CATEGORICAL PERCEPTION IN CATALAN SIGN LANGUAGE

By

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THESIS

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Abstract

Sign languages share some linguistic properties with oral languages. Indeed, this is supported by de observation that both modalities are sensible to the same linguistic phenomena. In the present study we focus on categorical perception during sign language. To do so, we study whether deaf children signers, hearing children signers and hearing adult non-signers perceived handshape contrast pairs as belonging to distinct categories or continuously. Categorical Perception for four handshape contrast pairs of Catalan Sign Language (LSC) was measured by means of a forced choice identification task and an ABX discrimination task. All three groups performed similarly in the identification task, labelling categories at a similar point along the stimulus continuum. In addition, the data from the discrimination task supported the effect of categorical perception across groups: participants were more accurate in discriminating between category boundaries compared to within categories. However, not all pairs were perceived in the same manner, suggesting that perception can vary depending on which handshape contrast continuum is presented. The results obtained showed that Categorical Perception exist for LSC though linguistic expertise in sign language appears to be somewhat independent of handshapes perception.

Keywords: categorical perception, Catalan Sign Language, handshape, language.

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1.  Introduction

Categorical Perception is a psychophysical phenomenon in which a change in some variable along a continuum is perceived, not as a gradual change from one type to another but as sets of instances of discrete categories (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). “Physical” because we have a stimulus that vary along a physical continuum with the same magnitude interval; and “psycho” because the effect of categorical perception provides a qualitative difference in how we perceive similar things depending on whether or not they are classified in the same category. In the experimental paradigm of categorical perception, in order to study how we store different inputs as belonging to the same category, commonly it has been observed the interaction of two tasks: the identification task and the discrimination task. Identification task allows us to assess whether changes is a continuum are distinguish as belonging to two different categories. Besides that task, it has been used discrimination task to assess whether discrimination between stimuli is much more accurate between categories than within them. In other words, all stimuli in a given category should be perceived as indistinguishable, whereas stimuli between categories should be perceived as different. These differences for category membership, between-category vs. within-category, are also observed considering reaction times. Categorization of ambiguous stimuli takes longer than categorization of less ambiguous stimuli; in other words, detecting stimuli variability within categories takes longer than variability between categories.

Over the past decades this phenomenon has been the main field of many studies and not without discussion since results were not always supporting the same theoretical approach. Early surveys testing categorical perception were done in spoken language(Liberman, Harris, Hoffman, & Griffith, 1957). In these experiments, participants listened to synthesized speech sounds that span the voice onset time (VOT) continuum between /ba/ and /pa/. The first half of the continuum was identified as /ba/ and the second half was consistently identified as /pa/ showing two well defined categories. In addition, discrimination between different stimuli within a category was at chance. Categorical perception has not obtained such clear results for a fricative-affricate continuum such /sa-tsa/ and /ʃa-tʃa/ (Ferrero, Pelamatti, & Vagges, 1982) and even weaker for approximants such as /r/–/l/ (Rosen & Howell, 1987), while the perception of vowel stimuli exhibits a mainly continuous pattern through the continuum. Such perceptual differences in speech sound types have been attributed to differences in some acoustic cues: rapid CV or VC transitions and transient release bursts in stops versus fairly long and steady formant structures in vowels (Pisoni, 2013). While results differed depending on phonemes properties, since phonemes are the basic unit of language's phonology it seemed unquestionable that categorical phonemic perception was a phenomenon unique to humans. However other studies showed that we can found categorical perception in non-human trained animals. Chinchillas display the same perceptual discontinuities for VOT as do humans (P K Kuhl & Miller, 1975), and testing crickets with speech like stimuli (Wyttenbach, May, & Hoy, 1996) suggested that categorical perception may be a basic and widespread feature of sensory systems not solely human. Therefore for different populations we can find categorical perception depending on the features of the stimuli presented. Knowing that categorical perception varies depending on the characteristics of the stimuli presented, next key issue refers to expertise of participants with perceived stimuli.

Several researches have studied that newborns are able to perceive any phoneme (even nonnative speech contrasts) up to 6 months of life. (Werker, Gilbert, Humphrey, & Tees, 1981) tested two pairs of Hindi contrasts in 7-month old English infants. These infants were able to discriminate Hindi speech contrasts but adults did not. Bosch & Sebastián-Gallés (2003) showed that three groups of 4 month-old infants (Catalan monolingual, Spanish monolingual, and Catalan-Spanish bilingual) reached discrimination on a vowel contrast (/e/ - /ɛ/) present only in Catalan. By 8 months, discrimination ability for Spanish monolinguals and bilinguals was reduced, and only the bilingual group recovered the discrimination at 12 months. This pattern of differences between newborns, infants and adults has been closely linked to experience. Exposure to a language in early months of life increases the refinement of phonetic categories, decreasing speech perceptual abilities for nonnative phonemes.

So far we have dealt with the issue of categorical perception in language; but more accurately it should be noted that we have been considering language in its oral modality. Modality is commonly known as the mode by which language is perceived and produced; by this definition are differentiated the auditory-vocal modality of spoken languages and the visual-gestural modality of signed languages. It has been described several properties shared between modalities, but controversial results have been obtained by drawing on expertise as the core of categorical perception of sign language. Here we want to explore categorical perception in Catalan Sign Language (henceforth LSC) analyzing what are the common effects and the differences of experience upon linguistic modality.

1.1 *Signs, brain and language*

Sign languages are visual languages that use a system of manual, facial and body movements as the means of communication. As in the case of oral languages, there are many sign languages around the world, and LSC is the language used by the deaf community in Catalonia. As recent studies shown, language and the brain are flexible with respect to modality and sign languages are processed dominantly in the left hemisphere of the brain, just as all other oral languages are. In addition, both oral and sign languages can nurture brain development, are acquired by children in the same timeframe and this acquisition shows similar patterns and milestones (Meier & Newport, 1990; Sandler & Lillo-martin, 2006).

Hearing children begin to making cooing noises at approximately 2-3 months of age, and begin babbling between 3-6 months of age. At the same period a deaf child also begins to babble, referred to as “finger-babbling”. Hearing 6-month old children will begin producing jargon speech. Between 6-12 months, deaf children will use manual jargon, and will communicate with gestures, such as pulling and pointing. Many hearing children will produce their first few words between 12-18 months of age and many deaf children will sign their first word around 8 months of age and up to 10 or more signs by 12 months of age (Andrews, Logan, & Phelan, 2008). In spoken languages, children's phonological competence and their phonetic performance need to be differentiated carefully. Three years old children are not able to articulate some phonemes, but are able to recognize the auditory difference. This fact shows different performance regarding children’s phonological rule and production of the speech. For the sign languages, we can make the same distinction. Although three years old are not able to perform well-defined handshapes, they are able to recognize them. Later language developmental milestones (from 1-4 years of age) further evidence a similar order of progression.

