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Counting in Sign Language

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Do the visuomanual modality and the structure of the sequence of numbers in sign language have an impact on the development of counting and its use by deaf children? The sequence of number signs in Belgian French Sign Language follows a base-5 rule while the number sequence in oral French follows a base-10 rule. The accuracy and use of sequence number string were investigated in hearing children varying in age from 3 years 4 months to 5 years 8 months and in deaf children varying in age from 4 years to 6 years 2 months. Three tasks were used: abstract counting, object counting, and creation of sets of a given cardinality. Deaf children exhibited age-related lags in their knowledge of the number sequence; they made different errors from those of hearing children, reflecting the rule-bound nature of sign language. Remarkably, their performance in object counting and creating sets of given cardinality was similar to that of hearing children who had a longer sequence number string, indicating a better use of counting than predicted by their knowledge of the linguistic sequence of numbers.

Key Words: deafness; counting; sign language; number.

It is widely believed that preverbal children as well as animals possess an instinct of number, which reveals itself in two systems for representing numerosity (Dehaene, 1997; Gallistel & Gelman, 1992). A first system, serving to represent small numerosities exactly, accounts for the ability to apprehend rapidly and accurately the numerosity of collections of up to four items. A second system, serving to represent large sets, underlies the ability to apprehend approximately the numerosity of large collections. This latter system is not limited by set size,

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but its accuracy decreases as set size increases. In contrast to other animals, human children—at least those with normal hearing—also develop a third system for representing numbers, which involves verbal counting. This linguistic counting system allows the representation of exact numerosity, independently of the set size. It also allows the computation of exact additions and subtractions, leading to the representation of propositions like “three plus five is eight.” In order to use the linguistic system efficiently for counting, children must realize that each number word corresponds to an exact number of objects (Spelke & Tsivkin, 2001).

In deaf children, however, the linguistic counting system takes the form of manual counting. It differs from verbal counting in two main respects, either or both of which may have an impact on the development of counting knowledge. First, while verbal counting is aural-oral, manual counting is visuomanual. The number string is produced by manual gestures involving movements of fingers (see below for a more precise description). Research has underlined a strong relationship between the use of fingers and numerical abilities (see Dehaene, 1997, for a review). Hearing children often use their fingers spontaneously to count. Their pointing and touching gestures facilitate counting accuracy of sets, probably because it helps them to implement their knowledge of one-to-one correspondence (Alibali & DiRusso, 1999; Fuson, 1988; Gelman & Meck, 1983; Saxe & Kaplan, 1981; Shaeffer, Eggleston, & Scott, 1974). In addition, children suffering from digital agnosia are often dyscalculic (Grigsby, Kemper, & Hagerman, 1987; PeBenito, Fisch, & Fisch, 1988), and some children with specific deficits in numerical abilities are impaired on tactile-perceptual tasks (Geary, 1993; Rourke & Conway, 1997). Furthermore, assessment of neuropsychological tests involving tactile and digital perception in 5-year-olds predicts mathematical achievement 1 year later (Fayol, Barrouillet, & Marinthe, 1998).

The second difference between visuomanual counting in deaf children and verbal counting in hearing children results from the structure of the sequence of numbers. The French number–word sequence has an underlying base-10 structure. In oral French, the first 16 numbers are conventional; there is nothing in their pronunciation that indicates their numerosity or their sequential relationships. For example, one cannot predict that “huit” (8) follows “sept” (7). From “dix-sept” (17), the sequence of number words gives an indication of how the sequence is built up, that is, by concatenation of a number for the decade (“dix”) followed by the appropriate digit unit (“sept,” “huit”, or “neuf”). After the number “vingt” (20), the words are produced in a consistent, rule-bound, pattern. The words for the decades from 30 to 90 (“trente,” “quarante,” “cinquante,” “soixante,” “septante,” and “nonante”) have a relationship with the corresponding units 3–9 (“trois,” “quatre,” “cinq,” “six,” “sept,” and “neuf”). The decade number word is concatenated with a word between one and nine.

The analysis of hearing children’s number string errors reflects the partly conventional, partly rule-bound nature of the oral sequence of number words. Errors found in oral sequence of numbers involve omissions (e.g., 11, 12, 14, 15), repetitions (e.g., 11, 12, 10, 11, 12, 13), and reversals (e.g., 11, 12, 13, 15, 14)(Grégoire & Van Niewenhoven, 1995). Children also have problems with the succession of the decades. For example, a child can sometimes correctly count up to 29 and then skip to 40. Other characteristics are acoustic confusions, e.g., children confusing between "treize" (13) and "seize" (16) or between "quinze" (15) and "cinquante" (50). Errors in the formation of number words also occur, e.g., a child can count "dix-neuf, dix-dix" (19, 10-teen).

