect the character of their linguistic and nonlinguistic experiences. Knowledge, thinking tools, and linguistic patterns are conveyed by adults by means of sign language to these children, and their own activity is determined by the biological endowment of organism (the quality of genes); these factors—environmental and genetic—interact, leading through the successive stages of their development to the emergence of complex forms of cognition. On the other hand, it is worth emphasizing that the results of this study should be treated with caution. As mentioned earlier, the hearing children were examined by a researcher who is deaf but who also uses Polish language fluently. It also should be pointed out that the hearing children’s results in this study are comparable to the (hearing) children’s outcomes in the studies by Jurkowski (1961, 1967) and Pietrulewicz (1983). Therefore, it would be necessary to conduct a similar study of the development of analogical reasoning in deaf and hearing children in order to confirm the results of the presented study. This study could be carried out by both the deaf and hearing researchers.

Appendix 1: A Set of Verbal Analogy Tasks

The series of verbal analogy tasks based on the opposite relation

1. well : badly :: nicely : ____
2. light : heavy :: expensive : ____
3. sad : merry :: industrious : ____
4. ill : healthy :: rich : ____
5. month : year :: day : ____
6. poison : death :: food : ____
7. frosts : ice :: rain : ____
8. inattention : accident :: lack of food : ____
9. bomb : ruins :: thunderbolt : ____
10. bath : bathroom :: blanket : ____
11. corridors : school :: streets : ____
12. shelves : cupboard :: storeys : ____
13. lie : truth :: love : ____
14. corridors : school :: streets : ____
15. learn : knowledge :: work : ____
16. far : near :: long : ____
17. drawers : desk :: pockets : ____
18. sadness : weeping :: joy : ____
19. clearness : darkness :: white : ____
20. juice : plant :: blood : ____
21. downpour : wetly :: heat : ____
22. sell : buy :: rest : ____
23. wool : sheep :: feathers : ____

The series of verbal analogy tasks based on the part-whole relation

1. well : badly :: nicely : ____
2. light : heavy :: expensive : ____
3. sad : merry :: industrious : ____
4. ill : healthy :: rich : ____
5. month : year :: day : ____
6. poison : death :: food : ____
7. frosts : ice :: rain : ____
8. inattention : accident :: lack of food : ____
9. bomb : ruins :: thunderbolt : ____
10. bath : bathroom :: blanket : ____
11. corridors : school :: streets : ____
12. shelves : cupboard :: storeys : ____
13. lie : truth :: love : ____
14. corridors : school :: streets : ____
15. learn : knowledge :: work : ____
16. far : near :: long : ____
17. drawers : desk :: pockets : ____
18. sadness : weeping :: joy : ____
19. clearness : darkness :: white : ____
20. juice : plant :: blood : ____
21. downpour : wetly :: heat : ____
22. sell : buy :: rest : ____
23. wool : sheep :: feathers : ____

The series of verbal analogy tasks based on the causality relation

1. well : badly :: nicely : ____
2. light : heavy :: expensive : ____
3. sad : merry :: industrious : ____
4. ill : healthy :: rich : ____
5. month : year :: day : ____
6. poison : death :: food : ____
7. frosts : ice :: rain : ____
8. inattention : accident :: lack of food : ____
9. bomb : ruins :: thunderbolt : ____

Appendix 2: A Set of Numerical Analogy Tasks (The Meanings of Symbols: a—The Opposite Relation, b—The Class Membership Relation, c—The Part-Whole Relation)

1a. \( (2 + 1) : (2 - 1) :: (7 + 3) : (____) \)
   \( (2 + 1) \ a \)
   \( (7 - 3) \ b \)
   \( (8 - 2) \ c \)
   \( (3 + 7) \ d \)

2b. \( (8 + 8) : (8 \cdot 2) :: (2 + 2 + 2 + 2) : (____) \)
   \( (3 \cdot 3) \ a \)
   \( (2 \cdot 8) \ b \)
   \( (8 + 2) \ c \)
   \( (2 \cdot 4) \ d \)
3c. 4 : 8 :: 3 : (____)
   (9) a
   (6) b
   (10) c
   (12) d

4b. (4 + 4 + 4) : (4 · 3) :: (5 + 5 + 5) : (____)
   (3 · 4) a
   (5 · 4) b
   (4 + 3) c
   (5 + 4) d

5a. (8 · 4) : (8 : 4) :: (6 · 2) : (____)
   (6 : 2) a
   (12 : 2) b
   (4 · 1) c
   (8 : 2) d