Sign languages display the full array of hierarchically organized linguistic stages as oral languages, and can be analyzed at the phonological, morphological, grammatical and lexical levels. In this study, we focused on one of the stages that are engaged in a related exposure to language, such as phonology. In language, phonology is the study of the smallest part of the language that conveys meaning. In spoken languages, a phoneme is the minimal unit of sound that conveys meaning. Even though in sign languages phonology is not based on sound but is spatial, phonemes (or cheremes as indicated by Stokoe, 1960) have the same role such as in oral languages. Stokoe showed that the signs in the lexicon of ASL (American Sign Language) are comprised of a relatively small number of meaningless units which can be combined to build a potentially large lexicon.

In sign languages the smallest units of language, the phonemes, are defined by four general parameters: handshape, location, movement and orientation (Stokoe defined the first three and the fourth was later added). *Handshape* is the shape of the hand referred to specific configurations of fingers and thumb. *Movement* specifies the action that the handshape and/or arm perform. *Orientation* describes the orientation of the palm relative to the signer. *Location* refers to the location of the sign on or in front of your body. If we change any of these parameters of a sign, then we have changed the meaning of the sign. A fifth parameter that is often added to this list is *facial expression* and/or *non-manual markers*. Facial expression fall under the more general category of non-manual markers which consists of the various facial expressions, head tilting, shoulder raising, mouthing, and similar signals that we add to our hand signs to create meaning.

We have seen that both oral and sign languages are thought to function in an analogous way but differences seem to be obvious regarding the transmission modalities. Spoken languages utilize the vocal-auditory tract while sign languages have a manual-visual modality of transmission. Therefore we can consider both languages have phonemes as the basic phonological units, but it is important to consider the modality of perception of these phonemes is strongly different. Here we want to analyze to what extent the fact that perceiving signs and words through such different modalities can influence our perception of these categories.

As described above, perception has been strongly related to language experience, therefore if experience mediates how we perceive spoken languages it may be the case that experience also plays a decisive role in the way that humans perceive sign languages. Is has been suggested for both behavioral and neural research that there is a critical period– when there is an abrupt decline in plasticity- or a sensitive period – when the decline is more gradual and a few plasticity remains through lifespan- for language acquisition (Lenneberg, 1967). These surveys showed a strong relationship between the age of exposure to a language and the proficiency reached in that language (Johnson & Newport, 1989) .It is well known that the variability in age of exposure to a signed language is related to language performance in adulthood (Emmorey, Bellugi, Friederici, & Horn, 1995; Mayberry, 1993). Newport (1990) studied deaf adults acquiring ASL as their primary language, and the results showed effects of age of exposure on their grammatical skills. However, age of exposure seems not to affect all the stages of language learning in the same manner. We can acquire semantic and lexical processing as late learners; therefore the levels related to the process of meaning are preserved throughout life. The critical language learning period is related to the formal properties of language (phonology, morphology and syntax) but the issue would be to what extend these formal properties would show some continuing ability to learn signed languages once we have passed the critical age.

Age of acquisition has been considered extremely important in determining language skills. However in the case of deaf children some of them don't acquire any language before school, thus age of acquisition for a L1 or for a L2 is conditioned by three more factors: (i) adequate input of L1 or L2, meaning adequate exposure to language, (ii) how the language is practiced, meaning how and with whom the language is produced and (iii) language evaluation, in the sense of follow up and language correction. Deaf individuals, unlike hearing individuals, vary considerably in the age of exposure to their first language and some of these children at home do not speak sign language because their parents do not know signs; they will therefore only communicate with this modality in school. In addition, deaf children are exposed to many adults who do not have sign language as their first language and may not be proficient in this language, meaning they are exposed to models that are not optimum for the development of language. Furthermore, the fact that their interlocutors do not have high sign language skills can also influence the comprehension of the message, learning from poor role models and communicating later from the base of errors unconsciously learned. Another issue to consider is how speaking a vocal-auditory language influence in learning a manual-visual language in both deaf and hearing.

From all the above we draw that if experience with LSC is crucial for categorical perception: (i) we must find differences between groups at the location of perceptual boundaries; (ii) the more experienced in LSC the more degree of sensitivity at perceptual boundaries compared to within-category handshape variation. With these experiments we want to explore whether deaf signers develop unique abilities for perceiving distinctions that are relevant to LSC similar to those for spoken languages, and how the language used by their parents influences the development. On the same line we wonder whether late exposure to sign language may have consequences upon subsequent stages of sign language comprehension. We compare the performance of hearing participants and deaf participants analyzing how language is categorized from a manual-visual modality as a second language.

2. Methods

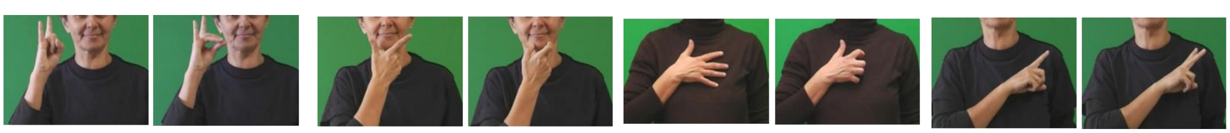
2.1. *Participants*

Participants in this study included a control group and two groups of interest. The control group was comprised of ten hearing adults who had had no exposure to a signed language (age range 23-38). The two groups of interest were nine prelingually deaf children Catalan Sign Language (LSC) signers (age range 9-12 years) and sixteen hearing children who have been learned sign language in the same school as the deaf participants (age range 10-11 years). Data from one deaf participant was excluded from the analysis because he performed at chance on the discrimination task described below.

For the group of deaf signers, LSC alone or LSC and Catalan or Spanish were the primary languages they used on a daily basis. The hearing children have been in contact with LSC from the age of three, which means eight years of experience using LSC, but did not report using it as their primary language.

2.2. *Materials*

Four phonemic handshape contrast pairs were used corresponding to actual LSC signs: [horns] vs. [0-2 horns] -TREE vs. GIRAFFE -; [L] vs. [crvd-L] -COLOUR vs. LIKE-; [1] vs. [V/2] -PEE vs. GREEN-; [B-bar] vs. [Claw]-MINE vs. BOTHER-. In an attempt to replicate experiments performed by Morford et al. (2008), we used the same handshape contrast (B-bar vs Claw) even though the meaning in Catalan Sign Language is a bit different (MINE-BOTHER instead of MY-COMPLAIN). All other phonological parameters were held constant across the stimuli for each continuum, therefore the movement, location and orientation remained constant for all steps.



