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Structural biases that children bring to language learning: A cross-cultural look at gestural input to homesign

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ABSTRACT

Linguistic input has an immediate effect on child language, making it difficult to discern whatever biases children may bring to language-learning. To discover these biases, we turn to deaf children who cannot acquire spoken language and are not exposed to sign language. These children nevertheless produce gestures, called *homesigns*, which have structural properties found in natural language. We ask whether these properties can be traced to gestures produced by hearing speakers in Nicaragua, a gesture-rich culture, and in the USA, a culture where speakers rarely gesture without speech. We studied 7 homesigning children and hearing family members in Nicaragua, and 4 in the USA. As expected, family members produced more gestures without speech, and longer gesture strings, in Nicaragua than in the USA. However, in both cultures, homesigners displayed more structural complexity than family members, and there was no correlation between individual homesigners and family members with respect to structural complexity. The findings replicate previous work showing that the gestures hearing speakers produce do not offer a model for the structural aspects of homesign, thus suggesting that children bring biases to construct, or learn, these properties to language-learning. The study also goes beyond the current literature in three ways. First, it extends homesign findings to Nicaragua, where homesigners received a richer gestural model than USA homesigners. Moreover, the relatively large numbers of gestures in Nicaragua made it possible to take advantage of more sophisticated statistical techniques than were used in the original homesign studies. Second, the study extends the discovery of complex noun phrases to Nicaraguan homesign. The almost complete absence of complex noun phrases in the hearing family members of both cultures provides the most convincing evidence to date that homesigners, and not their hearing family members, are the ones who introduce structural properties into homesign. Finally, by extending the homesign phenomenon to Nicaragua, the study offers insight into the gestural precursors of an emerging sign language. The findings shed light on the types of structures that an individual can introduce into communication before that communication is shared within a community of users, and thus sheds light on the roots of linguistic structure.

1. Introduction

1.1. Background

The effects of language input on child language learners are at once obvious and controversial. In most cases, a child growing up hearing Spanish will become a native speaker of Spanish; a child growing up hearing English will become a native speaker of English. Clearly, input matters. However, the degree to which specific characteristics of language input affect the child learner's course of language-learning is difficult to pinpoint.

From Chomsky's earliest formulations of the "poverty of the stimulus" argument (Chomsky, 1980), child language researchers have written extensively about how children appear to learn their native languages from remarkably little linguistic input (Gleitman & Newport, 1995; Gordon, 1985; Lidz, Waxman, & Freedman, 2003; Valian, 2014), and interpret this phenomenon as evidence for innate linguistic knowledge. Challenging this interpretation is substantial evidence that children's language productions mirror utterances provided by their parents (Behrens, 2009; Goldberg, 2016; Lieven, 2016). For example, the frequency of individual items/constructions in a child's input affects the time-course of acquisition and types of errors the child makes in

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learning these items/constructions (Ambridge, Kidd, Rowland, & Theakston, 2015).

Given the evidence that language learning in typical situations reflects linguistic input, children who experience extremely impoverished language input might be expected to display little ability to communicate in a linguistically structured manner (Tomasello, 2005, 2009). But this hypothesis turns out to be incorrect—just because children *use* linguistic input does not mean that linguistic input is *essential* for all aspects of language development. Children might be able to invent at least some aspects of language even if they are not exposed to any linguistic input at all, as we learn from studies of deaf children.

Deaf children born to signing parents acquire sign language the same way that hearing children born to speaking parents acquire spoken language (Petitto & Marentette, 1991; Lillo-Martin & Henner, 2020)–they go through the same stages of language acquisition with approximately equivalent timing. Most deaf children, however, are born to hearing parents who do not know sign language and may not seek out sign language input for their children (despite demonstrated positive effects of learning a sign language and no known negative effects, Humphries et al., 2016; Hall, Hall, & Caselli, 2019).[1] Deaf children who do not learn to speak and have no access to sign language lack linguistic input. Nevertheless, they use gestures, called *homesigns,* to communicate and these homesigns have been shown to have many, although not all, of the properties of natural language (Goldin-Meadow, 2003a). Because the communication systems that homesigners develop are not influenced by input from an established language, homesign has the potential to shed light on how children naturally structure their communications.

Homesigners lack the linguistic input children typically have as they acquire language. But homesigners do have access to the co-speech gestures that hearing speakers produce (Goldin-Meadow, 2003b), and it is theoretically plausible that these gestures influence deaf children's homesigns. However, previous work has found that co-speech gesture in the USA is structured differently from homesign (Goldin-Meadow & Mylander, 1983; Hunsicker & Goldin-Meadow, 2012) and thus cannot serve as a model for its linguistic structure. Nevertheless, attempts to identify connections between parents' and homesigners' gestures may have been thwarted by the paucity of gestures USA hearing parents produce when interacting with their homesigners (Goldin-Meadow & Mylander, 1984). That is, connections between co-speech gestures in deaf children's environments and their homesigns may exist, but may be difficult to isolate in such a sparse sample. Here we examine whether structural aspects of child homesign can be traced to communicative gestures produced by hearing family members in Nicaragua, a gesturally rich environment, and the USA.

Gestures that hearing parents provide homesigners in Nicaragua may be different from the gestures provided by USA hearing parents for two reasons. First, Nicaragua is a gesture-rich culture. The hearing culture has a large repertoire of gestural emblems (conventionalized gestures with stable meanings), and hearing individuals in Nicaragua often gesture without talking (Coppola, 2015). There is evidence that homesigners borrow emblems from their hearing parents (Fig.1 shows a hearing mother and deaf child each producing DRINK, a Nicaraguan emblem). In general, homesigning children produce emblems that their hearing parents produce (e.g., the proportion of a homesigner's emblems that could be traced to that homesigner's mother was 0.88 for 4 Chinese homesigners and 0.73 for the 4 USA homesigners studied here, Wang, Mylander, & Goldin-Meadow, 1993). Second, the oralist tradition in deaf education (focusing on vocal communication to the exclusion of manual communication) is not strong in Nicaragua (Polich, 2005), and hearing people are not advised to refrain from gesturing to deaf individuals. Nicaragua, where parent gestures are potentially frequent and uninhibited, would thus provide a clearer vantage point on our question than the USA. In addition, the potential increase in numbers of gestures that hearing parents produce would allow us to use more sophisticated statistical techniques than originally used to address the impact that gestural input has on homesign (Goldin-Meadow & Mylander, 1983, 1984, 1998).