Unlike in oral French, the sequence of numbers in Belgian French Sign Language (BFSL) has a base-5 structure. (We use the term "Belgian French sign language" because of the differences between the production of the signed number string in Belgium and in France and between the Belgian French Sign Language and the Belgian Flemish Sign Language.) The signs corresponding to numbers are produced with a single hand. The number sign formation for cardinal numbers in BFSL are presented in Fig. 1. One (1) is produced by extending the index finger, with the palm facing the body. Two (2) corresponds to the extension of the index and middle fingers. Three (3) is the extension of the index, middle finger, and ring fingers. Four (4) is the extension of the index through pinkie fingers. Five (5) is the extension of the four fingers and the thumb. Note that for the number signs one to five, the number of extended fingers represents the exact numerosity, and number is inherently represented in the structure of each individual linguistic symbol. Six (6) is produced by extending the thumb alone, with a straight movement produced twice. Seven (7) is the extension of the thumb and index finger. Eight (8) is the extension of thumb, index, and middle fingers. Nine (9) is produced with the extension of the thumb, index, middle, and ring fingers. The decade numbers (10, 20, 30, etc.) are produced by configuring the hand as for the unit number, but palm facing forward, and then snapping the fingers shut against the thumb. Ten (10) is thus produced by snapping the extended index finger against the thumb, palm facing forward. Eleven (11) through nineteen (19) are produced exactly like the first nine numbers except that the palm of the hand is initially facing down and then with a wrist's rotation movement, the palm is brought up simultaneously with an extension of the fingers, which are wiggled a couple of times and finally come to rest, fully extended. The production of numbers within the decades from 20 is a simple concatenation of the decades digit followed by the appropriate units digit. For example, 23 is produced with the 20 sign (i.e., snapping the index and middle extended fingers shut against the thumb), followed by the extension of the index, middle, and ring fingers.

The way in which the linguistic counting system represents number in BFSL presents differences from and similarities with the way oral French represents number. One main difference is that, compared to oral French, the structure of the sequence of numbers in BFSL is rule-bound at an earlier point in the series of numerals (see Secada, 1984, for a similar argument about the sequence of number signs in American Sign Language). BFSL number signs follows a consistent base-5 rule. From 1 to 5, 6 to 9, 11 to 15, 16 to 19, 21 to 25, and so on, one adds a finger for the next number. This production rule relates to contiguous pairs of numbers from the very first sign number (1), while counting to 16 in French

FIG. 1. The number sequence in Belgian French Sign Language.