Tree [horns] vs. Giraffe [0-2 horns] Color [L] vs. Like [crvd-L] Mine [B-bar] vs. Bother [Claw] Pee [1] vs. Green [V/2]

Figure1. Handshape contrast pairs.

In order to create the visual homologue to classic spoken language perception experiments, each handshape from the contrast pair became the endpoint of an eleven-step continuum, depicting equally spaced steps between the two endpoints (Figure 2). The handshapes were articulated by a deaf LSC signer adult standing against a green chroma key. Movements from one endpoint to the other were digitally recorded and videos were sampled at a rate of 25 frames/sec. The pictures for each stimuli continuum were generated with MPC-HC and were presented on a laptop computer using E-Prime software. As the experiment was carried out with children rather than the classical response method using a keyboard, participants were asked to respond using a gamepad. A block practice with a different handshape continuum [U-L] vs. [U-H] - HORSE vs. RABBIT- preceded each task. Generally,

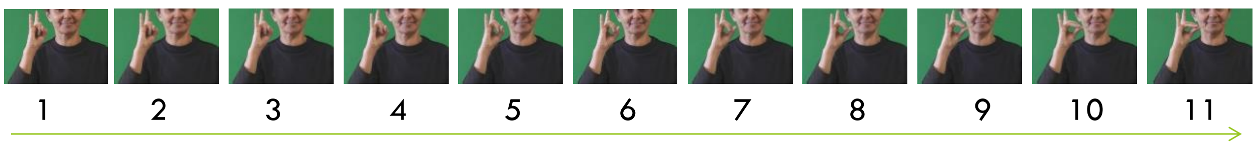


Figure2. Example of stimulus continuum varying from the sign TREE [horns] to the sign GIRAFFE [0-2 horns].

If the categorical perception broadly exists in sign language, we should find a similar effect on all contrast pairs analyzed. However, given the results of previous studies, we predicted that categorization performance would differ across these four continuums, leading to clearer effects in the least discriminable pair. In other words, the less discriminable is a pair the bigger the effects of categorical perception.

2.3. Procedure

After obtaining informed consent, all the participants performed two tasks: an ABX discrimination task and a forced choice identification task with accuracy and reaction times recorded for both tasks.

2.3.1. Discrimination task

The discrimination task was always presented before the categorization task and was based on an ABX matching to sample paradigm. Participants were presented with a pair of stimuli ([A] followed by a blank black screen inter-stimulus interval [ISI], and then a second stimulus [B]) as well as a target stimulus [X] identical to the first [A] or the second stimuli of the pair [B]. Based on previous studies (Emmorey, McCullough, & Brentari, 2003) stimulus [A] and [B] were displayed for 750ms each, the [ISI] was displayed for 1 sec and the [X] was displayed for 1 sec.

A response screen in which appeared a number 1 on the left and a number 2 on the right followed each ABX presentation, during which participants pressed the left or the right button of the gamepad (if they thought the target stimulus matched the handshape presented first [A] or second [B]).

The stimuli pairs for discrimination task involved two step comparisons, so for each 11 step continuum there were nine comparisons (1-3, 2-4, 3-5, 4-6, 5-7, 6-8, 7-9, 8-10, 9-11). Each comparison was presented four times (4 ABX orders were possible: AAB, ABA, BBA, BAB) resulting in 36 combinations fully randomized for each continuum handshape pair.
Participants' accuracy to distinguish between the members of the stimulus pair was measured by their ability to select the appropriate match to the target stimulus.

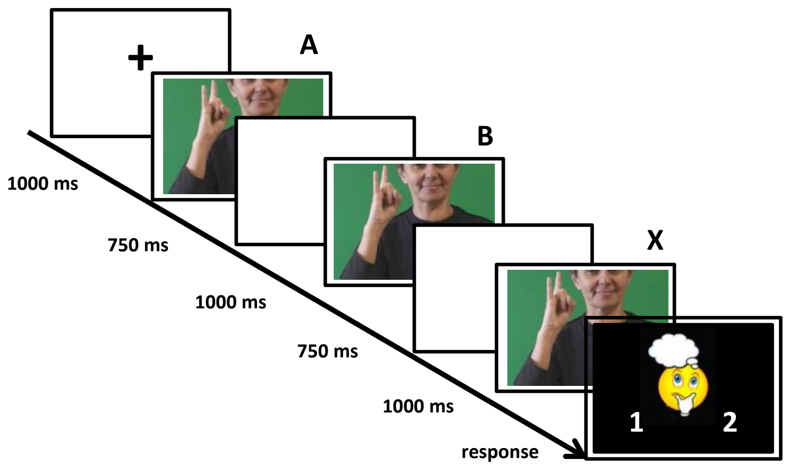


Figure 3. Trial structure in the discrimination task. Example of an ABX triad for the TREE_GIRAFFE continuum where A and B were two steps apart on the continuum and X was always identical to either A or B.

2.3.2. Identification task

The identification task consisted in a binary forced-choice categorization. The four handshape continuums tested were presented into four independent blocks. The blocks consisted of one repetition of each contrast pair. Blocks were preceded by a brief practice session using a different handshape continuum (HORSE-RABBIT) and the opportunity to ask questions. The order of presentation of each continuum for the four blocks and of the trials within a continuum was randomized across participants.

At the start of the identification task for a continuum, each participant was shown two cartoons (one on the left and one on the right) related to the two handshape endpoints. Pressing designated keys on the gamepad participants could see the endpoint handshape labelled with cartoon 1 or 2. Once participants identified the two handshape endpoints, one image out of the 11 images continuum was presented. Stimuli were presented for 750ms followed by a black screen with the two previous cartoons. Participants were asked to decide which cartoon that image most closely resembled. The endpoint handshapes were available only at the start of a given block and not during the actual identification trials.

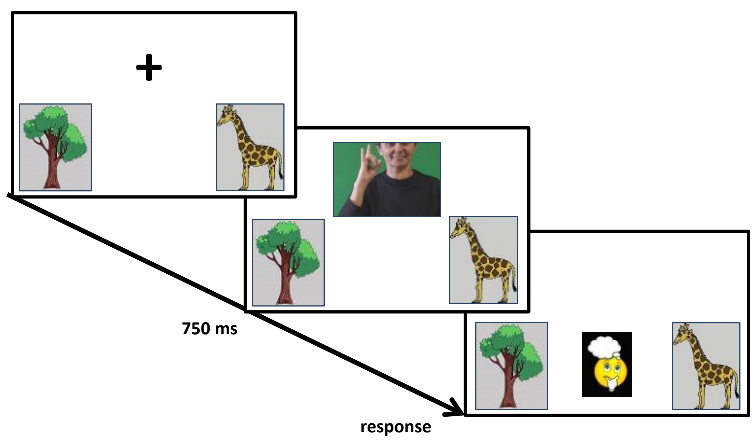


Figure 4. Trial structure in identification task. The two cartoons were always present on the screen and one handshape stimulus of the continuum was randomly selected in each trial.