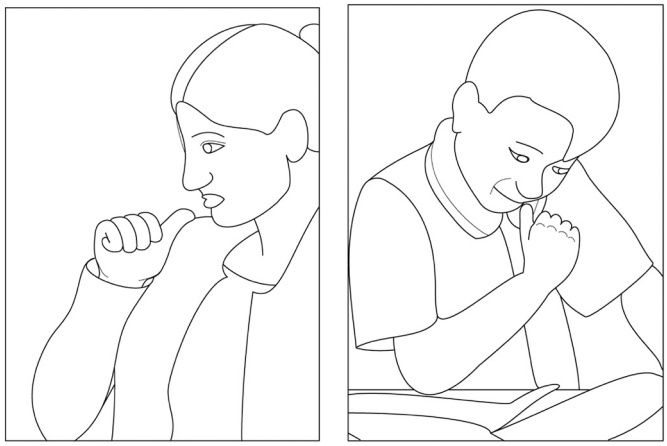

Fig. 1. A Nicaraguan hearing mother and her deaf homesigning child each producing DRINK, a gestural emblem used by hearing speakers in Nicaragua.

1.2. Research question and hypotheses

Young homesigners have been found to develop gesture systems containing many properties of natural language—for example, a stable lexicon (Goldin-Meadow, 2003a; Richie, Yang, & Coppola, 2014), productive combinatorial structure (Goldin-Meadow & Yang, 2016), sentence-level structure (Goldin-Meadow & Feldman, 1977; Goldin-Meadow, Namboodiripad, Mylander, Ozyurek, & Sancar, 2015), grammatical categories of nouns and verbs (Goldin-Meadow, Butcher, Mylander, & Dodge, 1994), complex sentences (Goldin-Meadow, 1982; Goldin-Meadow & Mylander, 1998), and complex noun phrases (Hunsicker & Goldin-Meadow, 2012). We focus here on two of these structural properties because they entail hierarchical structure, a central property of language: (1) Complex gesture sentences, sentences containing two or more propositions; for example, *soldier marches and soldier beats drum.* The two propositions are subsumed under a single sentence node (Goldin-Meadow, 2005, p. 211). (2) Complex gesture noun phrases, noun phrases used to refer to a single entity, but containing a demonstrative gesture (indicating the particular entity under discussion) and a noun gesture (providing information about the entity's class); for example, *that bird.* The demonstrative plus noun in a complex noun phrase are subsumed under the noun phrase node in the sentence (e.g., [*that bird*] *pedals,*Hunsicker & Goldin-Meadow, 2012, p. 745–747).

Our goal is to describe the gestural input Nicaraguan homesigners receive from their hearing families, and compare it to the gestural input USA homesigners receive. We then examine the relation between these inputs and child homesign, focusing on the two structural properties just mentioned (complex sentences and complex noun phrases) and also on a general measure of development (gesture sentence length). We explore three possibilities:

(1) If gestural input available to homesigners is more structured in Nicaragua than the USA, and if this input provides a model for structural aspects of homesigns, then access to the input might lead Nicaraguan homesigners to construct more complex linguistic systems than USA homesigners.

[1] Medical professionals often dissuade hearing parents from exposing deaf children to sign language. Since success in spoken language learning varies widely for children using amplification or cochlear implants (see Hall et al., 2019), this situation too frequently results in language deprivation. Signing environments provide the only fully reliable path to linguistic competence for deaf children.

(2) Alternatively, gestures produced by hearing individuals might not provide a model for structural aspects of homesigns. If so, differences found between hearing families' gestures in Nicaragua and the USA should have no impact on homesign structure. Nicaraguan homesign might be no more complex than USA homesign, and both systems should be unrelated to gestural input from hearing families.
(3) Finally, because gesture is homesigners' primary vehicle for communication (unlike hearing families whose primary communication system is speech), homesigners' gestures might be more complex than the gestural input they receive from hearing families. If so, we will add to evidence that children can introduce structural properties into their communications without a model for these properties (Goldin-Meadow, 2003a, 2005).

1.3. Theoretical encapsulation

Child homesigners are deaf children whose hearing losses prevent them from using the spoken language that surrounds them, and whose hearing parents have not provided them with access to sign language. These children lack input from an established and shared language. Nevertheless, they communicate with the hearing people in their worlds, and use homesigns to do so. In typical language-learning circumstances, children are exposed to input from an established language from birth, and that input has a massive and immediate effect on their language acquisition. It is therefore difficult to discover from typical language-learning circumstances the biases (if any) that children bring to language-learning, unless of course a child develops a structure that is not found in that child's input (e.g., Crain, 1991). But because the communication systems that homesigners use are not influenced by input from an established language, homesign has the potential to shed light on these biases and, as a result, the contributions child learners make to the structure of all human languages.

2. Methods

2.1. Participants

To explore our hypotheses, we observed 7 Nicaraguan deaf homesigning children (ages 3;05–11;03 yrs.;mos, 4 female) during naturalistic play at home with their hearing family members, and compared them to 4 previously described homesigners in the USA (3;09–4;11, 1 female) and their hearing family members (Goldin-Meadow & Mylander, 1998). Recruitment of homesigning children is a labor-intensive endeavor, particularly in Nicaragua, where many methods were used. Some children were recruited via deaf community contacts in Nicaragua. This method can take several weeks to result in the recruitment of one new participant, and sometimes yields no new participants even after a substantial investment of time. Other participants were recruited as they entered school in Managua, just before they learned Nicaraguan Sign Language from their deaf peers. Approximately 1–3 children in the age group of interest enter the school each year, and this recruitment can only take place once a year (at the beginning of the Nicaraguan school year), thus making it difficult to recruit a large sample of this unique population. The 4 USA children were first described in Goldin-Meadow and Mylander (1984), along with 6 other USA children; all of these children were recruited in the 1970's from oral deaf schools in the Philadelphia and Chicago areas. The 4 USA children were originally selected to compare to 4 Chinese homesigners in Goldin-Meadow and Mylander (1998) because their hearing family members were visible on the videotapes, thus allowing insight into gestural input to homesign. The two observation sessions that best matched the ages of the Chinese homesigners were used for the USA children. These two sessions are also used here as they are a reasonable age match for the Nicaraguan homesigners (their ages overlap with the younger Nicaraguan children; Nicaraguan homesigners were generally discovered at older ages than the USA and Chinese children). The USA videotapes not described here were either taken at younger ages, or did not have hearing family members on the tape.