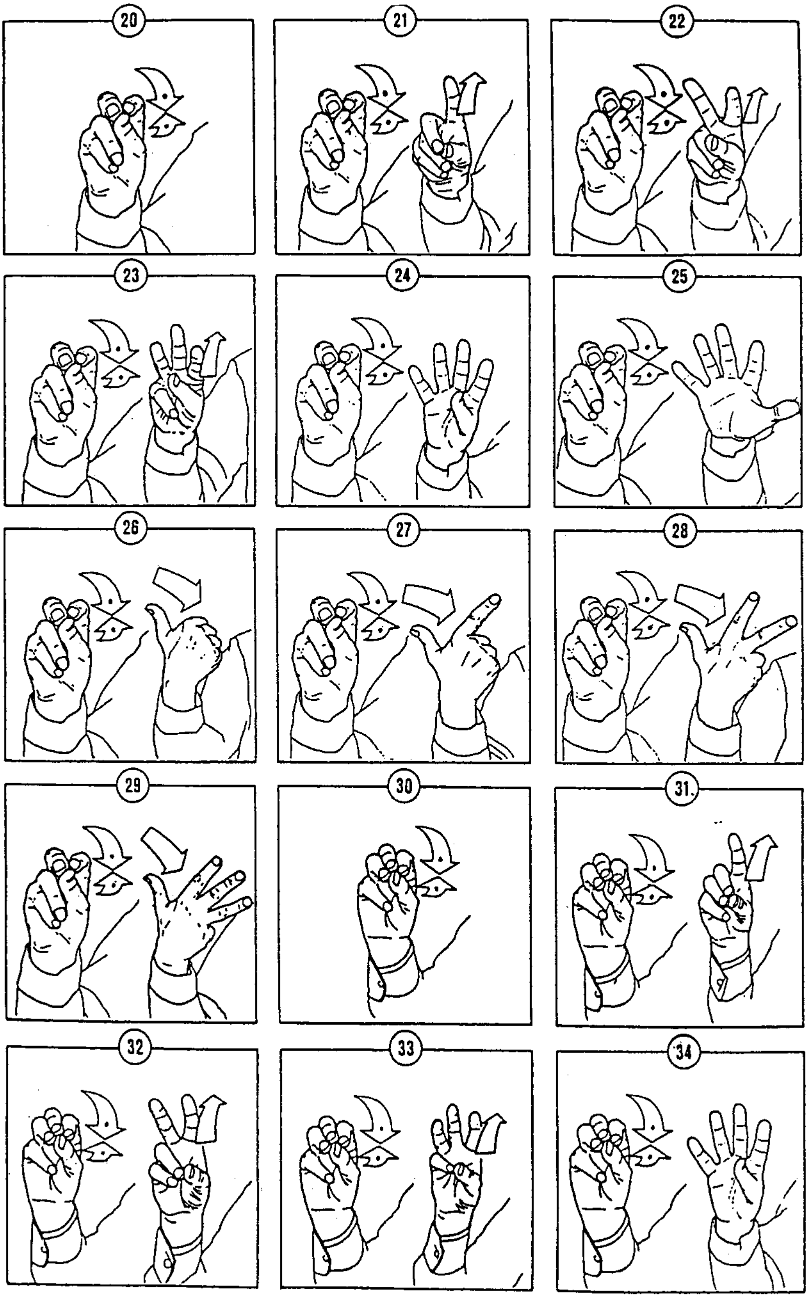

FIG. 1—*Continued*

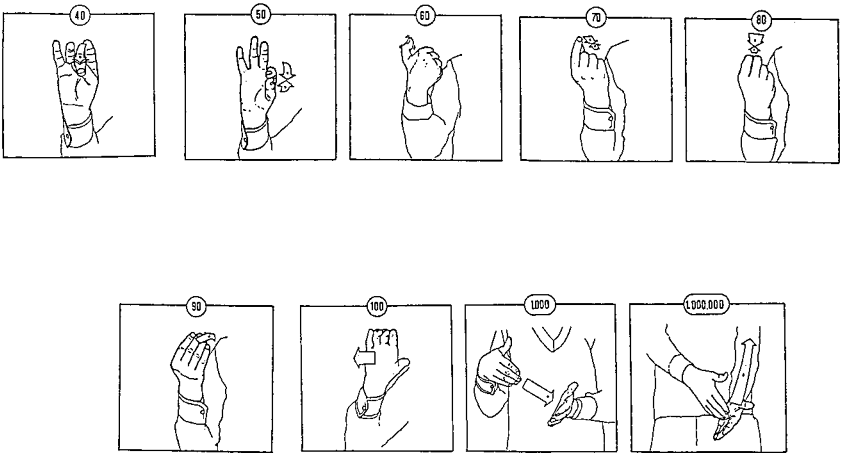

FIG. 1—*Continued*

requires mastering an unordered set of names. One similarity between the two languages lies in the production of numbers within the decades from 20; in BFSL the sign of the decades digit and the appropriate units digit are concatenated (this rule does not apply to the numbers between 11 and 19).

The difference between the structure of the linguistic system in BFSL and in oral French leads us to expect that hearing and deaf children should learn differently how to map linguistic counting onto their preexisting representations of numbers. Cross-cultural studies of hearing children have already indicated that the way in which the linguistic counting system represents number influences the time taken to learn the number sequence. Indeed, Chinese children are more precocious than English children for the acquisition of the teens because the base-10 structure of this part of the sequence is more obvious in Chinese than in English (Miller, Major, Shu, & Zhang, 2000; Miller, Smith, Zhu, & Zhang, 1995). The present study is aimed at comparing the development of abstract and object-counting in deaf children with that of hearing children.

Until recently the abstract counting ability of deaf children has received little investigation. Nunes and Moreno (1998) reported that oral counting in English is difficult for deaf children, and Secada (1984) found that deaf children take longer to learn to count in sign language than their hearing peers in oral language. An experiential deficit with numbers may explain this delay. Number words are rarely found in deaf children's vocabulary (Griswold & Commings, 1974; Marschark, 1993). In schools specialized in deaf education, children are often taught in small groups (e.g., up to eight children) and thus could be less trained in counting up to 20 or 30 than hearing children. On the basis of previous studies (Gentile, 1972; Nunes & Moreno, 1998; Secada, 1984), an age-lag in deaf children's mastery of the counting numbers was predicted.

Our second prediction directly concerns differences related to language structure. Secada (1984) found that deaf children matched with hearing children for knowledge of the counting string performed better in giving which number comes after x, as well as in counting backward. This indicates a better knowledge of the relation between contiguous numbers. We expected that the deaf would generate a different pattern of errors than the hearing in the abstract counting task, with deaf children making fewer omission errors than hearing children at the portions of the number string where the language differs (between 1 and 5, 6 and 9, etc.).

Our third prediction concerns the knowledge of one-to-one correspondence for object counting. The task of object counting involves more than just the linguistic skill of producing a sequence of numbers. Those numbers must be applied in a one-to-one manner to the objects being counted. Fuson (1988) has proposed that pointing serves to create the required one-to-one match between number words and objects. In hearing children, number words are spoken orally and exist in time, while the objects to be counted exist in space. Objects and words are connected through pointing. Two types of errors violate the principle that each object would be tied with one and only one number word. Attention errors are those in which children skip or recount objects. Principle errors are those occurring when children produce a number without making the correspondence with an object or point to an object without saying a number.

Unlike with the case of oral languages, the production of signed numbers exists in both space and time. Pointing can co-occur with the manual production of each number, with the sign itself inflected toward the counted object. Given that children who are signing can point while producing sign numbers, the one-to-one correspondence between number signs and objects could develop earlier in deaf children than in hearing children. This would entail greater accuracy in object counting as well as a lower proportion of principle errors. Indeed, deaf signers seem to have very accurate correspondences in counting objects regardless of their mastery of the number sequence (Secada, 1984). As in Miller et al's study, accuracy for creating sets of a given cardinality was also investigated, by asking children to give a certain number of items to a frog-puppet. This task, when performed by counting out the required number of elements, constituted a second measure of accuracy of counting. It can also reveal deaf children's comprehension of number signs. For example, children who consider that the number of extended fingers directly reveal numerosity should give one object when they are asked to give six of them (see Fig. 1).

METHOD

Participants

Twenty-one deaf children (8 girls and 13 boys) between the ages of 3 years 11 months and 6 years 7 months, were tested. All attended a special school for the deaf in Brussels, except for 1, who was mainstreamed in a school for hearing children. One child, age 47 months, was in the preparatory class, 7 children were in the first year of school (mean age 4 years 7 months; *SD* 4.8 months), 7 were in the second school year (mean age 5 years; *SD* 2.7 months), 3 were in the third school year (mean age 6 years 1 month; *SD* 1 month), and 3 were in the first grade (mean age 6 years 4 months; *SD* 3.6 months). Degree of hearing loss in the better ear, calculated on 500, 1000, 2000, and 4000 Hz, was profound (90 dB and greater) for 15 children, severe (70–90 dB) for 4, and moderate (40–70 dB) for 2 children. Three had deaf parents. It was not the policy of the schools to let us test deaf children's intellectual abilities. However, according to their teachers and speech therapists, none of the children had any intellectual or emotional disorders.