6c. 8 : 24 :: 5 : (____)
   (10) a
   (20) b
   (16) c
   (15) d

7b. (6 + 6 + 6 + 6) : (6 · 4) :: (2 + 2 + 2 + 2) : (____)
   (4 + 6) a
   (2 · 6) b
   (2 · 4) c
   (6 + 2) d

8a. (3, 6, 9) : (18, 15, 12) :: (6, 9, 12) : (____)
   (15, 18, 21) a
   (13, 14, 15) b
   (13, 10, 7) c
   (4, 7, 10) d

9c. 6 : 18 :: 4 : (____)
   (8) a
   (16) b
   (12) c
   (20) d

10b. (1 + 1 + 1) : (1 · 3) :: (4 + 4) : (____)
   (4 + 2) a
   (4 · 2) b
   (1 · 4) c
   (3 + 1) d

11a. (2, 4, 6) : (6, 4, 2) :: (3, 6, 9) : (____)
   (2, 3, 4) a
   (3, 6, 10) b
   (9, 6, 3) c
   (4, 7, 10) d

12c. 5 : 10 :: 10 : (____)
   (15) a
   (20) b
   (25) c
   (30) d

13b. (2 + 2 + 2 + 2) : (2 · 5) :: (3 + 3 + 3) : (____)
   (3 · 3) a
   (2 + 5) b
   (3 + 2) c
   (5 · 2) d

14a. (2, 3, 4) : (4, 3, 2) :: (3, 4, 5) : (____)
   (6, 7, 8) a
   (5, 4, 3) b
   (4, 5, 6) c
   (3, 2, 4) d

15c. 4 : 16 :: 2 : (____)
   (8) a
   (6) b
   (12) c
   (4) d

16b. (3 + 3 + 3 + 3) : (3 · 4) :: (6 + 6 + 6) : (____)
   (6 · 6) a
   (4 · 3) b
   (6 · 3) c
   (3 + 3) d

17a. (2, 4, 6) : (8, 6, 4) :: (6, 8, 10) : (____)
   (12, 10, 8) a
   (3, 5, 7) b
   (4, 6, 8) c
   (12, 14, 16) d

18c. 9 : 27 :: 1 : (____)
   (1) a
   (3) b
   (2) c
   (54) d
Appendix 3: A Set of Figural-Geometric Analogy Tasks (The Meanings of Symbols: a—The Opposite Relation, b—The Part-Whole Relation)

Notes

1. According to McNeil’s (1985) and Marschark’s (1993) claims, gestures are verbal symbols, which can enable young deaf and hearing children to recognize the specific properties underlying the meanings of their first signs and words. So these gestures perform a symbolic function that consists not only in representing the reality elements, but also in enabling these children to acquire all semantic features of signs and words.

2. Sharpe means the sign language used by deaf persons within the deaf community, so this communication mode is not based on the spoken language grammar.

3. An artificial sign system is a gestural representation of spoken language, that is, the signs that accompany the words are produced while formulating the sentences according to the rules of spoken-language grammar. This is an entirely communicative system (not a linguistic system) that has been created for educational goals. It is used mostly by hearing teachers in interactions with deaf children. In this case, the artificial sign system is based on Polish.

4. As the analysis of results showed, in task 13 (lie : truth :: love : ____), DCDP from both age groups (0% and 6.25%) obtained considerably lower outcomes than HCHP from both age groups (20% and 65%).

5. One should mention that four younger DCHP and two older DCHP had deaf siblings; it may suggest that these children partially communicated with their siblings in sign language. Although they can communicate with each other in everyday life situations by means of sign language, it does not indicate that they have consistent contact with this language. It is important to take into account whether their hearing parents, who have rich experiences, are inclined to accept sign language as an alternative communication mode. As mentioned earlier, neither hearing parent of the deaf children used sign language in the interactions with his/her deaf child. On the other hand, the deaf siblings may not possess full linguistic competence in sign language, so it is difficult to treat these children as having consistent contact with developed sign language. In a family where all members communicate with each other in sign language, the linguistic interactions between them become more intensive. It could, in turn, enrich these children’s linguistic and nonlinguistic experiences.

6. The exception is the last figural-geometric analogy task based on the opposite relation. In this task, the figure in the B term is the mirror image of the figure in the A term, so this task does not require the 180° rotation of the figure.

7. The reversal interpretation is a mental process whose use facilitates the understanding of signed utterances formulated by the signer. In this language, the syntax is organized spatially. This entails the necessity of forming the signed space while constructing the sentences. The signed space reflects the real world and is represented in the signer’s mind. This signer, creating his/her utterances in sign language, “uses the space from his or her own point of view,” so the observer, being also
a signer, “must mentally reverse the spatial relationships in order to compute the correct spatial array” (Lillo-Martin, 1997, p. 97) and understand the mentioned signed utterances.

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