3. Results

We report first the results on the identification task even though the discrimination task was tested before. Based on previous studies of categorical perception in sign language (Baker, Idsardi, Golinkoff, & Petitto, 2005; Best, Mathur, Miranda, & Lillo-Martin, 2010; Emmorey et al., 2003; Morford, Grieve-smith, Macfarlane, Staley, & Waters, 2009; Sevcikova, 2013) by definition discrimination should be better and faster across a perceived boundary than within categories. So first we must know where the boundaries were (identification task) to in a subsequent analysis (discrimination task) classify the handshape contrast pairs as between or within category.

3.1. Identification Task

For all the four continua tested, adult non-signers, hearing signers and deaf signers identified the stimuli as belonging to two different categories, with a clear boundary between them.

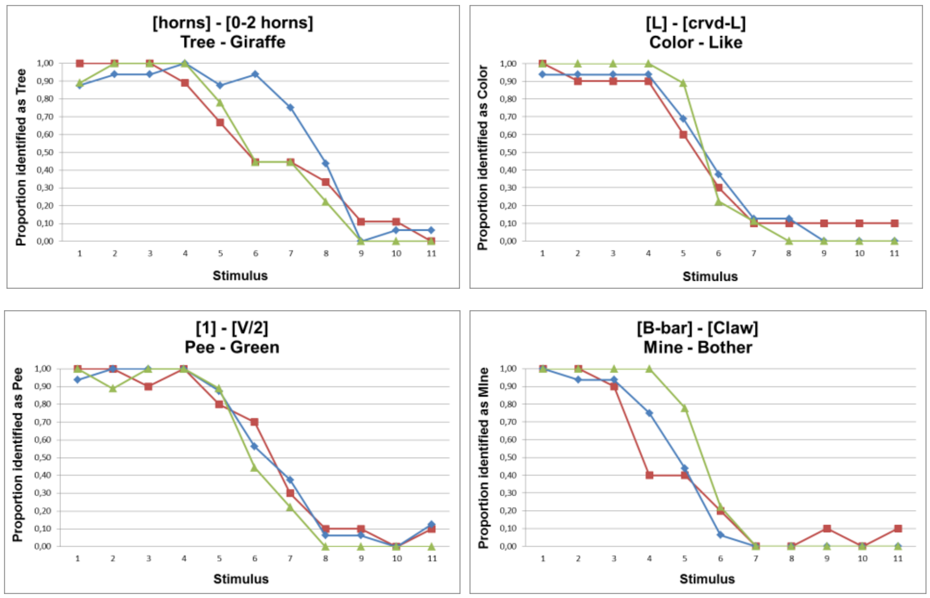


Figure 5. Identification function for the handshape contrast pair continuums.
Note: RED, deaf children signers; BLUE, hearing children signers; GREEN, hearing adult non-signers.

We observed differences in their responses, as they located the category boundary in different point across all handshape contrast continuums. Table 2 reports the boundary location for each subject and handshape pair. In order to assess whether the four handshape pairs had the same perceptual characteristics, we conducted a generalized linear model analysis. Significant differences were found for all four handshape pairs, so we concluded that the pairs were not equally discriminable (Table 3). Hence we could not collapse the boundaries for handshape pairs' data and the analysis was conducted for each pair separately.

A second generalized linear model analysis allowed us to determine that the three groups performed comparably (Table 4). Although no significant differences were found for the boundaries between categories across groups, there was variability between participants within groups (Table 2). Therefore we opted to take the boundaries of each subject to label between and within pairs in the discrimination task.

These results suggest that linguistic experience in LSC appear to be somewhat independent to perceive handshapes categorically.

3.2. Discrimination Task

An indication that participants have signed categorical perception is that for a given handshape contrast, pairs that straddle the category boundary should be easier to discriminate than those that are within the same category. In an idealized function of categorical perception, we should see a peak of discrimination for the between category pair and lower accuracy within categories. As it has been shown for the identification task, participants varied among them in identifying category boundaries and also depending on the handshape continuum perceived; thus category membership pairs (between-category or within-category) were determined individually for each subject.

Discrimination accuracy comparing between-category pairs and within category pairs was analyzed with a 3 x 2 repeated measures ANOVA, with group (deaf signers, hearing signers and non-signer adults) as the within-subjects factor and category membership as the between-subjects factor. This analysis (using an alpha level of 0.05) revealed an effect for the category membership [$F(1,31)=10.900$, $p=0.002$] in which higher scores were obtained for the between-category pairs, pairs that straddle the category boundary, in comparison with the pairs within the same category. We found significant differences in the accuracy for the three participants' groups [$F(2,31)=27.683$, $p<0.001$)]. Overall, non-signer adults were more accurate than hearing signer children and the latter were more accurate than deaf signer children (Table 5). However, the fact that a given group is more accurate than another does not imply by itself a more robust effect on categorical perception or the interference of language background. What determines the strength of the effect is the interaction; that is whether differences between category membership pairs are significant for one group compared to the other group. The interaction between groups of participants and category membership revealed no significant differences [$F(2,31)=0.591$, $p=0.560$]. Thus, although there were differences in accuracy values across groups, no group demonstrated a higher categorical perception compared to the other groups. In contrast to the classic categorical perception framework, we did not find an effect of signed language exposure that could be a determining factor of the categorical perception of the LSC.

We analyzed the variants of the ABX trial type to be sure that this factor could not bias the responses obtained in discrimination task. We conducted a 3 x 4 repeated measures of variance (ANOVA), with group (deaf signers, hearing signers and adult non-signers) as the within-subjects factor and trial type (ABA, ABB, BAA, BAB) as the between-subjects factor. This analysis (using an alpha level of 0.05) revealed no main effect for trial type [F(1,1190=0.727, p=0.394] which indicated that differences in the response trial type were not significant. No interaction was found [F(33,1190)= 0.976, p=0.508] between trial type and participants. Variants of the ABX trial type were not determinants in the participants' performance therefore data for all the responses belonging to the same trial type was collapsed for subsequent analysis.