Nineteen children were exposed to a manual communication at home (in Belgian French Sign language, in signed French, or in Signed Coded Completed French). Language production in Signed Coded Completed French respects the morphosyntax of spoken French. The semantic words (nouns, including numbers, verbs, and adjectives) are produced using the corresponding signs, while the syntactical morphemes (articles and prepositions) are produced in Cued Speech (Charlier, 1992). The parents of 12 of the children also used Cued Speech (Cornett, 1967) as an aid to speechreading. For the remaining two children, oral communication was used at home. All of these children were regularly exposed to signs at school, mainly to Signed Coded Completed French. It should be noted that the structure of the linguistic counting system in BFSL, described in the introduction, is the same in signed French and in Signed Coded Completed French.

The matching of deaf children with hearing children is always problematic. A chronological age-matching design seemed unsuitable, given that the deaf children were enrolled in less advanced school classes than the hearing children of comparable age. The deaf children would have received less counting instruction at school than the hearing children. We therefore decided to match the two groups by school year, meaning that the deaf children were on average 1 year older than the hearing children.

Twenty-eight hearing children (13 girls and 15 boys) were selected: 10 children (mean age 3 years 8 months; *SD* 3.5 months) attended the first year of school, 10 attended the second year (mean age 4 years 10 months; *SD* 3.9 months), and the remaining 8 were in the third year (mean age 5 years 6 months; *SD* 1.5 months). In each school year, children were chosen at random from the children in the class. It should be noted that children in both hearing and deaf groups had received some instruction in counting in the school years.

Although race and social class data were not systematically collected, the majority of deaf and hearing participants were Caucasian and from a middle-class neighborhood.

Tasks

The three tasks were directly adapted from Miller et al.'s (1995) study. In the *abstract counting task*, children were asked to count as high as possible. If necessary, they were prompted by saying "Count, as one, two, ..." Whenever they stopped, they were encouraged to continue by two prompts. First, the experimenter asked, "What comes after (x)?" (where "x" was the last number counted). If children did not pursue counting, the experimenter repeated the last three numbers, ending on a rising tone. For example, for a child stopping at 29, the experimenter said, "twenty-seven, twenty-eight, twenty-nine . . .?" Children who did not pursue counting after the second prompt were given the next task. The number string production task was administered twice, once at the beginning of the first session and again at the beginning of the second session. Children who counted successfully to 100 were stopped. For the analyses, data from the better performance were used.

In the *object-counting task*, children were asked to count series of animals (e.g., dog, hen, and goat) or cartoon characters (e.g., Mickey and Bambi) printed at the center of wood plaques (8 cm long × 4 cm wide). They were asked "How many Mickeys (or hens or dogs . .) are here?" Thirteen collections were created, divided into small, medium, and large sets, containing, respectively, four collections of 3 to 5 items (i.e., 3, 5, 4, and 3 items), four collections of 6 to 9 items (i.e., 6, 8, 9, and 8 items), and five collections of 10 to 14 items (i.e., 10, 12, 14, 11, and 10 items). All items in each collection were of the same character (or animal). Note that some cardinals of the collections were repeated (e.g., collections of 3 items appeared twice in the small set) and that in each set, the various numerosities were presented randomly in order to prevent children from guessing the cardinality of the collections. In the *creation task*, children were asked to give a certain number of items (e.g., dog, hen, goat, Mickey, Bambi) to a frog-puppet by removing the named number of items from the box. The same 13 collections of items were requested, divided into three sets as in the object-counting task.

The object-counting and the creation tasks were each preceded by a practice task consisting of two trials (with two and four items, respectively). During the practice task, the experimenter ensured children's understanding of the instructions and helped them to find the answers if necessary. The order of sets (i.e., small, medium, and large) was constant for all participants. All children were initially given the "small" set. They received the subsequent sets if they succeeded at counting (or if they succeeded at creating set) on at least one of the trials of the previous set.

Two sessions lasted approximately 20 min each and began with the abstract counting task. In session one, the object-counting task followed; in session two, the creation task followed. Instructions were given orally by the experimenter (i.e. the second author) to the hearing children, and in sign language or signed French to the deaf children, by a hearing interpreter in sign language. Hearing children's abstract counting was tape recorded, and the tester wrote down the child's response for the two other tasks. Deaf children's performance was videotaped and coded later with the help of a sign language interpreter.

RESULTS

For the sake of homogeneity between deaf and hearing children's data, the results of the three deaf children who were in the first grade and of the younger deaf child who was in the preparatory class were not included in the analyses. The data of the abstract counting task are presented first. Next, the analyses on the data of the object counting and creating sets tasks are presented together. The highest number reached in the abstract counting tasks and in object counting tasks are compared in the final section.

Abstract Counting

The first goal of these analyses was to look to the development with age group of the mean highest number reached in abstract counting by the deaf and by the hearing children. As the data of the two groups suggested differences in learning trajectory, we then looked at the number of children who stopped counting after one error. Finally, we analyzed the pattern of errors made by the two groups.

Two types of scoring were used for evaluating children's abstract counting. First we considered the highest number produced before an error, or the highest number produced if there were no errors, and we called this highest number the "strict score." Omission, repetition, or inversion errors were not admitted in the strict score. Next, we admitted a maximum of two such errors in the last five numbers produced, and we called the highest number thus obtained the "lenient score." We assumed that the lenient score could reveal children's knowledge of higher numbers beyond the ordered sequence they already possess.

