Mathematical concepts in young deaf signers from Brazil: a comparative study

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ABSTRACT

Much research has been demonstrating that deaf children underachieve in mathematics in comparison to hearing children. If the underachievement is comprehensive to all level of schooling and affects counting, computational and problem solving abilities, then, it is necessary to investigate whether this achievement gap is already present during the early childhood education. The present study investigated young hearing children's and deaf signers' knowledge of initial mathematical concepts and procedures. The results revealed no differences in the mental representations of quantitative information by deaf signers and all groups of hearing children. But significant difference was found on the symbolic numerical skills between groups, suggesting that these skills are dependent on individual's experiences and are affected by environmental factors.

Keywords: mathematics concepts; mathematics procedures; deaf children; early childhood education

RESUMO

Muitos estudos tem demonstrado que as crianças surdas apresentam baixo desempenho escolar em matemática em comparação com as crianças ouvintes. Se considerarmos que o baixo desempenho parece compreender todos os níveis de escolarização e afeta habilidades como contagem, cálculo e resolução de problemas, então mostra-se necessário investigar se esta diferença de rendimento está presente antes da escolarização e no seu início – series iniciais. O presente estudo, portanto, investigou o conhecimento de conceitos e procedimentos matemáticos em crianças surdas e ouvintes entre cinco e seis anos de idade. Os resultados revelaram que não há diferenças nas representações mentais das informações quantitativas entre crianças surdas e ouvintes. Entretanto, foram encontradas diferenças significativas nas habilidades para lidar com as informações numéricas simbólicas e exatas, sugerindo que estas diferenças estão relacionadas com as experiências individuais e são afetadas por fatores ambientais.

Palavras chave: conceitos matemáticos; procedimentos matemáticos; surdez; educação matemática.

Introduction

This study is justified by the data coming from recent research which points to a lower achievement in mathematics by deaf children compared to hearing children. For example, some experimental and statistical studies (Gregory, 1998; Kluwin, Moores, 1989; Nogueira & Zanquetta, 2008; Nunes & Moreno, 1998; Wood, Wood, Howart, 1983; Wood, Wood, Kingsmill & French, 1984; Traxler, 2000) have shown that deaf children have a lower academic performance or below average in the area of mathematics reasoning and computation compared to hearing children of the same grade and age. The difficulties in mathematics were detected in both the elementary and high school levels (Blatto-Vallee, Kelly, Gaustad, Porter & Fonzi, 2007; Bull, Blatto-Vallee & Fabich, 2006; Lang & Pagliaro, 2007; Leybaert & Van Cutsem, 2002). If the underachievement is comprehensive to all level of schooling and affects counting, computational and problem solving abilities, then, it is necessary to investigate whether this achievement gap is already present during the early childhood education. Do deaf children arrive in kindergarten with the same understanding of early mathematical concepts and procedures (informal knowledge) of that of hearing children?

In relation to early mathematical concepts that children develop during the early childhood education years, studies of hearing children in this age group have shown that before the starting of formal schooling (i.e., before the first grade), children construct and acquire a wide range of non-symbolic and symbolic quantitative-numerical concepts (Ginsburg, Klein, Starkey, 1998). This means that during the pre-school years, children develop several mathematical concepts and procedures, such as the understanding of equivalence (more, less and the same), of-one-to-one correspondence, counting, comparison, quantity transformation, calculation, and problem solving skills. Initially, these concepts are developed in a non-symbolic fashion, that is to say that children do not need to know the numerals names or even to know the numerals (symbols) or any mathematical symbol to understand the concepts of equivalence, object individuation, amount, discrete set, and quantitative change. But, at the same time that children have these non-symbolic abilities to deal with quantitative information, they are also involved in learning about the numerals, the numbers sequence, the counting procedures and goals. Thus, during the early years gradually correlate non-symbolic representations with symbolic numerical concepts (Baroody, 1992; 2000; Bisanz & LeFevre, 1992; Dehaene, 1997; Feigenson, Dehaene, Spelke, 2004; Huttenlocher, Jordan, & Levine, 1994; Mix, Huttenlocher & Levine, 2002; Mix, 1999; 2002; 2009; Wynn, 1990; 1992a; 1992b). Concomitantly, young children are also acquiring procedures and principles involved in counting through the experiences in which they take part on (Briars & Siegler, 1984; Fuson, 1986; Fuson, Richards & Briars, 1982; Fuson, Secada & Hall, 1983; Gallistel & Gelman, 1990; Gelman & Gallistel, 1978; Siegler & Robinson, 1982; Shipley & Shepperson, 1990). Young children also develop ideas about the cardinal values, ordinal relations and nominal functions of numbers (Wiese, 2003).