Further analyses were conducted to determine categorical perception within group for each handshape contrast pair. Taking the classic sign language categorical perception framework, for a given handshape contrast pair, if the results for the identification task would have continuity in the discrimination task we should expect higher accuracy values in the between-category handshape contrast pairs compared with lower and equivalent discrimination values for the within-category handshape pairs. Hearing children were more accurate in the between-category pairs than within-category pairs for all four continuums (Figure 5 & Table 5). Deaf children were more accurate between-category for the handshape contrasts [horns] vs. [0-2 horns] (TREE vs. GIRAFFE); [1] vs. [V/2] (PEE vs. GREEN); and [B-bar] vs. [Claw] (MINE vs. BOTHER) but not for [L] vs. [crvd-L] (COLOR vs. LIKE). Adults were more accurate between category for PEE vs. GREEN, MINE vs. BOTHER and COLOR vs. LIKE but not for TREE vs. GIRAFFE in which they were more accurate within-category.

Paired T-test comparisons were conducted separately by group on each contrast continuum, in order to determine in which continuum the groups showed significant differences in the between-category and within-category pairs. For the non-signer adults group, only the continuum MINE_BOTHER reached significant differences [t(9)=3,331, p=0,009] between categories. The same handshape continuum was also significant for the hearing signers (t(11)=2,33, p=0,04) but not for the deaf signers. In addition hearing signers was the only group showing significant differences for the COLOR_LIKE continuum [t(9)=2,408, p=0,039]. For the deaf signers' group, the only significant continuum was TREE_GIRAFFE [t(4)= 4,833, p=0,008]. No group had significant differences between-category compared to within-category for the PEE_GREEN continuum.

Although significant differences were not consistent for the three groups and for all four handshape contrast continuum, What is observed based on this analysis is that while there appears to be the existence of a potential effect of categorical perception in Catalan sign language, this varies greatly within the same group of participants depending on which handshape continuum is perceived.

Turning now to the issue of the variability within groups, a visual inspection of the data revealed largest variability for the group of deaf children compared to the other two groups (Table 4). Following previous studies showing differences between deaf native and deaf non-native signers (Best et al., 2010; Morford et al., 2009) we conducted further analysis for each subgroup of deaf participants. We are aware that the small sample does not allow us to draw strong conclusions, but the goal of this subsequent analysis has been to look for an explanation for the observed variability and propose questions for further research. Deaf native signers were more accurate for the discrimination task than deaf nonnative signers. Differences, however, were not observed for the two category membership conditions (between and within). Within-category both subgroups performed in a similar way although for between-category pairs deaf native signers were considerably more accurate. A separate T-test for deaf native signers revealed significant differences in accuracy for discrimination between-category versus within-category pairs [$t(7)=2.63$, $p=0{,}033$]. In contrast, no significant differences were found for the deaf nonnative group [$t(10)=0.18$, $p=0{,}86$]. This pattern is in line with what showed Morford et al. (2009), where the deaf native signers showed higher results in categorical perception than deaf nonnative signers.

Due to little statistical power related to the small number of participants, we conducted sign detection in order to look at the categorical perception effect in each participant individually. 7 out of 8 deaf children observed responded more accurate detecting handshape contrasts between categories that within the same category. Specifically, higher scores between categories than within categories were consistent in all 3 native signers and 4 out of 5 non-native signers. In the group of hearing children this occurred in 10 out of 16 children, and the same effect was observed in 7 out of 10 adult participants.

As a complementary analysis in this study, we looked at the reaction times in relation to the category membership. Looking the results of reaction times and categorical perception it has been claimed (Pisoni & Tash, 1974; Sevcikova, 2013)) that if there is an effect of categorical perception, reaction times in the between-category pair should be slower than reaction times in the within-category pairs. The reason for that would be that we can perceive the between-category pair as less ambiguous than the within-category pairs, leading therefore to faster responses. Reaction times in the discrimination task (Table 6) were analyzed with a 3 x 2 repeated measures of variance (ANOVA), with group (deaf signers, hearing signers and adult non-signers) as the within-subjects factor and category membership (between-category or within-category) as the between-subjects factor. This analysis (using an alpha level of 0.05) revealed no main effect for reaction times between or within category [F(1,31=0.281, p=0.6] which indicated that differences in the reaction times between conditions were not significant. There were no main effect for group [F(2,31)=0.393, p=0.678] meaning that the three groups did not differ in reaction times overall and performed comparably in all of the conditions for category membership. No interaction was found [F(2,31)=0.432, p=0.653]. Thus, although previously it has been found an effect of category membership for the three groups of participants, this effect has not been corroborated with the reaction times.

4. Discussion

Categorical perception in sign language has been tested in some groups of adults and infants but to our knowledge, no previous study has explored sign categorical perception in children. We considered necessary to study this age group building a junction point between the results found for infants and adults, therefore we have attempted to explore LSC categorical perception in 10-12 year olds. Experience is considered an influential factor in the development of the categorical perception of language, and so we wanted to control as far as possible this factor performing the study of deaf and hearing children attending the same school. In a bilingual school (understood as oral language and sign language) three year old children begin contact with sign language, and this language is present throughout their schooling. In this context it should be stressed that even for children who began learning sign language at the same age, LSC is considered the first language of deaf children and a second language of hearing children, and their linguistic productions are quantitatively and qualitatively different. A group of non-signer adults was also studied and compared with children's groups, and categorical perception in LSC was found for all three groups and it appeared to be independent of previous experience. However, given some differences in the results, then we consider whether it can be considered a specific linguistic perceptual process or a general perceptual process.

In the present study, we used two tasks widely known to assess categorical perception both for speech and sign perception: the identification task and the discrimination task. Categorical perception inferred from the results obtained with these tasks, has been commonly associated with previous exposure to the type of input perceived. That is, contact with language in the first six months of life seems to help build categories shaping categorical perception in spoken language (Sebastián-Gallés, 2006). Some authors have been claimed the same occurs in the field of categorical perception in sign languages (Baker et al., 2005; Emmorey et al., 2003).

But some differences must be considered in these different domains. In the field of speech perception, it has been shown that if a person has no experience with phonemes, he is unable to make a clear distinction between categories (Patricia K. Kuhl et al., 2006). Interestingly, this does not seem to be the case in sign languages. The finding that groups of hearing non-signers, hearing L2 signers, deaf native signers and deaf nonnative signers has been performed similarly across the identification task, suggest that sign categories may have a perceptual as well as a linguistic basis (Emmorey et al., 2003). That is, in our research non-signer adults as well as hearing signers and deaf signers identified each handshape continuum as belonging to a two different categories. The shape of the identification curve as well as the location of the category boundary did not vary significantly with LSC years of experience. Thus it seems that the ability to detect visual features involved in identifying handshapes is not affected by linguistic experience in sign language. Furthermore, the results seem to suggest that the age of the participants was not a crucial factor in performing the task. Indeed, this result is not that surprising if we consider previous research done with 4-month-old hearing infants in Baker et al. (2006). These infants could categorically discriminate phonetic handshape contrasts in ASL, even not having been exposed to a signed language. But we should keep in mind that even if not exposed to a sign language, a baby is exposed to many hand signals of their environment enhancing communication (Wu & Coulson, 2007). Spoken language accompanied by gesture language is used through cultures to express that we want food and drink, or when we are happy or angry. In this way, given than we perceive hand movements linked to meaning throughout our childhood, it could be that this ability does not disappear in subsequent stages of development.