All of the children were profoundly deaf and unable to learn spoken language even with hearing aids (which only USA participants wore), and none had received a cochlear implant. Moreover, none of the children had been exposed to an established sign language. But all had developed gestural systems to communicate with their hearing family members and thus were considered homesigners. As just noted, the populations studied here are rare, making our sample size the maximum reasonably achieved.

2.2. Procedure

The deaf child participants in Nicaragua were observed in their homes as they interacted with their hearing families, using procedures developed to observe the 4 deaf child participants in the USA (see Goldin-Meadow & Mylander, 1984, for details). Children played with toys, communicated about picture books, and communicated spontaneously about events and objects in their environments during the observation sessions. Hearing family members communicated freely with the deaf homesigner with minimal interference from experimenters. Sessions were videotaped for later coding and analysis. Some children were observed over multiple sessions (as many as three); some were observed only once. Further details about number of sessions per child can be found in Table 1.

2.3. Coding modality for family members

Utterances were classified according to modality: *speech-alone*, *gesture-alone*, or *speech + gesture*. In order to be classified as *speech + gesture*, both the gesture(s) and the vocal speech produced by the family member had to occur within the same utterance and overlap in time course. All vocal and gestural utterances directed toward the homesigner by family members were coded. Although it is possible that the deaf children perceived any gestures that their hearing family members produced, regardless of whether those gestures were directed to the child, our goal was to look at whether sensitivity to the child's need for gestural input differed across cultures. We therefore chose to limit our analyses to the gestures hearing family members directed to the homesigners. However, we did not require that the homesigner visibly attend to the family member's communicative attempt in order for this utterance to be included in the analysis simply because we needed to use the same criterion for responses to gesture and responses to speech. It is not possible to tell whether a child, particularly a deaf child, is paying attention to auditory input; we therefore did not require that the child visibly display attention for *either* gesture *or* speech. Finally, any speech that occurred while the speaker was off camera was also not coded as it was impossible to tell whether it occurred with gesture.

Data from all sessions for all children were summed. A randomly selected subset of the identified utterances was coded by a second coder, the same coder in both cultures; agreement between coders was 89.5% ($N = 211$) for Nicaraguan families and 81.5% ($N = 200$) for USA families. Coders were blind to predictions about differences between cultures (Nicaragua, USA) and between groups (homesigners, hearing family members) in all analyses. In cases of disagreements, the original coding was used.

2.4. Coding gesture structure for family members and child homesigners

All the hand gestures produced by hearing family members and their homesigning children were coded according to the system described in detail in Goldin-Meadow and Mylander (1984:15-32); body position, facial expression, and vocal modulation were not counted as gesture. Gestures were identified using two criteria: The movement had to be

Table 1
Quantitative description of the data analyzed.

			Number of gestures (Total Gesture Strings)		Number of complex Utterances (Total Utterances)		Number of complex arguments (Total Arguments)	
	Child	Age	Children	Families	Children	Families	Children	Families
Nicaraguan	1	3;05	2802 (1786)	328 (223)	142 (1079)	1 (86)	15 (1231)	0 (63)
	2	3;11	255 (207)	693 (363)	2 (148)	13 (211)	0 (138)	0 (110)
	3	4;07	451 (380)	973 (579)	4 (133)	19 (305)	0 (66)	2 (127)
	4	4;10	134 (106)	175 (107)	1 (90)	3 (65)	2 (98)	0 (39)
	5	5;08	731 (484)	830 (462)	29 (323)	24 (343)	2 (296)	0 (204)
		7;03	858 (575)	134 (107)	46 (472)	0 (43)	3 (302)	0 (28)
		8;03	892 (632)	348 (268)	18 (408)	2 (117)	8 (234)	1 (67)
	6	8;09	664 (320)	135 (80)	22 (163)	1 (47)	8 (220)	0 (20)
		9;10	555 (329)	116 (80)	24 (224)	1 (27)	6 (217)	0 (12)
	7	11;03	2459 (1588)	208 (104)	178 (995)	4 (51)	9 (872)	0 (21)
US	1	3;09	187 (128)	204 (151)	4 (112)	3 (82)	1 (81)	0 (48)
		4;02	272 (169)	234 (159)	5 (121)	6 (123)	1 (52)	0 (97)
	2	3;09	550 (355)	108 (99)	11 (227)	0 (73)	1 (175)	0 (59)
		4;11	308 (206)	103 (74)	14 (188)	4 (61)	7 (82)	0 (39)
	3	3;10	93 (64)	69 (52)	0 (51)	1 (44)	0 (36)	0 (35)
		4;02	221 (136)	67 (48)	11 (96)	1 (31)	0 (69)	0 (15)
	4	3;11	878 (567)	141 (106)	27 (426)	3 (65)	31 (270)	0 (49)
		4;06	1471 (756)	111 (85)	90 (596)	1 (43)	9 (381)	0 (32)

communicative in intent (i.e., produced when gesturers believed, and thus acted as though, they had another's attention), but was not a functional act on an object or person (Goldin-Meadow & Mylander, 1984:17). For example, reaching to pick up a toy communicates a child's desire for the toy but it does so by directly acting on the world, and was therefore not considered a gesture. In contrast, an open palm held out flat (a *give* gesture), produced while making eye contact with the person holding the toy, communicates a request for the toy indirectly and so was considered a gesture.

Once isolated, gestures were coded along the three dimensions used to describe signs in conventional sign language: shape of the hand, location of the hand with respect to the body, and movement of the hand. A change in any one of these dimensions during the stroke of the gesture was taken to signal the end of one gesture and the beginning of another (see Goldin-Meadow & Mylander, 1984:18).

Motoric criteria were also used to determine the end of a string of gestures and thus sentence boundaries. Two gestures were considered separate sentences if the gesturers paused or relaxed their hands between the gestures (see Goldin-Meadow & Mylander, 1984:18). Gestures that were not separated by pause or relaxation of the hands were considered part of the same sentence.

Homesigners produce three different types of gestures: deictic gestures, iconic gestures, and markers. Deictic gestures refer to objects by pointing to, or holding up, the intended referent and can be used to refer to any entity that is present (and, in some cases, entities that are not present, Butcher, Mylander, & Goldin-Meadow, 1991). Iconic gestures represent an aspect of an object or action through pantomime (e.g., moving two fists as though beating a drum, *beat*) or visual depiction (e.g., forming a circle with the thumb and index finger, *round*). Emblem gestures were included in this category though they are not necessarily iconic in form. Markers are typically conventional gestures (e.g., flipping the palms from palm-down to palm-up) and were used by homesigners to modulate their gesture sentences (see Franklin, Giannakidou, & Goldin-Meadow, 2011, for an analysis of question and negative markers in homesign).