As can be seen from this little review of research in mathematics development, there is a developmental change that happens during the preschool years reflecting the passage from non-symbolic (non-linguistic representations) to symbolic (linguistic) numerical abilities when children move from imprecise numerical representations to the use of exact numbers. Studies seemed to indicating that non-symbolic math abilities are not dependent on external inputs (Deahene, 1997; Mix et al., 2002). Contrastingly, the symbolic numerical abilities are dependent on children's experiences, learning, linguistics inputs, and cognitive abilities (Barbosa, 2004; Feigenson, Dehaene & Spelke, 2004; Mix et al. 2002; Mix, 2009). In order for a child to function in the modern highly enumerated society, she needs to learn to manipulate mathematical and numerical symbols to express exact numerosities and to solve equations. Thus, the quality and amount of input that a child receives about mathematics concepts and procedures at home and at school, the opportunities that a child have to use numerical vocabulary to express mathematical ideas, the child's family socioeconomic status (SES), and the linguistic and cognitive abilities of each child may influence academic achievement of mathematics, which at this level has a symbolic nature (Jordan, Kaplan and Olah, 2006; Jordan & Kaplan, 2009). Although most of the mathematics difficulties that early childhood and elementary educations teachers deal in their classrooms are concerned with the symbolic abilities, the predictive power of non-symbolic representations to latter mathematics achievement should not be disregarded (Jordan & Kaplan, 2009).Therefore, considering the developmental pathway from non-symbolic to symbolic mathematics concepts and procedures, and considering the environmental factors that may influence the development in the symbolic domain, it is necessary to investigate the non-symbolic and symbolic math skills of a group of children that appears to be at risk of mathematics difficulties such as the deaf children.

So far, there is a paucity of studies on the development of mathematical concepts and procedures of non-symbolic and symbolic nature done with deaf children of preschool age. For example, in the development of counting, the few existing studies suggest that deaf children have difficulty learning the number sequence (Leybaert, Van Cutsem, 2002). But, there is no conclusive evidence to say whether this difficulty is due to problems with memory load or information processing (Hitch, Arnold, Phillips, 1983), or perhaps, is due to restricted participation in experiences involving counting at home and at school (Nunes, 2004). Despite the absence of a definitive explanation, it seems fairly grounded to suppose that all these factors might operate together to produce some difficulties in applying counting encountered by deaf children.

Apart from the acquisition of numerical sequence, there are many other issues related to quantitative-numerical knowledge of deaf children that also need to be investigated (Barbosa, 2009; Mayberry, 2002). For example, the issue related to the ability of deaf children to non-symbolically represent numerical information by the time that they enter school. In a recent study, Zarfaty, Nunes and Bryant (2004) addressed this question by demonstrating that 3- and 4-years old deaf children are able to remember and reproduce a set of different objects under a spatial and temporal condition. This means that young deaf children are able to mentally represent numbers. However, this study was made with deaf children receiving oral education. In Brazil, by law, all the deaf children must be educated using sign language which is considered the natural language of the deaf community. Therefore, the results of Zarfaty and colleagues may not be generalizable to children who are educated in a sign context.

Another issue that needs investigation is the deaf children's counting errors. We know that there are very characteristically counting errors committed by young hearing children when they are learning the counting procedures (Fuson, 1986; Gelman & Gallistel, 1978). But, on the other hand, we do not have enough information about counting error in deaf children. We need to know what kinds of counting errors are common to deaf children, especially deaf children using sign language due to the double load of their fingers to point and count. And whether there is any difference between deaf and hearing children regarding the common counting errors.