Figure 2 presents hearing and deaf children's mean highest number evaluated by the strict and the lenient scores and broken down by age groups. Consistent with the literature, deaf children had lower counting ability than hearing children,

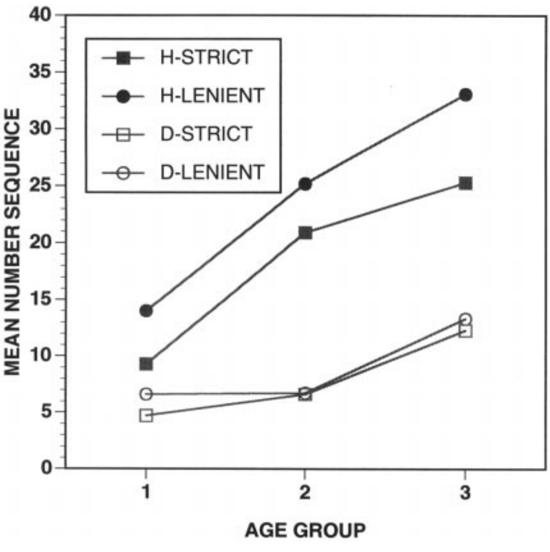

FIG. 2. Mean number sequence in the abstract counting task by age group and language. H = Hearing; D = Deaf.

whatever the score. In addition, while hearing children's lenient score outnumbered their strict score, no difference between the two scores appeared for the deaf sample. Finally, the mean highest number increased in a linear fashion for the hearing groups, but not for the deaf ones.

Separate ANOVAs of deaf and hearing groups were first performed, in which the between-subject condition was age group (1st, 2nd, and 3rd), in order to focus on the pattern of developmental trends within each participant groups, who differed in size and variance.

Deaf subjects. The ANOVA on the strict score yielded a significant effect of age group, $F(2, 14) = 8.96$; $p < .005$. Tukey's HSD post hoc tests indicated the following pattern: 1st = 2nd < 3rd. The ANOVA on the lenient score yielded no significant effect of age group, $F(2, 14) = 3.37$; $p > .05$.

Hearing subjects. The main effect of age group was highly significant on the strict score, $F(2, 25) = 20.36$; $p < .001$. Post hoc Tukey's HSD tests indicated the following pattern: 1st < 2nd = 3rd. There was also a significant effect of age group on the lenient score, $F(2, 25) = 8.07$; $p < .005$. The Tukey post hoc comparisons indicated the following pattern of age groups: 1st = 2nd < 3rd.

Deaf and hearing subjects. ANOVAs performed on the data of deaf and hearing subjects, in which the between-subject condition was hearing status (deaf or hearing), revealed significant effects of hearing status on the strict score, $F(1, 43) = 25.20$; $p < .001$, as well as on the lenient score, $F(1, 43) = 24.18$; $p < .001$. Hearing children's mean abstract counting was higher than that of deaf children, whatever the score.

The differences between hearing and deaf children led us to look at the number of children who stopped counting after one error in their number string, despite the prompts given by the experimenter. Given the small number of children involved, we confined ourselves to a description of the data. The percentage of children who stopped counting after one error in their number string was higher in deaf (77%) than in hearing children (39%). The proportion of hearing children adopting such a behavior was 30% in the 1st age group and 50% in the 2nd and 38% in the 3rd age groups, in deaf children these proportions reached 71, 86, and 67% in the 1st, 2nd, and 3rd year groups, respectively. Interestingly, the numbers at which children stopped counting varied more in hearing children than in deaf children. In the hearing group, the stop occurred at 3, 6, 10 (two children), 15, 19, 22, 28, 29 (two children), and 30. In the deaf group, the stop occurred at 3, 4, 5 (seven children), 8, 9, and 15 (two children). Most of the deaf children stopped counting in the portion of the number sequence where a new production rule should be adopted, (i.e., after 5 and after 15).

The description of errors in abstract counting takes into account the first error made by the children in their number string. The most common error in the two groups consisted of omission of one or several numbers. This kind of error was more common in hearing children than in the deaf children (64% of the hearing children made omission errors compared to 24% of the deaf children). In the hearing children, the omission occurred below 10 (1 child), between 12 and 19 (6 children), and between 23 and 29 (10 children). Among the deaf children, the number omitted was either below 10 (3 children) or the number 20 (2 children).

Next came the repetition errors of one or several numbers, made by 14% of the hearing children and 10% of the deaf children. Errors coming from an incorrect use of the production rules were observed only in those children whose numerical chain went beyond 14. Such errors occurred in two hearing children and three deaf children. For example, one of the deaf children counted "twenty-eight, twenty-nine, twenty-ten, twenty-eleven, . . . twenty-nineteen, twenty- . . ., thirty-one, thirty-two, thirty-three . . . thirty-nine, thirty-nine, thirty-ten, thirty-eleven, thirty-twelve, . . . thirty-nineteen, thirty-twenty." Seven deaf children made "linguistic" errors: Four represented the number 10 with their 10 fingers extended; the three others signed the numbers beyond 10 without the movement of the wrist.

Object Counting and Creation Tasks

The data from the object counting and the creation tasks are presented together because they show similar tendencies. Children's performances in these two tasks are evaluated through an analysis of their correct responses. Because no obvious difference between the two groups appeared, we found it interesting to compare the length of children's abstract counting and the highest number they used for counting and creating sets of objects. Finally, errors data are described.

For object counting, a correct response was credited when the number that ended the number sequence corresponded strictly to the number of items presented. For the creation task, a correct response was credited when children gave exactly the number of items asked, independently of whether they counted. The mean percentage of correct responses for hearing and deaf children, broken down by set of items and age groups are presented in Fig. 3. Accuracy in object counting and creation sets depends on the set size and the age groups; children showed greatest accuracy on the small set, intermediate accuracy on the medium set, and lowest accuracy on the large set. Children's performance increased with age on the different sets. No difference appeared between deaf and hearing children.