We focus here on two structural properties previously identified in homesign—complex sentences and complex noun phrases. Deictic and iconic gestures formed the building blocks of these two structural properties. We also included a measure of gesture string length because (at least in some languages) increasing length is correlated with increasing linguistic skill in the early stages of language acquisition (Brown, 1973). Markers were included in our length analyses, but not in our structural analyses.

We measured gesture length, complex sentences, and complex noun phrases in the gestures produced by each homesigner and the gestures produced by the homesigner's hearing family members. For each measure, we entered gesture string into our mixed effects regression analyses as an individual data point (i.e., every gesture string produced by a child or family member at each of the sessions the child was observed was entered into the analysis), with fixed effects for culture (Nicaragua or USA), group (child or family members), child age at observation (some children were observed at more than one age, see Table 1), and an interaction between factors (when including the interaction did not prevent the model from converging), as well as a random effect for participant. Our analyses include mixed effects regressions and logistic mixed effects regressions; in both types of analyses, the β coefficient indicates effect size.

The same coder transcribed the videotapes for both cultures in our reliability assessments; that coder did the original coding of the USA data and trained the subsequent coders. In cases of disagreements between coders, we used the original coding.

(i). *Length of gesture string.* Each string of gestures was coded for the number of distinct gestures it contained. The total number of gestures produced by each individual was tabulated and that number was divided by the total number of gesture strings the individual produced to arrive at a mean length of gesture string. To assess reliability for gesture string length, a second coder independently transcribed a subset of the data for each group and culture. Agreement between coders was 95% (N = 293) for Nicaraguan homesigners; 83% (N = 572) for hearing Nicaraguan families; 93% (N = 195) for USA homesigners; and 89% (N = 316) for hearing USA families.

(ii). *Proportion of complex sentences.* All gesture sentences were coded with respect to the number of propositions they contained. Once the boundaries of a gesture sentence were established using the motoric criteria just described, we used both the form of the gestures and the context in which the gestures were produced to assign meanings to propositions (see Goldin-Meadow & Mylander, 1984:26–32, for a detailed description of how propositions were assigned meanings and for examples). Sentences containing two or more propositions were classified as complex; sentences containing a single proposition were classified as

simple.[2] Agreement between coders for identifying complex sentences was 93% ($N = 289$) for Nicaraguan homesigners and 95% ($N = 858$) for their hearing families; 95% ($N = 174$) for USA homesigners and 97% ($N = 238$) for their hearing families.

(iii). *Proportion of complex noun phrases.* All gestures referring to an entity were classified according to whether they functioned as a complex noun phrase (see Hunsicker & Goldin-Meadow, 2012, for details). Three types of gestures were used to refer to entities: (i) Pointing gestures refer to the entity toward which they are directed (e.g., pointing at a toy in the room to refer to that specific toy). This type of gesture functions like a demonstrative (e.g., *this, that, her*), pointing out a particular object but not categorizing it. (ii) Pointing gestures, called category points, do not refer to the particular object they indicate, but rather to an object of the same type (Butcher et al., 1991), e.g., a pointing gesture at an empty bubble jar present in the room, produced to request a full bubble jar from the next room. These gestures function like nouns in that they evoke the category by indexing an object that is an instance of that category to which the object belongs (in this case, the category of *bubble jars*) rather than the particular object (*that jar*). (iii) Iconic gestures represent an object by evoking some aspect of the intended referent, e.g., a twisting gesture produced to refer to a bubble jar. We included only iconic gestures used as nouns; Goldin-Meadow et al. (1994) describe the criteria used to distinguish noun iconic gestures (as in the bubble jar example) from verb iconic gestures (e.g., when the twisting gesture is used to refer to the act of twisting the jar lid). Noun iconic gestures resemble category points in that they do not specify a particular object, but rather specify a category of objects (in this case, *bubble jars*).

Each of these three types of gestures was used on its own to identify entities. But, at times, a demonstrative gesture and a noun gesture (either a category point or an iconic gesture) were both used to refer to the same entity (e.g., point at bird combined with an iconic noun gesture for *bird*, palms flapping at sides). The demonstrative gesture in this type of combination indicates the particular entity under discussion, whereas the noun gesture provides information about its class. Hunsicker and Goldin-Meadow (2012) found that these types of multi-gesture nominals functioned semantically and syntactically like single gesture nominals in a USA homesigner, and thus warrant the label *complex noun phrase*.

The following 5 criteria were used to identify complex noun phrases: (i) the two gestures in a complex noun phrase must refer to the same entity; (ii) the gestures must be within the same sentence; (iii) the gestures must be contiguous; (iv) the gestures must be of two different types (e.g., two pointing gestures at the same bird were not considered a complex noun phrase, even if they occurred in the same sentence and were adjacent); (v) the gestures must serve the same semantic role. This last criterion rules out predicate nominal sentences. For example, homesigners sometimes point at a picture of a bird and then produce the noun gesture *bird* in order to identify the picture as a bird; in this case, the noun gesture is functioning as a predicate nominal (e.g., *that's a bird*), rather than as part of a nominal constituent (e.g., [*that bird*]*pedals a bike*). Predicate nominals were not coded as complex noun phrases. As noted earlier, we used the criteria in Goldin-Meadow et al. (1994) to determine whether an iconic gesture was referring to an object (and therefore a nominal, e.g., the flapping gesture that categorized the bird, who was not flying) or to an activity (and therefore a predicate, e.g., the pedaling gesture that described the activity of the bird, who was riding a bike).

Agreement between coders for isolating nominal constituents was 90% ($N = 433$) for Nicaraguan homesigners; 98% ($N = 498$) for hearing Nicaraguan families; 92% ($N = 115$) for USA homesigners; and 100% ($N = 47$) for hearing USA families.

[2] There were very few gesture sentences, particularly for the hearing family members, that contained more than two propositions. It was therefore impossible to code complex sentences as a continuous variable.