But, most important, we need to have more information about the relationship between sign language and numerical concepts in deaf children. Does having a language that is processed in a different modality, i.e. visual-spatial, influence the way deaf children understand mathematical information? It is important for educational purposes to know how the linguistic modality and linguistic abilities of deaf children might influence their numerical thinking and problem solving skills. In this regard, researchers have been busy investigating how a language that is produced and processed in a visual-spatial modality, i.e. sign language, may contribute to cognitive development, considering both the cognitive aspects that are more dependent on the linguistic stimuli (symbolic) and those that are less dependent on these same stimuli (non-symbolic). The results from these studies generally point to the hypothesis that, in cognitive functions less dependent on the linguistic stimuli, deaf and hearing children seem to have a similar development (Blatto-Vallee, Kelly, Gaustad, Porter & Fonzi, 2007; Bull, Blatto-Vallee & Fabich, 2006; Zarfaty, et al. 2004). For example, some studies have shown that deaf children exhibit a developmental time and path similar, or even superior, to that of hearing children in several non-linguistic cognitive abilities, such as: facial recognition, construction with logic blocks, motion perception, spatial memory and spatial location (Bevalier, Newport, Hall, Supalla & Boutla, 2006; Blatto-Vallee et al., 2007, Sato, Cattaneo, Rizzolatti, Gallese, 2007). The superiority in the development of these non-linguistic cognitive functions has been attributed to the use of sign language which, by its characteristics contributes positively to the development of skills to manipulate information in visual and spatial modes (Bull et al., 2006; Blatto-Vallee, et al., 2007). These same studies seem to indicate that deaf children who are not exposed to linguistic stimuli of sign language and who do not receive proper education in age appropriate, do not show this similarity and superiority in the development of these cognitive functions. So, being exposed to sign language from an early age increases the performance of deaf children in cognitive functions associated with visual processing, which, therefore, may affect the development of mathematical concepts. But this correlational link has not yet been established. In sum, there is also a need for studies with the focus on the relationship of sign language and mathematical concepts.

The issues outlined above motivated the realization of this study, which is an initial attempt to put forward a research agenda about mathematical cognition in Brazilian deaf signers. The study presented here focused on comparing young deaf signers and hearing children of the same age, same socioeconomic background and same school system (public vs. private) in their quantitative and numerical (non-symbolic and symbolic) mathematical skills. This investigation seems necessary if we intend to promote good levels of academic achievement in the area of mathematics for all children and, consequently, to reduce the achievement gap in mathematics between deaf and hearing children. The present study, therefore, aimed at investigating young hearing children's and deaf signers' knowledge of initial mathematical concepts and procedures.

Methodology

Participants:

Forty-three children between the ages of 5- and 7-years old participated in this study. From this total, 11 children were deaf and 32 were hearing children who composed the comparison groups. The participants were organized into four groups, as follows: a) Group 1: composed of 11 deaf children, mean of age 6-years old; b) Group 2: composed of 11 hearing children attending a center of early childhood education from the public school system; mean of age 5-years old; c) Group 3: composed of 10 hearing children attending a center of early childhood education from the private school system; mean of age 5-years old; d) Group 4: attending a center of early childhood education from the public school system; mean of age 6-years old. Pairing deaf children with hearing children in experimental studies is always problematic because of the variability of cognitive skills presented by deaf children, and because of the difficulty to assess the language proficiency using some standardized measures in sign language. Thus, the groups of hearing children were created to control for the variables of age (Groups, 2 and 4) and type of schooling (Groups 2, 3 and 4). For more details about participants' mean age and groups' composition, see Table 1.

Deaf children, who participated in this study, all attended public schools and were receiving instruction in Brazilian sign language (Libras). Since in Brazil there is no available language standardized tests in sign language to support the pairing of the groups based on their linguistic abilities, knowledge of Libras of at least one year was established as a criterion for participation. Due to the fact that in Brazil there is a visible and documented difference between the quality of the education delivered by private schools and state supported public schools, which reflects the country's socioeconomic inequalities, the control for type of schooling seemed necessary. In other words, in Brazil the vast majority of children attending public schools come from low-income families and, contrastingly, the children attending private schools come from higher income families.

The participation in this study was voluntary, and the children's parents, or guardians, signed a consent form. Some children were tested in their school and some children were test at the university' lab. Parents who brought their children to be tested in the lab were monetarily compensated for the costs of transportation.

Procedures:

Every child participated in two sessions of about 40 minutes each. The sessions took place within an interval of one week from each other. The deaf signers were assessed in Libras by a research assistant who was a deaf graduate student to whom Libras was her native language. The principal investigator conducted the sessions with hearing children. All sessions were videotaped to ensure greater accuracy of data collection and analysis.

Eleven experimental tasks comprised the study (see Table 2). The tasks were designed to tap on two important factors: non-symbolic and symbolic quantitative-numerical representations. The research assistant and others deaf students from the graduate program in Deaf Studies helped adapting and translating the experimental tasks to Libras. It was important to assure that the experimental tasks would have the same focus and cognitive load to both groups of children that experience language in different modalities. Several pilot studies were conducted to reach this assurance. The research assistant received training in the tasks of this experimental study prior to work with the group of deaf children.