Deaf children. Mixed ANOVAs were performed in which the between-subjects factor was age group and the within-subject factor was the set size (small, medium, large). In the object counting task, significant main effects of set size, $F(2, 28) = 31.96$; $p < .001$, and age group, $F(2, 14) = 10.82$; $p < .001$, were observed. The interaction between these two main effects was also significant, $F(4, 28) = 4.95$; $p < .005$. In the creation set task, the main effects of set size, $F(2, 28) = 19.92$; $p < .001$, and of age group, $F(2, 14) = 27.06$; $p < .001$ were highly significant, while the interaction between these two factors was not, $F(4, 28) = 2.10$; $p > .10$.

Hearing children. In the analysis on object counting accuracy, there were significant main effects of set size, $F(2, 50) = 23.16$; $p < .001$, and age group, $F(2, 25) = 5.40$; $p < .001$. The interaction was not significant, $F(4, 50) = 2.02$; $p < .10$. Similar results were observed in the creation set task: significant effects of

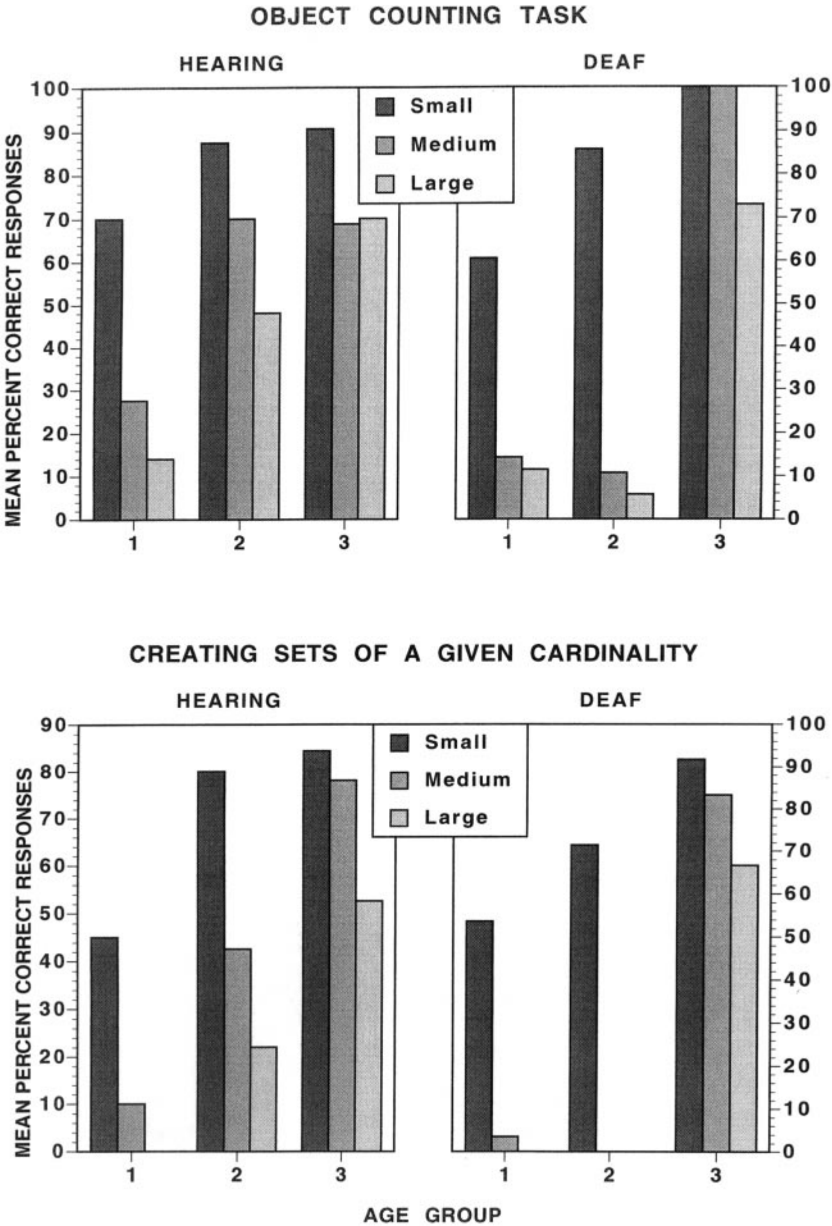

FIG. 3. Mean percentage of correct responses in the object counting and creation tasks by age group and language.

set size $F(2, 50) = 24.88$; $p < .001$; and age group, $F(2, 25) = 7.95$; $p < .005$, and no interaction, $F(4, 50) = 1.38$.

Deaf and hearing children. Mixed-design ANOVAs with hearing status (Deaf, Hearing) as between-subjects factor and set size as the within-subject factor were performed on the data of the object counting task and creation task. These analyses yielded no significant effects of hearing status, nor was the interaction with hearing status significant.

Error analysis. Errors in the object counting task were categorized into three types. Principle errors refer to children producing a number while making no correspondence with an object or pointing to an object while producing no number. Attention errors refer to children skipping or recounting objects. Number string errors were recorded when children's counting deviated from conventional number production, in oral language for the hearing children and in sign language for the deaf children. The number of trials in which each type of error occurred was summed within each set size (max. = 4 for each set). These sums were then converted to percentages. Only those children who had passed both the small and the medium sets were included, that is, all hearing children and 16 deaf children. The percentage of trials on which errors of each type occurred, broken down by set size (small, medium), hearing status, and age group, appears in Table 1.