3. Results

3.1. Descriptive characteristics of the sample

A total of 4517 communicative acts (2548 Nicaraguan; 1969 USA) that hearing family members directed toward homesigners were transcribed and classified according to the modality in which they occurred: gesture-alone, speech and gesture (in the same communicative act), or speech-alone. We then characterized communicative acts containing gesture along three dimensions: mean number of gestures per string; proportion of complex gesture sentences (out of all gesture sentences; the remaining sentences were simple one-proposition sentences); proportion of complex gesture noun phrases (out of all gesture noun phrases; the remaining noun phrases contained only one gesture, either a noun gesture or a deictic gesture). We identified 2373 Nicaraguan and 774 USA gesture strings, 1295 Nicaraguan and 522 USA gesture sentences, and 691 Nicaraguan and 374 USA gesture noun phrases in the hearing families for analysis. Finally, we classified homesigners' gestures in each culture using the same dimensions, and compared complexity measures for each homesigner to the measures for his/her hearing family members. A total of 6407 Nicaraguan and 2381 USA gesture strings, 4035 Nicaraguan and 1817 USA gesture sentences, and 3674 Nicaraguan and 1146 USA gesture noun phrases were analyzed in the homesigners. Table 1 presents details on the data analyzed.

3.2. Gesture in relation to speech in Nicaraguan and USA hearing families

As expected, we found differences in how frequently gesture and speech were used in Nicaragua vs. the USA. Hearing family members used fourteen times more gesture-alone communicative acts with homesigners in Nicaragua than in the USA, and they used seven times more speech-alone communicative acts with homesigners in the USA than in Nicaragua (Fig. 2; Fig.S1 in Supplementary Materials presents data for hearing family members at each child session, and shows essentially no overlap in either gesture-alone or speech-alone communicative acts between Nicaragua, in blue, and USA, in red; all figures were produced using the ggplot2 package in R Studio orMicrosoft Excel). We performed a series of logistic mixed effects regressions to characterize how many gesture-alone and speech-alone utterances were directed at homesigners in each culture. The models contain fixed effects for culture (Nicaragua or USA, dummy coded with Nicaragua representing the intercept), homesigner age at each test session, a culture by age interaction, as well as a random effect for participant (for details, see Supplementary Materials).

Focusing on *gesture-alone*, we found a significant effect of culture (more gesture-alone strings in Nicaragua than USA), $\beta = -4.74$, $p = .01$, no effect of homesigner age, $\beta = 0.18$, $p = .67$, and no interaction between age and culture, $\beta = 0.16$, $p = .70$. Focusing on *speech-alone*, we again found a significant effect of culture (more speech-alone strings in USA than in Nicaragua), $\beta = 8.09$, $p < .001$, an effect of homesigner age (fewer speech-alone strings produced by family members directed to homesigners at older ages), $\beta = -0.47$, $p < .001$, and an interaction between age and culture, $\beta = 0.99$, $p < .001$ (more speech-alone utterances produced with older children in Nicaragua than in the USA).

Previous work shows that when gesture is produced with speech, it is structured differently from when it is produced without speech (Goldin-Meadow, McNeill, & Singleton, 1996). There is thus the potential for homesigners in Nicaragua to have experienced structurally different gestural input from homesigners in the USA. Our next step is to examine structural aspects of the gestural input Nicaraguan and USA homesigners receive from their hearing parents.

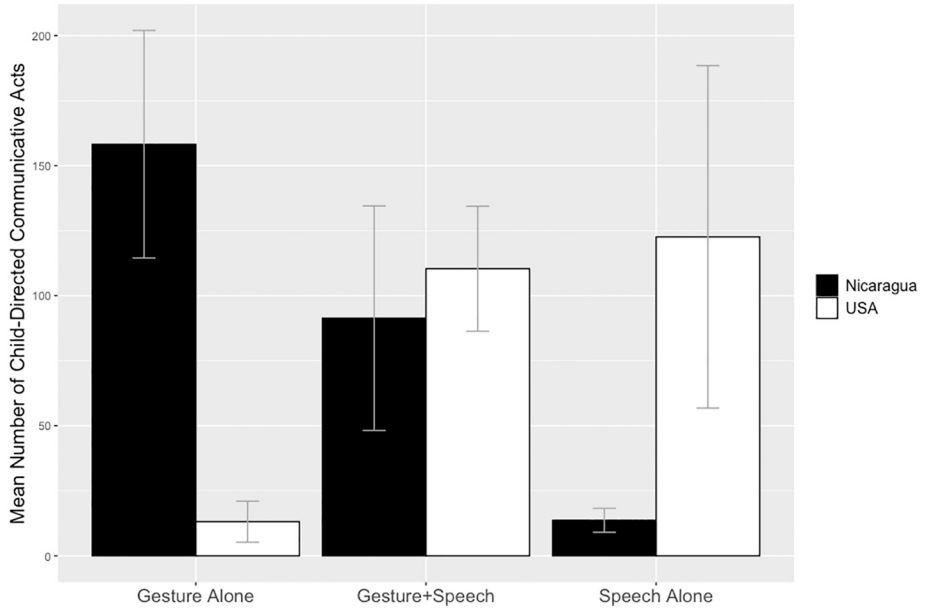

Fig. 2. Mean number of child-directed communicative acts produced by hearing family members in Nicaragua vs. USA, classified according to whether the act contained gesture-alone, speech + gesture, or speech-alone. Error bars indicate standard errors.