The tasks 1 to 3, focused on non-symbolic (non-linguistic) quantitative knowledge. In these tasks, children briefly saw a given set and then it was hidden under a squared cover. Then the children had to reproduce the set with the same quantity of items, in the homogeneous condition. In the heterogeneous condition, children need to reproduce a set with the same quantity and order of the items. In this last condition, children were test in spatial condition in which the different objects were laid out in front of the child, and in the temporal condition in which the objects were presented to the child and then put inside an opaque box through a secret window, this way the child had no spatial view of the items. On task 4, children were showed some cards with pictures of small objects and pets and were asked to describe what they saw ("Tell me, what do you see?") in order to assess their spontaneous quantitative vocabulary. Task 5, focused on the knowledge of numerical sequence, and children were asked to count up to the higher number that they knew. Their stop counting points was used in this study. Tasks from 6 to 11, which made up the second session of this study, focused on counting, numerical and arithmetical knowledge. The tasks 6, 7 and 8 focused on counting and on cardinality by assessing skills employed to move from counting to cardinality. Thus, on task 6 the children were asked to count heterogeneous objects placed on different containers for each quantity. On task 7, they were requested to count oversized cards contained homogenous stickers horizontally organized. On task 8, the children were requested to count actions of a monkey puppet. On task 9, children were presented with a bucket full of miniature colored bears and were asked to give the amount requested by the experimenter ("give me X"); this task assessed the children's understanding of cardinality by starting from the cardinality and applying counting procedures. Tasks 10 and 11 assessed children's understanding of addition and subtraction; these tasks had hidden results, and in order to succeed in these tasks, children must be able to (a) represent a cardinality of a set and retain that representation briefly, (b) transform the initial representation according to addition or subtraction of items, and (c) produce the answer that informs the result of the transformation.

The researchers presented the tasks as games that the children were invited to play. In all the tasks, before the testing trials, the children received familiarizations trials. Only after demonstrating good understanding of each of the tasks, then the children were presented with the testing trials.

Table 1 **Groups and Mean Age of Participants in Months**

	Mean Age of Participants in Months				
Four Groups of Children		**Low**	**High**	**Mean**	**SD**
1- Deaf Children 6-year- olds	1	61.00	90.00	73.54	8.58
2- Hearing Children – S. Schhol 5-year-olds	1	59.00	68.00	63.09	3.33
3- Hearing Children – P. Schhol 5-year-olds	0	61.00	71.00	66.40	4.11
4- Hearing Children – S. Schhol 6-year-olds	1	69.00	80.00	73.72	3.03

Table 2 **Experimental Tasks**

Focus	Tasks
Session 1 Mental representation of quantity	1- Reproduction of homogeneous sets with the following quantities: (1, 2) 3, 4, 6, 8 – one trial for each set 2- Reproduction of heterogeneous sets in a spatial condition with the following quantities (2) 3, 4, 6 – one trial for each set 3- Reproduction of heterogeneous sets in a temporal condition with the following quantities (2) 3, 4, 6 – one trial for each set
Espontaneous numerical vocabulary	4- "What do you see" – twelve cards with the following quantities 3, 4 , 6, 8 and 10
Counting sequence	5- "Count up to the highest number that you know"
Sessão 2 Counting	6- Counting objects and informing the cardinality: 3, 6, 10, 15 items. – one trial for each set 7- Counting stickers horizontally organized and informing the cardinality: 6, 10, 15, 30 – one trial for each set 8- Counting actions: 3, 4, 6, 10 jumps – one trial for each set
Cardinality	9- "Give me X" (1, 2) 3, 4, 6 & 10 – two trials for each numeral
Arithmetic	10- Addition with objects and hidden results: 3+1; 4+2; 7+3; 1+3 one trial for each computation 11- Subtraction with objects and hidden results: 3-2; 4-1; 7-3; 10-1 one trial for each computation

Data Analysis and Results

Initially, this project involved fourteen deaf children. But three children were removed and the remainders composed a group of eleven deaf children. The causes of elimination were: one child was excluded for having residual hearing and used spoken language, and two other children had no understanding of Libras, although both were six-year olds, therefore presenting a very deficient communication. There was not any kind of exclusion from the study in the groups of hearing children.