Given the absence of data in some cells, we confined ourselves to a description of the data. Errors of the three types were more numerous with the medium than with the small set. On average across the three age groups, there were no differences in attention or principle errors between deaf and hearing children, but deaf children made more sequence number counting errors (see the two "All" columns). An additional error (not reported in Table 1) consisted of producing numbers repeatedly (i.e., without taking into account the whole collection). For a

TABLE 1
Mean Percentage of Trials (*SD* is Parentheses) on Which Errors of Each Type Were Made as a Function of Hearing Status, Age Group, and Set Size in Object Counting Task

	Hearing children				Deaf children			
Type of errors	1st (10)	2nd (10)	3rd (8)	All (28)	1st (6)	2nd (7)	3rd (3)	All (16)
Attention								
Small	8(17)	3(8)	6(18)	5(14)	0	4(9)	0	1(6)
Medium	35(32)	10(13)	6(18)	17(25)	13(21)	25(38)	0	16(29)
Principle								
Small	10(17)	0	0	4(11)	10(17)	0	0	4(11)
Medium	28(36)	3 (8)	9(27)	13(28)	21(40)	18(31)	0	16(31)
Number string								
Small	25(37)	5(16)	0	11(26)	21(39)	7(19)	0	12(28)
Medium	50(44)	10(24)	0	21(36)	63(49)	50(48)	33(58)	52(49)

collection of eight items, for example, children counted, "one, two, three, one, two, one, two, three." This type of error was made by four hearing children, who had a standard number sequence that exceeded the size of the collection to count. For example, one hearing child, with a strict score of 25, produced "one, two, three, four, five, . . . one, two, three, four" when counting a collection of nine items. Six deaf children displayed this behavior on collections of which the cardinal was equal to or larger than their standard number sequence.

Errors in the creation set task were not examined systematically. However, one kind of error of theoretical interest was examined, namely confusions between visually similar sign numbers (see Fig. 1). For example, when asked to give 6, 8, 9, and 10 objects, children gave 1, 3, 4, and 2 objects respectively. This kind of error was made at least twice by 7 of the 17 deaf children. However, 5 of them had a strict score equal or lower than 5, thus, in principle, not sufficient to count the number of objects requested.

Comparison between abstract counting and object counting tasks. The final question addressed was the extent to which children were able to use the number sequence they produced in abstract counting for object counting and creating sets. Two new scores were calculated. The "counting-max" score corresponds to the maximum set size correctly counted, accepting only one error in the last three collections counted. Similarly, the "creating-max" score corresponds to the maximum set size correctly created, again accepting only one error in the last three trials. The mean number reached in abstract counting, together with the mean counting max and creating max for deaf and hearing children, broken down by age groups, appears in Table 2.

These data were analyzed using mixed ANOVAs, with task (abstract counting, counting max, and creating max) as the within-subject factor and age group (1st, 2nd, and 3rd) as the between-subjects factor. In deaf children, the main effect of task was nonsignificant, $F(2, 28) = 1.41$, as was the interaction between task and age group, $F < 1$. In hearing children, however, the effect of task was highly significant, $F(2, 50) = 79.68$; $p < .001$; the interaction between age group and task

TABLE 2
Mean Correct Number String (*SD* in Parentheses) in Abstract Counting, Object Counting, and Creating Sets as a Function of Hearing Status and Age Groups

	Hearing children			Deaf children		
	1st	2nd	3rd	1st	2nd	3rd
Abstract counting	9(5)	21(7)	25(5)	5(2)	7(2)	12(5)
Objects counting	7(4)	11(5)	12(4)	4(2)	6(2)	11(5)
Creating sets	4(3)	8(5)	10(5)	4(2)	4(2)	12(2)

was also highly significant, $F(4, 50) = 6.81$; $p < .001$. Additional analyses, revealed that the effect of task was significant at each age group level as follows: 1st, $F(2, 18) = 7.58$; $p < .005$; 2nd, $F(2, 18) = 24.69$; $p < .001$; and 3rd, $F(2, 14) = 109.49$; $p < .001$. It is also interesting to note that among the 17 deaf children, 8 reached a higher number in abstract counting than in object counting, 4 reached the same number (5), and 5 reached a higher number in object counting than in abstract counting. Among the 28 hearing children, 22 reached a higher number in abstract counting than in object counting, 4 reached the same number, and only 2 reached a higher number in object counting than in abstract counting. To sum up, while hearing children counted by rote well beyond their actual quantitative abilities, deaf children had a true quantitative grasp of the numbers they produced.

DISCUSSION

Our experiment was designed to investigate the possible influences of the language modality (signed versus oral) and the linguistic structure of the sequence of numbers on the development of the conventional number string and on the use of the number string for counting objects. We begin by relating our predictions to the results. We then discuss two general interpretations of our data and end by offering suggestions for future research.

Our first prediction was that deaf children's conventional number sequence in abstract counting would be shorter than that of hearing children of the same school level (see Gentile, 1972; Nunes & Moreno, 1998; Secada, 1984). The data of the abstract counting task support this prediction. The mean highest number produced by hearing children age 3 years was between the mean highest number produced by deaf children ages 5 and 6 years. These data point to a 2-year delay in the production of the signed number sequence in deaf children. Other aspects of the data also suggest differences between the two groups. The lenient score was not different from the strict score and did not vary with age group in the deaf children, who generally stopped counting after one single error. By contrast, hearing children's lenient score was larger than their strict score and increased with age group. Deaf children's lack of knowledge of large numbers may be due to many reasons having nothing to do with the linguistic counting system. Hearing loss is generally associated with fewer opportunities for incidental learning (Furth, 1966; Liben, 1978; Marschark, 1993; Nunes & Moreno, 1998). For example, Furth suggested that deaf youngsters' poor results in educational assessments can be explained by an "experiential deficit." Access to sources of information available to hearing children like radio and television broadcasts and conversations around the table in the family is limited in deaf children. School environment could be another critical factor, as shown by children mainstreamed in schools for hearing children producing longer number strings than children in special schools for the deaf (Wood, Wood, & Howarth, 1983; Wood, Wood, Kingsmill, French, & Howard, 1984). For example, counting the children present in the class is a usual activity at the age levels included in our study. While the deaf were in classes of maximum 8 children in the special school, the hearing were in classes including between 20 and 30 children. Finally, the hearing status of the parents could be important: Hearing parents with a deaf child could be less involved than deaf parents with a deaf child or hearing parents with a hearing child in training/testing numbers. Although we found no evidence for this idea, as the three children born to deaf parents did not produce a longer standard number string than the other deaf children, the small sample size precludes any firm conclusion on this point.