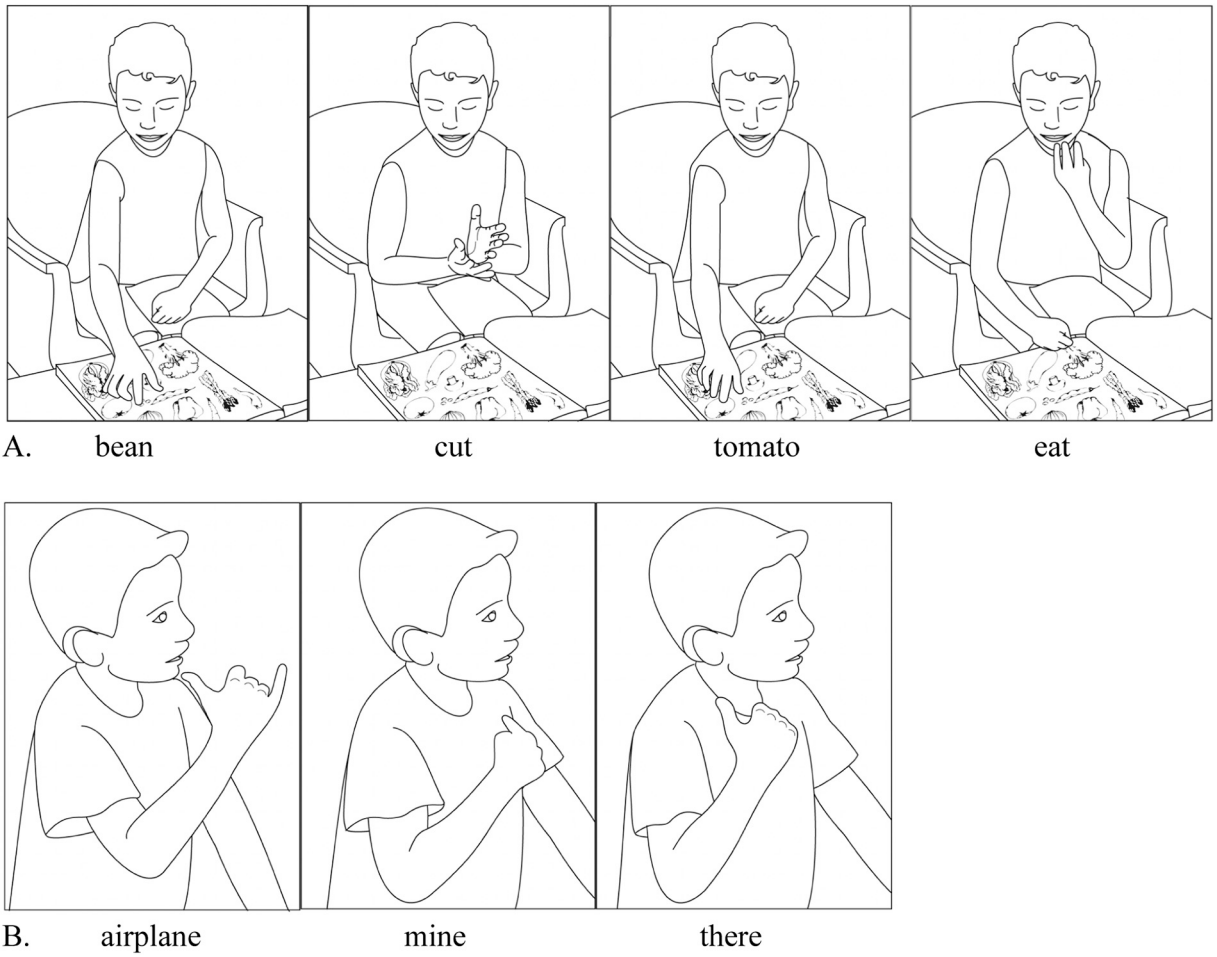

Fig. 3. A Nicaraguan homesigner producing a complex sentence (A) and a homesigner producing a complex noun phrase (B).

3.3. Structure of hearing family members' gestures in Nicaragua vs. the USA

We quantified the complexity of the gestures each homesigner and his/her family members produced in Nicaragua and the USA in terms of length of gesture strings (mean number of gestures in a string), and the two linguistic structures previously reported in homesign:

(i). *Complex sentences,* which were defined as gesture sentences containing two or more propositions (Goldin-Meadow & Mylander, 1998). For example, a Nicaraguan homesigner pointed at a picture of a *bean*, followed by a gesture for *cut* (= proposition 1), and then pointed at a picture of a *tomato*, followed by a gesture for *eat* (= proposition 2), all within a single gesture sentence, i.e., {[bean cut] [tomato eat]}, see Fig. 3A.

(ii). *Complex noun phrases,* which were defined as gesture noun phrases containing two consecutive gestures referring to the same entity (Hunsicker & Goldin-Meadow, 2012). For example, a Nicaraguan homesigner produced a gesture for *airplane*, followed by a point to self (= *mine*), and a point away (= *there*); *airplane mine* constitutes a complex noun phrase embedded within the larger sentence, i.e., {[airplane mine] there}, Fig. 3B.

We first compared gestural input from hearing family members in Nicaragua vs. the USA. Fig. 4 displays the three gesture measures—mean length of gesture strings (top), proportion of complex sentences (middle), proportion of complex noun phrases (bottom)—produced by hearing family members in Nicaragua vs. USA (left graphs). For children who were observed at multiple sessions, the graphs present the hearing family data averaged over those sessions; Fig. S2 (left graphs) in Supplementary Materials presents the data for hearing family members at each child session for each of the three measures. We performed a series of a mixed effects regressions and logistic mixed effects regressions with fixed effects for culture, homesigner age at each session, and a culture by age interaction, as well as a random effect for participant (see Supplementary Materials).

Focusing on *gesture length*, we found a significant effect of culture (longer strings in Nicaragua than USA), $\beta = -2.25$, $p < .001$, but also an effect of homesigner age (longer strings tended to be produced with older children), $\beta = -0.17$, $p < .001$, which interacted with culture, $\beta = 0.37$, $p = .001$, reflecting the fact that the USA homesigners overlapped in age with only the youngest Nicaraguan homesigners (compare triangles vs. circles in Fig. 4, left top plot). Focusing on *complex gesture sentences*, we found a marginally significant effect of culture (more complex sentences in Nicaragua than USA), $\beta = -3.95$, $p = .10$, no effect of homesigner age, $\beta = -0.05$, $p = .46$, and no interaction between age