Turning now to the issue of the relevance of the discrimination task, all previous studies have reported that for a given group of participants (deaf native signers, deaf non-native signers, hearing signers and hearing non-signers) all stimuli continuums tested were classified as belonging to two different categories with a sharp boundary between them. Thus, traditionally categorical perception in sign language has been mainly based on the discrimination task. Considering this task, Baker et al. (2005) and Emmorey et al. (2003) claimed that American Sign Language is perceived categorically by deaf native signers but not by hearing participants.

In these studies as well as in Morford et al. (2009) and Best et al. (2010) identification performance was similar across groups regardless of language experience, so that the key point between studies was language expertise linked to the discrimination task.

If linguistic expertise in LSC is important for the perception of handshape contrast pairs, there should be differences between deaf children and hearing children in the accuracy located at the category boundaries. And compared to non-signer adults we should find larger differences, as they have had no previous experience with sign language. However, according to the results obtained, we cannot determine that there were significant differences between groups. All three groups of participants were more accurate on the category boundary for all four handshape continuums than within-category membership. We did not find low level handshape contrast pair's discrimination performance, so it seems that those who have not been exposed to sign language before 14 months have not lost the ability to categorize signs (but see Baker et al., 2006) The argument for a sustained handshape perception not being exposed to the LSC, would come from the fact that babies throughout cultures have experience with co-speech gestures. We gesticulate from childhood as a form of communication. Our expressions often are accompanied by gestures that evolve from only deictic and representational to more complex gesticulation. Co-speech gestures support our utterances and allow for better interpretation of spoken meaning (Wu & Coulson, 2007). This trait can be found throughout all cultures, although it is clear that gestures alone do not form a complete language as sign language. As we grow not only develop our linguistic discourse, our co-speech gestures evolve in meaning and represent more complex concepts. For participants, staring pictures with a handshape may be close to perceive a gesture (or a co-speech gesture) not to perceive a phoneme of a language. Rather than speaking of categorical perception in sign language it may be that we are assessing the perception of configurations performed by a hand, so participants showed a good categorization as they have had experience in this field.

Additional information relating sign language exposure and recognition of handshapes was provided in Morford & Carlson (2011) in where they compared the performance of deaf native signers, deaf non-native signers and hearing non-native signers on a sign recognition task. They found differences in this task between deaf native signers and deaf non-native signers, but interestingly enough the group of hearing L2 signers resembled more the group of native signers. Deaf non-native signers were clearly the weakest group on the sign recognition task. In our discrimination task results the group of hearing children resembled the group of deaf native signers more than the group of deaf non-native signers. In addition, as in Morford & Carlson (2011) deaf non-native signers were the group who clearly performed less accurate in the task. Our results support the argument that deaf native, deaf non-native signers and hearings differed in terms of performance, but the key factor is not clear. They differed in native language modality, in LSC experience and in speech experience, so we should considerer these factors apart from their individual capacities.

One weakness of our study concerns the number of participants, especially in the group of deaf children. The observed power for the data of the two subgroups of deaf children is not ideal due to the number of participants in the samples. This of course might influence the observed difference between the two subgroups. However, considering previous evidence on the influence of the early sign language experience during signed processing (Best et al., 2010; Morford et al., 2009), our results might be indicating the effect of language exposure. Deaf native signer children came from families with deaf parents and other deaf relatives. They belonged to associations of deaf people and perform activities in which they are constantly interacting with other deaf signer children and deaf signer adults. Observing the group of non-native signers, they had hearing parents and no other close relative in the family was deaf. They reported to use spoken language at home or a mixture of spoken language and sign language but none of them speak a correct sign language in their environment as a first language. In other words, native signers have had more contact with sign language, and therefore more quality sign language interactions throughout their growth, while non-native signers have had almost all their sign language linguistic experiences at school level. This leads to less accumulation of variability of interactions and a poorer linguistic experience. More linguistic interactions involves more experience perceiving the same handshapes (signs) produced by different signers, and this could lead to more refined categorical perception. But if experience appears to be important if we consider the differences between deaf native signers and deaf non-native signers, why should we find the effect of categorical perception in hearing LSC signers? And even more puzzling, why it was found categorical perception in non-signer adults as well?

Mayberry & Lock (2003) showed that adults who acquired a language in early life performed at near-native levels on a second language. This was observed regardless of whether adults were hearing or deaf or whether the early language was sign language or spoken language. Interestingly, deaf adults who could not access nor had little language expertise performed worse. The onset of language acquisition in early human development seems to be crucial since affect the capacity to learn language throughout life, independent of the modality of the early experience. One trait shared by non-signer adults, hearing signer children and deaf native signer children is not the experience in sign language but the experience of a first language. In the first two groups we are referring to the spoken language and in the third group we are referring to sign language. They have developed since the first months of life a language, have grown up with it and have had the most interactions speaking in that language. However, this is not the case of deaf non-native signers. Most deaf non-native signers generally do not achieve fluent oral L1 language acquisition either in spoken or written form. Here we can consider learning sign language as late functional L1 learning, even though this late L1 learning often occurs once periods considered critical to language development have already past. In addition, the fact that they learn sign language later and generally at home families are not proficient in sign language implies that they are not exposed to correct linguistic models, and therefore they do not develop this late L1 at the same level as their native signer peers. Thus, from the standpoint of the environment, individual linguistic differences between participants may come from whether the LSC is the native language or not and the amount and quality of communicative interactions inside and outside of school.

It is therefore possible that the relationship between categorical perception and sign language is not based on the linguistic experience in sign language but the linguistic experience of a L1 normally developed, making it possible to label the perceived stimuli properly. In the studies published to date, non-native signer adults participated with years of experience using sign language. In these experiments with children, they may have not developed a linguistic competence sufficient to allow them to differentiate the perceived handshape contrast pairs. Future research involving more non-native population of deaf signers will be needed to test this possibility.