Qualitative and quantitative analyses were conducted. Thus, children's performance on the experimental tasks was computed at two levels: (1) points for correct answers and (2) coding responses for qualitative analysis. The quantitative scores were used in ANOVA tests considering the four groups as independent variables and their scores on the tasks as the dependent measure.

In the experimental tasks that focused on the non-symbolic quantitative representations (tasks 1, 2 and 3), no statistical differences between groups of deaf and hearing children were found, as shown in the following results: a) task 1: F (3, 39) = 1.81, *p* = .161, b) task 2: F (3, 39) = .617, *p* = .608, c) task 3: F (3, 39) = 1.59, *p* = .205. All groups of children were able to reproduce hidden sets up to six items and were able to reproduce an ordered sequence (heterogeneous sets) also up to six items. Deaf children showed advantage in relation to hearing children in reproduce an ordered set presented spatially. These results confirm the hypothesis that deaf and hearing children are equally able to represent quantitative-numerical information in the non- linguistic context and that deaf children have a more easy time processing information presented spatially than temporally (Zarfaty et al., 2004). This means that deaf and hearing children arrive at school with the same ability to represent quantitative information, however, differently from hearing children, deaf children would prefer if the information is presented spatially. Most importantly, these results exclude the possibility that the deaf child is cognitively impaired in their non- symbolic quantitative representations.

We have learned from research on hearing children that certain abilities related to non-symbolic quantitative representations appear very early, even before the acquisition of conventional counting skills, and, that these abilities are very important for the later development of symbolic based numerical skills (Jordan et al. 2007; 2009; Mix et al. 2002). Considering this research finding, the deaf signers in this study, then, have some of the predicates to support their performance in more complex numerical symbolic tasks.

The other experimental tasks evaluated the symbolic numerical knowledge of the participants. Statistically significant differences between deaf and hearing children were found. The results of the task 4, that investigated the children's spontaneous use of numerical vocabulary when describing what they had seen in a card containing some stickers of objects and domesticated animals, revealed a statistically significant difference between the groups $F(3, 39) = 5.25$, $p = .004$. The Games-Howell post hoc test indicated that the deaf children differed from the 6-years old hearing children attending public school ($p = .005$, $d = 2.25$), and from the 5-years old hearing children from private school ($p = .013$, $d = 2.14$), but not from the 5-years old hearing children attending public school ($p = .093$). This means that both deaf and 5-years old hearing children from public school used very few quantitative-numerical vocabulary in their narratives. These results imply that although deaf signers and 5-years old hearing children from low income families are able to non-symbolically represent quantitative information, these children demonstrated little familiarity with numerical vocabulary, which means that just the fact of growing up in culture surrounded by numbers isn't enough to develop numerical vocabulary.

The task 5, which focused on the children's knowledge of the counting sequence, revealed that nine out of the eleven deaf children (82%) only could count up to 10; one deaf child count up to 15 and another up to 39. The majority of the hearing 5-years old children attending public school, eight out of eleven (73%), had their stop count point on 19; the other three stopped around 29. The older children form public school and the 5-year olds from private school showed a much higher number sequence (between 60 and 100). These results corroborated the findings of the previous task demonstrating a poor numerical vocabulary for the same groups of participants.

The data of the counting tasks (counting objects, figures and actions; tasks 6, 7 and 8) were merged to create the category "Counting" which appears in the Graph 1. The ANOVA test revealed a difference between the four groups of participants, $F (3, 39) = 12.05$, $p <.001$. It showed that the deaf children scored statistically lower in relation to some groups of hearing children, but not in relation to all groups. That is, deaf children did not differed from 5-year olds hearing children attending public preschool; both groups had significantly lower performance than the other groups.

An analysis of the different counting tasks separately revealed that all the participants had more difficulties in counting fixed figures horizontally aligned than counting loose objects. This might be attributed to the great demand in motor coordination between pointing and saying or signing the number -word that the task required. All the children had close to ceiling score in counting actions, which may be due to the fact that the action was performed slowly and the children were highly motivated by the puppet.