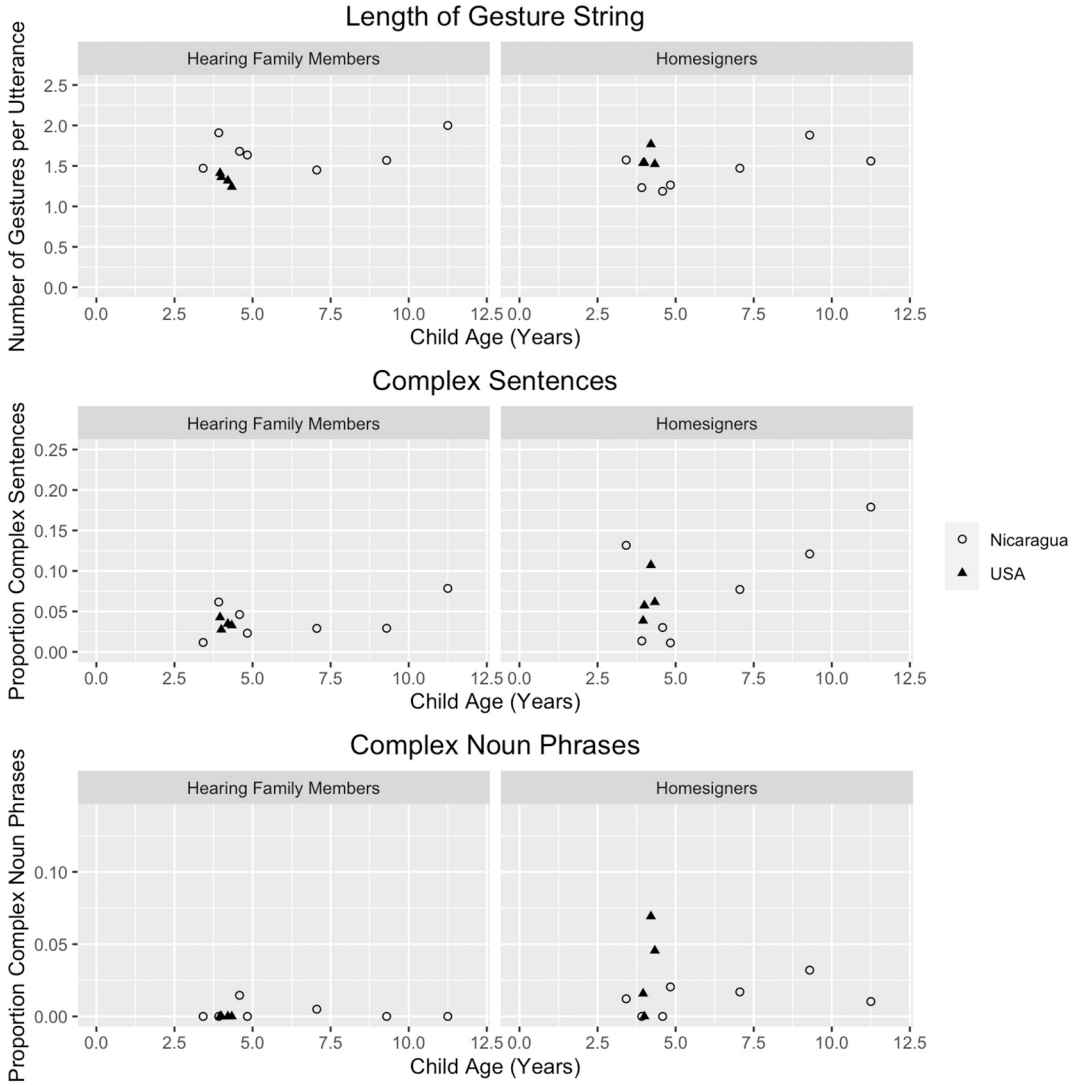

Fig. 4. Scatter plots of gesture string length (top), complex gesture sentences (middle), and complex gesture noun phrases (bottom) for hearing family members (left graphs) and homesigning children (right graphs) as a function of culture (Nicaragua in circles, USA in triangles).

and culture β = 0.84, $p = .13$ (Fig. 4, left middle plot). Very few *complex gesture noun phrases* were produced by hearing family members in either culture, making statistical analysis impossible: only 3 were identified, all in Nicaragua (Fig. 4, left bottom plot).

Because Nicaraguan family members produced substantial numbers of gestures with and without speech, we conducted an additional analysis on these participants including this factor. Contrary to our expectations, we did not find that gesture string length was longer for utterances that occurred without speech. In fact, gesture utterances occurring with speech were longer than those without speech, β = 0.45, $p = .006$. We found no effect of speech on complex sentences, β = −0.60, $p = .52$ (for more details, see Tables S11-S12 and Fig. S3, which presents gesture string length, complex gesture sentences, and complex gesture noun phrases for Nicaraguan hearing family members at each homesigner age, categorized according to whether the gestures were produced with speech or without speech).

3.4. Structure of homesigners' gestures in Nicaragua vs. the USA

Are these cross-cultural differences in hearing family members' gestures reflected in homesign in each culture? Fig. 4 (right graphs) displays the same three gesture measures for homesigners in Nicaragua vs. the USA. For children who were observed at multiple sessions, the graphs present the data averaged over those sessions; Fig. S2 (right graphs) in Supplementary Materials presents the data at each child session for each of the three measures. Focusing on *gesture string length*, although we found no main effect of homesigner age, β = −0.03, $p = .18$, we did find an effect of culture, β = −1.05, $p = .003$, which interacted with age, β = 0.28, $p < .001$—Nicaraguan homesigners produced relatively longer gesture sentences, particularly at older ages (Fig. 4, right top plot). Focusing on *complex sentences*, we again found no effect of homesigner age, β = −0.03, $p = .76$, but an effect of culture, β = −4.63, $p < .001$, which interacted with age, β = 1.09, $p < .001$—Nicaraguan homesigners produced many complex sentences, particularly at older ages (Fig. 4, right middle plot). Turning next to *complex noun phrases*, we found that homesigners in the two cultures did not show the same pattern as their hearing family members and, if anything, showed the opposite pattern: Nicaraguan homesigners produced marginally *fewer* complex noun phrases than USA homesigners, β = 3.63, $p = .08$; there was no effect of homesigner age, β = 0.13, $p = .20$, and no interaction between age and culture, β = −0.61, $p = .19$ (Fig. 4, right bottom plot).

To summarize thus far, we found differences in the gestures produced by hearing family members in Nicaragua vs. the USA, but those differences might reflect the fact that Nicaraguan homesigners were older than USA homesigners. The same age confound might also account for homesigner differences in gesture string length and complex sentences, although, notably, not for homesigner differences in complex noun phrases.

3.5. Relation between hearing family members' gestures and homesigners' gestures in Nicaragua vs. the USA

Our next step was to directly compare homesigners to hearing family members. We included three factors in these models (culture: Nicaragua vs. USA; group: homesigners vs. hearing family members; homesigner age, as a continuous variable), but did not include interactions among the factors because including these interactions along with the 3 factors makes the models not converge (unlike our earlier models containing 2 factors, which did converge when interactions were included). Note also that including all of the interactions would make the models difficult to interpret; see http://andrewgelman.com/2018/03/15/need-16-times-sample-size-estimate-interaction-estimate-main-effect/ on sample size needs for including interactions.