The description of the linguistic structure of sequence of numbers in Belgian French Sign language, and Miller et al.'s (1995) arguments and findings lead us to the second prediction, i.e., that hearing and deaf children should differ in how they map linguistic counting onto their preexisting representations of numbers. Two aspects of our data support this prediction. First, fewer omission errors of one or several numbers in the abstract counting task were made by deaf children than by hearing children. Second, the point at which deaf children stopped counting generally corresponded to the point at which a new production rule should be used (e.g., after 5 and after 15). If the children knew how to produce 1 and 2, they generally counted up to 5; if they knew how to produce 6, they generally counted up to 9, and so on. The way the linguistic counting system represents numbers influences children's acquisition of the number sequence. This has already been demonstrated in the case of spoken languages for hearing children (see Miller et al., 1995, 2000) and is extended here to the case of a visuomanual sign language.

Our third prediction was that deaf signers could develop an easier understanding of a principle important for object counting, i.e., "one sign–one object," because pointing often co-occurs with counting in sign language, with the sign number inflected toward the object to be counted. Remarkably enough, deaf children were as accurate as hearing children in object counting and creating sets up to 14 items despite their shorter number sequence. Both tasks were difficult for young children, but neither revealed group differences. The performance was strongly influenced by size of the collection and by age group. Tasks were more difficult when they involved larger set sizes and for children belonging to the first age group. On the whole, these data indicate good (school-level appropriate) understanding of one-to-one correspondence in the deaf children. This is remarkable given that all data available in the literature point to a 2- to 3-year delay in mathematic achievement of older deaf children compared to hearing children (Wollman, 1965; Wood et al., 1983, 1984).

Do these data mean that sign language helps the development of counting abilities? There are two alternative interpretations of the data. The first interpretation is based on the hypothesis that our deaf children did not suffer from a general cognitive delay despite their obvious linguistic impairment. In the abstract counting task, deaf children lag behind hearing children for many reasons that have to do with reduced learning opportunities (see above). The comparison between abstract counting and object counting tasks revealed that deaf children had a true quantitative grasp of the numbers they produced, while hearing children counted by rote well beyond their actual quantitative abilities. The knowledge of the one-to-one correspondence seemed to develop in the same way in both groups, as indicated by their similar performances in object counting tasks, including the frequency of principle errors. Deaf children's conceptual understanding was thus close to that expected for their age and significantly better than would be predicted by their knowledge of linguistic symbols for numbers. This interpretation lends credence to Miller et al.'s idea that "cross-language differences in counting competence should generally be limited to the symbolic system of number names, and are not involved in other aspects of counting such as understanding the mathematical basis of counting that are common features of learning to count in either language" (2000, p. 131). It also supports the idea of a certain amount of independence between children's linguistic skills and their conceptual skill put forward in the studies of specific language impaired children (Donlan, 1998; Donlan & Gourlay, 1999; Fazio, 1994, 1996, 1999) as well as children from low socioeconomic levels (Jordan, Huttenlocher, & Levine, 1992). For example, Fazio (1994) found that 5-year-olds with specific language impairment (SLI) were able to produce the standard number string only up to 5 compared with 20 for unimpaired children matched for chronological age. Nonetheless, the conceptual knowledge of the cardinality principle displayed by the SLI was close to that of the age controls. Jordan et al. (1992) found that middle- and low-income kindergarten children did not differ in performance on a nonverbal calculation task, whereas the middle-income children performed better than the low-income children on verbal calculation tasks. The linguistic delay (related to deafness, specific language impairment, or low socioeconomic status) may thus affect verbal mathematical abilities without having an effect on conceptual development.

The second interpretation is that sign language really works to advantage deaf children in their ability to map abstract linguistic counting onto their preexisting representations of numbers, as we initially hypothesized. The use of a visuomanual language facilitates deaf children's ability to grasp the quantity that a number corresponds to. It is only (or at least largely) because of general cognitive delays that the advantage is less clear, resulting in a delay in the abstract counting task and in similar performances as those of the hearing group in the object counting tasks. Should deaf children be matched with hearing children at a baseline assessing general cognitive functioning, the advantages provided by the use of visuomanual language on counting ability should emerge more clearly. A measure of participants' cognitive ability to manipulate quantities which would not be influenced by the level of linguistic development should be part of the design of future research. Future studies would also address the question of which aspects of a visuomanual language facilitate the development of counting abilities: the linguistic structure of the sequence of numbers and/or the modality of counting. The base-5 structure exists for Belgian French Sign Language and for American Sign Language (Secada, 1984), but not for French Sign Language. A cross-linguistic study of the development of counting in different sign languages would allow to examine the importance of the structure factor. In addition, a comparison between oral and manual systems that have comparable structure (if such systems exist) would allow to pinpoint the effects of modality.

It is not possible to choose between the two interpretations on the basis of the present data. It seems thus safe to conclude for the moment that sign language allows deaf children to develop object counting abilities at least as good as those developed by hearing children on the basis of oral language. For theoretical as well as for educational purposes, counting in sign language deserves more thorough investigation in the future.

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