Interestingly, two of the deaf native signer participants reproduced some handshapes of the screen with their hand during the task, while it was not observed any of the deaf participants with hearing parents to behave in this way. This may be because, in the same way that when we face a discrimination task we try to assign linguistic labels to a given stimuli, the act of copying handshape signs was his linguistic way of labelling the categories to perform the task. Further research in this field could test this hypothesis using a linguistic interference task. Given the peculiarity of sign languages, we could try different types of linguistic interference, as a verbal interference task or a manual interference task, to explore different forms of linguistic interaction that occurs in sign language.

In speech categorization Pisoni and Tash (1974) argued that reaction times were slowest for stimuli in the phonetic category boundary and fastest for the stimuli within the phonetic category, because there was less ambiguity when stimuli belonged to two different categories. Thus, the prediction linking reaction times and sign language perception is that when a participant is asked to determine whether two signs are the same or different, the time to arrive the decision may reflect the level of perceptual processing. However, there were no significant differences in processing times across groups (but see Sevcikova, 2013). Further, variability in reaction times was found between the four handshape contrast pairs, suggesting that differences were due to the different hand configurations rather than the perception of stimuli belonging to the same category membership. Thus it is possible that the mixed results of categorical perception observed in some previous studies were determined by the variability of handshapes and how the tasks were presented.

It has been shown that categorical perception is not equivalent for all speech contrasts; similarly, differences were found depending on the handshape contrast pair perceived. What are the characteristics of signs that can lead to a categorization effect is a question that remains still unresolved. In this study we have used signs related to concrete concepts (TREE_GIRAFFE, PEE_GREEN) and related to abstract concepts (MINE_BOTHER, COLOR_LIKE), but this distinction was not seem to be important for the categorical perception. Another classification would be possible focusing on places of articulation and handshape background: beside the body with green background (TREE_GIRAFFE); front upper body with black background (MINE_BOTHER); in the upper-right torso with black background (PEE_GREEN) and on the chin with the face as background (COLOR_LIKE). None of these parameters appears to have been crucial for categorical perception neither between groups nor within participants in the same group.

Here we have shown differences through groups both for identification task and discrimination task, depending on which handshape contrast continuum was presented. Even more interesting, results were also different for participants across handshape continuum blocks. This suggests that rather than belonging or not to a particular group (non-signer adults, hearing children LSC signers and deaf children LSC signers) perception of the categories in sign languages depends on which handshape pair is perceived.

5. Conclusion and Future Research

Deaf signers and hearing signers seem to have the same abilities in perceiving handshapes in Catalan Sign Language, and the same we applies for hearing non-signer adults. This appears to be at odds with some studies in the spoken modality revealing that the language background provides a strong effect on the perception of phonemic categories. Thus, we are doubtful that categorical perception of sign languages can be solely attributed by a domain linguistic process, due to linguistic expertise in sign language appears to be somewhat independent of handshapes perception.

Some limitations of the study should be acknowledged. One weakness concerns the design of the tasks. Blocks were simplified to avoid an effect of fatigue in children, but this entailed that a mistake in the identification task invalidated that block in the analysis of discrimination task. Adults reported fewer errors and were less confused than deaf children. Future analysis testing children should involve less handshape contrast pairs and more repetitions of each stimulus.

Another limitation was the number of participants. We thought we should conduct the experiment in the same school for the group of deaf and hearing, to control the factor of the education received and communicative environment. That is, in the school children see the same signed linguistic models and have the same communicative possibilities. Analysing the results it was observed that the greater variability lay in the group of deaf, but we did not have a large enough sample to split the group between native and non-native deaf signers and conduct a proper comparative statistical analysis. Future research involving a larger population of deaf native signers and deaf non-native signers will be needed to complete some research lines presented above.

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Appendix

Figures

Figure 1

Figure 1. Handshape contrast pairs

Figure 6

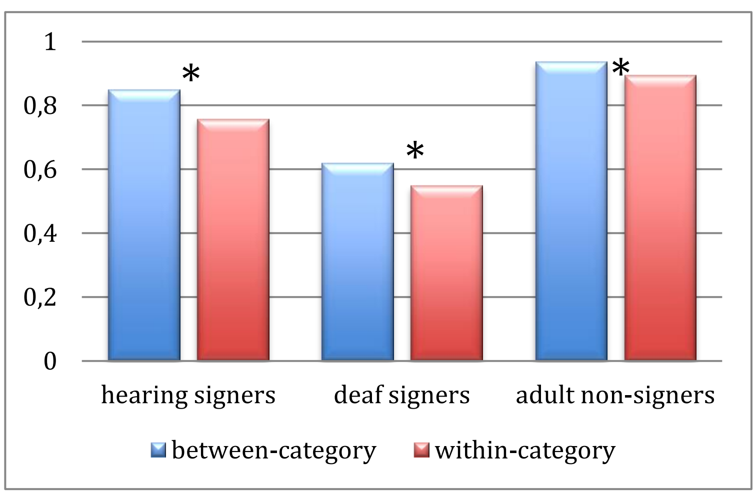

Figure 6. Mean percentage of correct discrimination for all four handshape pairs collapsed