In an initial analysis of counting errors, the results revealed that the deaf children committed more errors related to their limited number sequence. Which means to say that the majority of deaf signers had a short count list – only up to ten – and this influenced their counting accuracy for sets with more the ten items. For example, if a deaf child only knew how to count to ten and there was a set of fifteen figures to be counted and it was organized in one row of ten and another row of five stickers, then the child would start counting and when she got to the number ten she would stop and sign "Done. Ten and a lot!" or she would recount the set, only up to ten, and would sign "Ten" and count the other row and sign "Five" without adding the two quantities to form fifteen. The majority of the deaf children also used the iconic signs in counting (matching one finger to one object) and not the linguistic number sign. These results seem to suggest that the 6-years old Brazilian deaf signers with little numerical vocabulary and limited knowledge of the counting sequence do not yet count sets above ten items in a symbolic way, but they do it in an iconic way. Wiese (2003) suggests that there is developmental change from iconic (counting tallies, for instance) to symbolic counting that reflects the growth of children's symbolic processing. Hoiting and Slobin (2007), investigating the development of sign language, suggest that early process of sign language acquisition moves gradually from gestural indices and icons to more symbolic linguistic forms. Considering these hypothesis, it may be the case that 6-years old deaf signers in this investigation were in the early process of acquiring Libras, then, using a more gestural-iconic communication to express their yet weak knowledge of numerals lexicon and counting sequence. The weak knowledge of numerical lexicon may be a result of having fewer opportunities to practice counting above ten and this, therefore, might delay the passage from iconic to symbolic numerical abilities in deaf signers

The 5-years old hearing children from public school committed a varied of counting errors in all the counting conditions and sets. The majority of their mistakes are in their difficulty in coordinating pointing and counting, their weak knowledge of numerical lexicon, followed by some errors related to report the cardinality. For instance, it was common for this group of hearing children to count a set and inform a different cardinality from the last number-word spoken. This type of cardinality error was not committed by any deaf children in this study because they had the visual register of the cardinality on their fingers. Five-years old hearing children from low-income families also used very little their fingers during counting, this seems to influence negatively their counting accuracy (Jordan, Kaplan, Ramineni, 2008).

In general, the counting results suggest that both deaf and 5-years old hearing children from low-income families seem to have short counting sequence and difficulties in using some counting procedures. These factors may harm their mathematics learning and achievements.

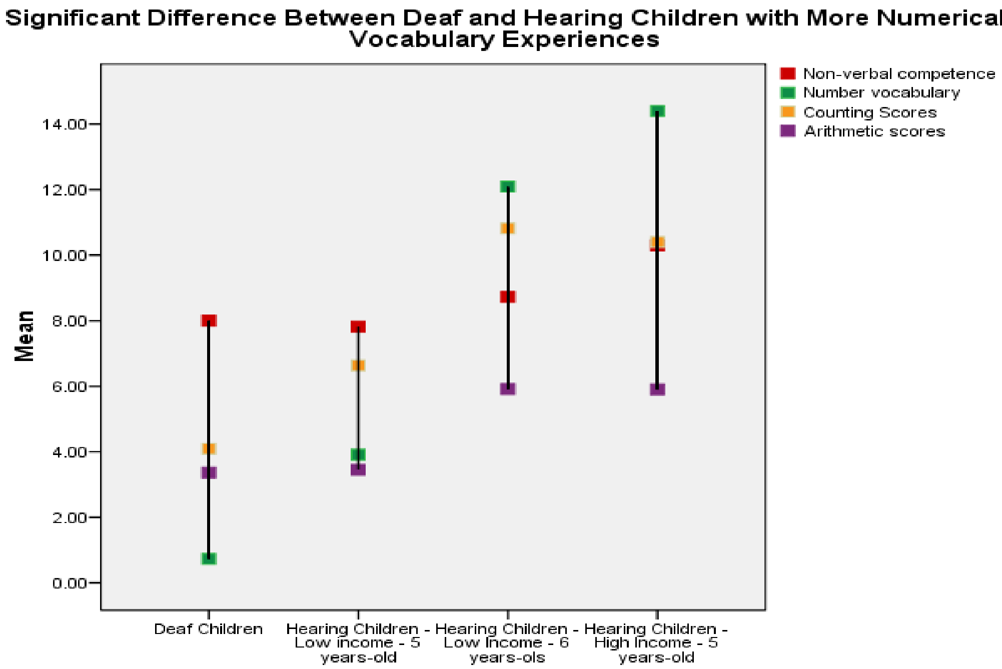
In the “give me x” task (task 9), which assessed children’s understanding of cardinality, deaf children had a significant low performance. Seven out of eleven deaf children could only produce sets up to three elements; two deaf children produced sets up to 4 elements; one deaf child could not do the task; and, only one deaf child could produce the sets of 3, 4, 6 and 10 items. This child with higher performance in cardinality task is the child with more knowledge of Libras. Here again it is possible to see the relationship between language and mathematical abilities. These results also confirm the hypothesis that the development of mathematical skills are gradual and that the acquisition of cardinality understanding, in particular, happens latter than counting (Fuson, 1983, Wynn, 1990; 1992). This was demonstrated by the fact that although all the deaf children could count up to ten, this skill did not automatically transferred to the performance in the cardinality task.

The comparison of groups’ performance in the cardinality task exhibited the same pattern seen on previous counting tasks. That is, deaf and 5-years old hearing children from low-income families scored the lowest compared to older children and children from higher income families attending private school.

The calculation tasks of addition and subtraction (tasks 10 and 11) demonstrated significant differences between the groups. In the addition task, a significant difference between groups was found, F (3, 39) = 6.03, p = .002. The post-hoc Tukey HSD test found that deaf children and 5-years old hearing children attending public had a similar lower performance than children from other groups. I.e., the deaf children had a lower performance compared to 5-years old hearing children attending private school (p = .004, d = 1.62), and older children 6-years old attending public school (p = .028, d = 1.33). And, the 5-years old hearing children from public school also had a lower performance in relation to 5-years old hearing children from private school (p = .029, d = .52), but not in relation to older 6-years old also attending the same public school . This suggests that 5-years old hearing from higher income families outperform deaf and hearing children from low-income families. In the subtraction task a significant difference between groups was found as well F (3, 39) = 3.41, p = .027. But, interestingly, the difference was significant only between 6-years old hearing children and 5-years old hearing children both from the public school (p = .036, d = 1.36). In general, deaf children found easier to subtract than to add.

In general, the results of the tasks assessing symbolic mathematical abilities demonstrated significant differences between the groups of deaf and hearing 5-years old children attending public school (low-income families), on one side, and, on the other, the groups of hearing 5-years old children from private school (higher income families) and 6-years old hearing children from public school (low-income families). These results eliminated the idea that deafness could cause mathematical difficulties since hearing 5-years old from public school showed the same pattern of results as deaf children. Then, these results suggest that the differences revealed by the experimental tasks reflect the difference of schooling type and of socioeconomic status (SES). Therefore, it seems that deaf signers and hearing children from low-income families are at risk of failure in mathematics education due to their early home and schooling experiences that provides them with fewer opportunities to support their symbolic numerical competencies.

Graph 1



Discussion

The present study revealed no differences in the mental representations of quantitative information by deaf signers and all groups of hearing children. This means that in tasks that do not require linguistic processing, the deaf and hearing children demonstrated the same capabilities, which support the inference that both groups start formal schooling with abilities to mentally represent quantitative information (Nunes, 2004; Zarfaty et. al., 2004). Research in this area suggests that these mental representations are the important intermediate step connecting young children's quantitative information processing and their subsequent development of numerical symbolic skills (Dehaene,1997; Huttenlocher et al.,1994; Mix et.al. 2002; Feigenson, Dehaene, Spelke, 2004). For instance, according to Feigenson et al. (2004), the exact representation of small numbers supports the development of more sophisticated numerical concepts.

But, the subsequent development of more sophisticated numerical concepts has a symbolic nature and its development is highly context and experience dependent (Barbosa, 2004). And that is when the gap in math achievement is evident, as it was demonstrated by this study's results. In all the tasks assessing symbolic numerical concepts, deaf children in general had a lower performance in relation to 5-years old hearing children from private school and for older 6-years old hearing children attending public school, but not in relation to 5-years old children from public school. Although the 6-years old hearing children from public school performed high in these tasks, they were one behind in comparison with the 5-years old from private school. Altogether these results revealed that the SES of the children influences more their mathematics achievement than the modality in which their language is processed.

Studies from other countries, such United States, report that children from low-income families perform strikingly low in mathematics compared to their counterparts from higher income families (Jordan & Kaplan, 2009; Jordan, Kaplan, Locuniack, 2007; Jordan, Kaplan, Olah, 2006. Klibanoff et al., 2006). According to these same studies, children from low-income families enter kindergarten lagging behind children from higher income families. In fact, the study by Jordan et al. (2006; 2009) revealed that low-income children were four times more likely than middle-income children to beginning school at low level of mathematics knowledge and to exhibiting flat growth in numerical competences through the initial elementary grades. In other words, poor children start formal schooling already behind in their informal mathematical concepts and demonstrate little growth throughout the elementary school years in comparison to higher income children. This investigation demonstrated that we find a similar situation in Brazil, i.e. the 6-years old hearing children from public school in this study had a performance equivalent to 5-years old hearing children attending private school indicating one year gap in their achievement in the measures utilized by this study. The studies reviewed above pointed out that the reasons for this well documented gap are related to learning opportunities and social experiences in which children engaged in, since just being part of a highly enumerated culture is not enough to develop mathematical concepts and vocabulary. This seems to be the case to hearing and deaf children who participated in this investigation.