Figure 7

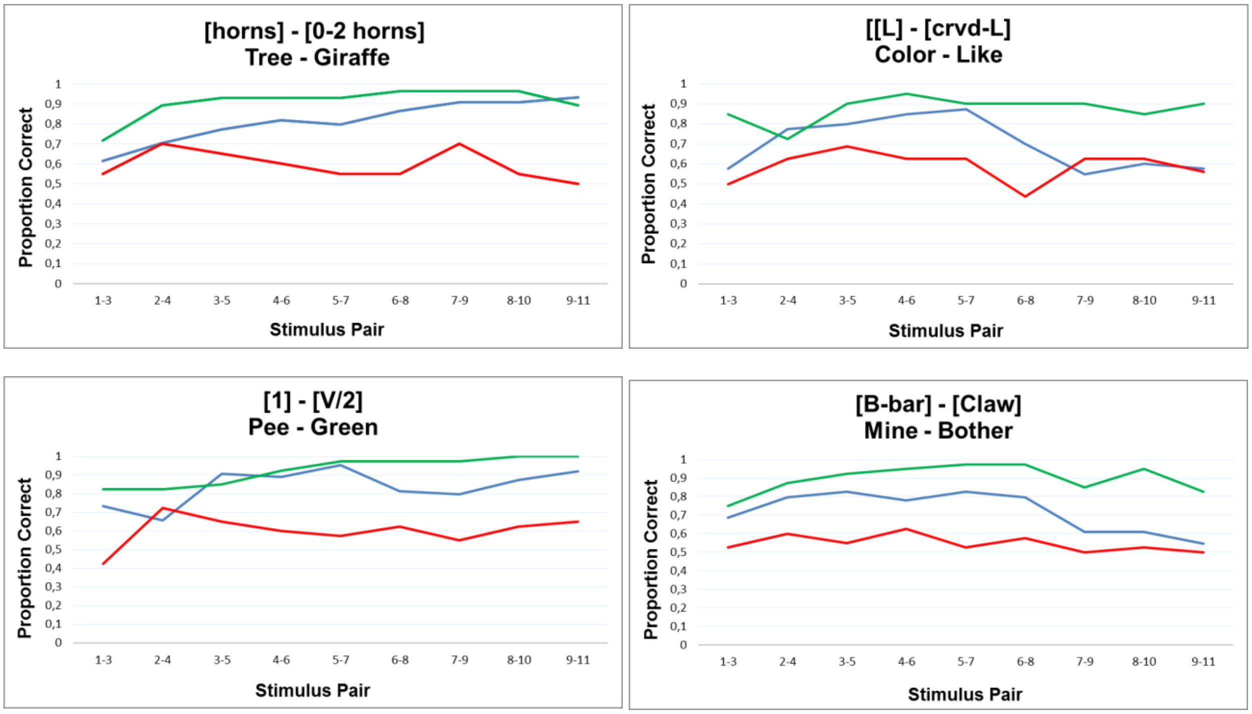

Figure 7. Discrimination function across handshape continuums
Note: RED, deaf children signers; BLUE, hearing children signers; GREEN, hearing adult non-signers.

Tables

Table 1

Group	Gender	Age at Test (years)			Age of Acquisition of LSC		LSC Experience (years)	
		Range	Mean	(SE)	Age	Range	Years	Range
Deaf signer children	4F/5M	9 - 12	10,667	(0,28)	3,89	0 -11	6,78	1 - 11
Hearing signer children	10F/6M	10 -11	10,067	(0,06)	3,31	3 - 8	6,75	2 - 8
Non-signer adults	5F/5M	23 - 38	31,70	(1,584)	(-)	(-)	(-)	(-)

Table 1. Characteristics of each participant group

Table 2

Participant Boundary Locations by Continuum

Group	Participant	Tree - Giraffe	Color - Like	Pee - Green	Mine - Bother
Deaf signer children	1	(-)	(-)	5	4
	2	8	6	(-)	4
	3	5	7	(-)	5
	4	6	(-)	8	(-)
	5	(-)	6	6	(-)
	6	(-)	(-)	(-)	3
	7	4	5	9	6
	8	9	(-)	7	5
	9	(-)	(-)	6	(-)
Hearing signer children	10	9	5	8	4
	11	8	5	(-)	5
	12	9	6	7	(-)
	13	8	7	(-)	7
	14	(-)	(-)	(-)	5
	15	(-)	5	8	(-)
	16	8	6	(-)	(-)
	17	6	8	8	(-)
	18	7	(-)	6	5
	19	9	6	7	6
	20	9	6	6	4
	21	9	(-)	6	5
	22	(-)	(-)	(-)	6
	23	(-)	(-)	7	5
	24	7	(-)	7	5
	25	(-)	6	5	6
Non signer adults	26	(-)	7	7	6
	27	8	5	8	5
	28	6	6	6	7
	29	5	8	7	6
	30	9	6	6	5
	31	(-)	7	(-)	7
	32	7	6	7	6
	33	6	8	8	6
	34	(-)	6	5	6
	35	5	6	8	6

Table 2. Boundary locations as determined by identification performance.
Data from continuums with no clear category boundaries was not considered for the discrimination task.

Table 3

Group	Estimate	STD	tStat	pValue
pee_green	6,324	0,345	18,326	5,11E-75
tree_giraffe	0,432	0,233	1,852	0,064
color_like	-0,674	0,234	-2,876	0,004
mine_bother	-1,511	0,243	-6,231	4,65E-10

Table 3. Handshape pairs generalized linear model analysis

Table 4

Group	Estimate	STD	tStat	pValue
Deaf signers	5,288	0,288	18,381	1,85E-75
Hearing signers	0,204	0,189	1,080	0,280
Non-signer adults	0,212	0,210	1,009	0,313

Table 4. Group of participants generalized linear model analysis

Table 5. Mean Percentage of Discrimination Accuracy

Group	Tree - Giraffe Category Membership Beetween	Tree - Giraffe Category Membership Within	Color - Like Category Membership Beetween	Color - Like Category Membership Within	Pee - Green Category Membership Beetween	Pee - Green Category Membership Within	Mine - Bother Category Membership Beetween	Mine - Bother Category Membership Within	4 pairs collapsed Category Membership Beetween	4 pairs collapsed Category Membership Within
Deaf signers	0.750 (.079)	0.575 (.060)	0.500 (.102)	0.601 (.080)	0.500 (.071)	0.489 (.050)	0.708 (.077)	0.552 (.032)	0.619 (.077)	0.549 (.032)
Hearing signers	0.863 (.062)	0.806 (.031)	0.850 (.055)	0.681 (.028)	0.840 (.051)	0.849 (.019)	0.833 (.056)	0.692 (.020)	0.846 (.056)	0.757 (.020)
Non-signer adults	0.892 (.074)	0.910 (.019)	0.900 (.006)	0.871 (.003)	0.972 (.028)	0.916 (.021)	0.975 (.025)	0.887 (.018)	0.937 (.025)	0.894 (.018)

Table 6. Mean Percentage of Discrimination Reaction Times

Group	Tree - Giraffe Category Membership Beetween mean	SE	Within mean	SE	Color - Like Category Membership Beetween mean	SE	Within mean	SE	Pee - Green Category Membership Beetween mean	SE	Within mean	SE	Mine - Bother Category Membership Beetween mean	SE	Within mean	SE	4 pairs collapsed Category Membership Beetween mean	SE	Within mean	SE
Deaf signers	875,55	(263,71)	1.373,34	(206,60)	1.151,13	(332,20)	998,68	(330,74)	809,09	(111,28)	893,16	(115,93)	1.091,83	(120,94)	976,24	(136,37)	979,45	(97,32)	1.061,97	(96,48)
Hearing signers	897,24	(129,65)	1.022,46	(67,87)	924,73	(172,50)	1.238,72	(128,53)	1.089,02	(140,24)	1.049,83	(79,07)	1.220,63	(203,88)	1.084,65	(91,33)	1.061,31	(82,37)	1.101,17	(46,34)
Non-signer adults	421,21	(64,99)	457,61	(39,24)	1.341,08	(290,73)	1.442,37	(173,83)	877,33	(142,78)	1.154,65	(88,87)	949,77	(130,65)	982,20	(112,72)	935,95	(106,59	1.057,61	(82,65)

Tables 5 and 6. Mean discrimination Accuracy and mean discrimination Reaction Times by handshape contrast pairs and participant group (s.e.m)