The results of this study demonstrated that low-income children from public school and deaf children have a weak numerical vocabulary. It appeared that both groups' performance in numerical tasks of counting, cardinality and arithmetic was negatively influenced by their weak knowledge of number-words or number-signs. Having a strong knowledge of number-words placed the higher income children, in this study, in an advantage position to perform better in the task of numerical competencies that were more dependent on linguistic abilities (Mix, Sandhoffer & Baroody, 2005). Thus, the results suggest that exposure to mathematical symbols and vocabulary might account for the individual variations documented. Other studies had demonstrated that the quality and amount of mathematical language at home and school varies greatly (Clements & Sarama, 2008; Jordan et al. 2007; Klibanoff et al., 2006) depending on children's SES, cognitive abilities, and schooling. For instance, research have shown that deaf signers have fewer opportunities to incidental interactions with quantitative-numerical information than hearing children, and they usually engage in less spontaneous mathematical games and activities – especially if they do not share the same language modality as their parents, as it is the case for deaf children from hearing parents (Kritzer, 2009). And, in the case of hearing children, research indicated that low-income families provide less support for mathematics and engage in less complex mathematical problems than higher income families (Jordan et al. 2007). The type of schooling also seems to influence children’s mathematics achievement. A comprehensive review by Clements and Sarama (2008) in some educational programs in United States revealed that public preschool programs provide fewer opportunities to learn mathematical concepts than private schools attended by higher income families. Although the investigation reported here had not explored the learning opportunities in these different schooling settings, it is largely documented in Brazil that public school programs lack in quality of the education provided in comparison to private schools (Cury, 2008). But, on the other hand, research also suggests that is possible to overcome these difficulties with a carefully designed instruction based on the learning strengths of deaf children (Nunes, 2004) and hearing children at risk of math failure (Clements& Sarama, 2008).

In summary, these results suggest that Brazilian deaf signers and hearing children from low-income families are at risk of low mathematics achievement and that both groups will benefit from a program for teaching mathematics that make use of concrete materials; provide vast amount of numerical experiences; improve mathematical vocabulary; and, design instruction grounded on children’s preferred learning mechanisms, strategies, and linguistic modality. Thus, to reduce the gap in academic achievement in the area of mathematics among deaf and hearing children, educational programs are needed in early childhood education to ensure conditions for development of quantitative and numerical knowledge of these children.

In conclusion, this study provides evidence that Brazilian deaf signers are equally capable to represent quantitative information as hearing children. However, they lag behind in symbolic mathematics abilities to hearing children from high-income families attending private school, but not to hearing children from low-income families attending public school. Research in the field has demonstrated that the non-symbolic quantitative competencies are important for later mathematics attainment and the symbolic mathematics skills are acquired by instruction and inputs from social experiences. Children at risk of failing in mathematics have difficulties with the symbolic skills involved in counting, numerical vocabulary, cardinality and arithmetic operations such as addition and subtraction. This seems to be the case for young deaf signers and children from low-income families in Brazil. However, these initial weaknesses in mathematics abilities are possible to be overcome with research based educational programs targeted to children’s linguistic modalities and learning strengths. For instance, deaf signers will prefer process information presented spatially than temporally, and both, deaf and hearing children from low-income families, will benefit from having more opportunities to experiment with mathematical concepts and to express mathematical ideas using appropriate mathematical vocabulary. Independent of the language modality (oral or visual-spatial), children need to take part in experiences that focus on numbers and their functions in order to develop a vocabulary to express numerical and mathematical ideas. Therefore, there is pressing need to improve the quality of public education for all children independent of their linguistic processing modality.

Because this study revealed a strong relationship between language and mathematics abilities, and because this study did not separately investigated the mathematical skills of deaf children from hearing parents and deaf children from deaf parents, further research is needed to examine if having a shared linguistic modality between children and parents influences children's mathematics skills. It is also important to develop instruments that make possible to pair deaf signers and hearing children by their linguistic abilities, this might give us a more accurate account of their individual variations.

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