Focusing on *gesture length*, we found no differences as a function of group (homesigners vs. family members), β = −0.04, $p = .76$, or culture (Nicaragua vs. USA), β = −0.19, $p = .16$ (Fig. 5, top graphs, left), and an effect of homesigner age, β = −0.04, $p = .005$ (Fig.S2, top graphs). Importantly, however, on the two structural measures, homesigners displayed significantly *more* complexity than hearing family members in both cultures. For *complex sentences,* there was an effect of group—homesigners produced more than hearing family members, β = 0.57, $p = .03$—but no effect of culture, β = −0.09, $p = .76$ (Fig. 5, top graphs, middle) or homesigner age, β = 0.05, $p = .30$ (Fig.S2, middle graphs). For *complex noun phrases,* there was also an effect of group—homesigners again produced more than hearing family members, β = 1.92, $p = .004$—but no effect of culture, β = 0.72, $p = .17$ (Fig. 5, top graphs, right) or homesigner age, β = 0.09, $p = .30$ (Fig.S2, bottom graphs).

If homesigners were using the gestures produced by their hearing family members as a model for their own gestures, then we should find a positive correlation between a homesigner and his/her hearing family members on each of our three measures. Fig. 5 (bottom graphs) presents scatterplots for each measure. In order to conduct this analysis, we calculated a single average figure for each homesigner and for each family member, across all sessions for that individual, for each of our three measures. There were no significant correlations between homesigners and hearing family members for any of our measures: mean *gesture length* ($\rho = -0.40$, $p = .22$), *complex sentences* ($\rho = -0.08$, $p = .82$), or *complex noun phrases* ($\rho = -0.32$, $p = .34$). It is, however, possible that averaging scores over multiple sessions distorted the correlational analyses. We therefore redid the correlations in two separate analyses for each measure. In the first analysis, we entered only the first session for each child and hearing family member; in the second analysis, we entered the second session for each child and family member observed more than once, along with the first session for all others. No correlation was statistically significant for any of the measures in these analyses.

Finally, we used a bootstrapping procedure to re-sample our data with 500 simulated samples to give a better estimate of the population parameters for each measure. For two of the three measures, the confidence intervals based on 500 bootstrap replicates include zero: gesture length 95% CI [−0.8767, 0.0684], complex sentences 95% CI [−0.7787, 0.7642]. We were unable to use this procedure for the complex noun phrases because the large proportion of parents producing no complex noun phases led to a standard deviation of zero in many of the bootstrapped samples. For gesture length and complex sentences, however, these results indicate that there likely is a true lack of relation between parents and children on these measures.

Because we were forced to collapse a great deal of data to conduct our correlational analyses, we took a second approach to the question of whether homesigners used the gestures produced by their hearing family members as a model for their own gestures. We ignored culture and entered the input provided by each homesigner's hearing family members as a factor into each analysis. We performed a series of a mixed effects regressions and logistic mixed effects regressions with fixed effects for hearing family member input, and homesigner age at each session, as well as a random effect for participant (see Supplementary Materials S13-S15). Focusing on *gesture length*, we found neither homesigner age (β = 0.01, $p = .80$) nor the average length of gesture utterances for family members (β = 0.14, $p = .21$) significantly predicted homesigner gesture utterance length. Focusing on *complex gesture sentences*, we found neither homesigner age (β = 0.01, $p = .16$) nor the average complex gesture sentence proportion for family members (β = −0.13, $p = .58$) significantly predicted homesigner complex sentence production. Focusing on *complex gesture noun phrases*, we again found neither homesigner age (β < − 0.01, $p = .91$) nor the average complex noun phrase proportion for family members (β = 1.24, $p = .08$) significantly predicted homesiger complex noun phrase production.

In sum, we found, in both Nicaragua and the USA, that, as a group, homesigners produced more complex sentences and more complex noun phrases than hearing family members and, as individuals, displayed no correlations with members of their hearing families on these measures.

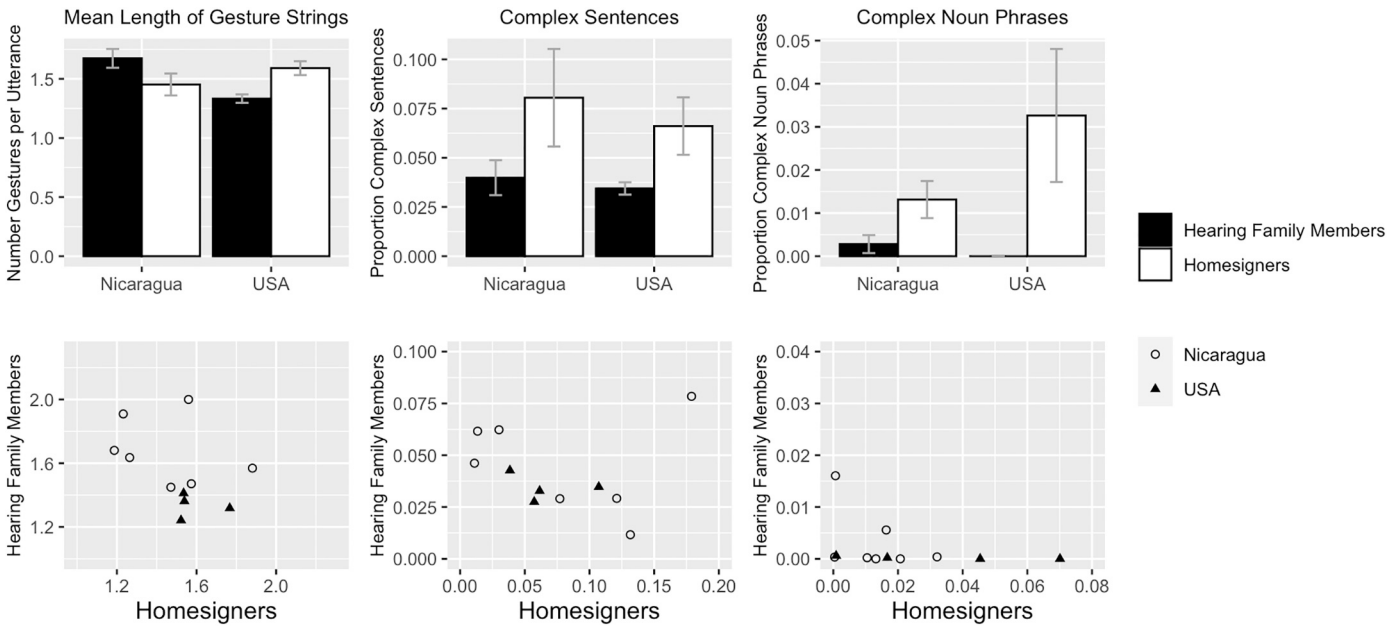

Fig. 5. Top: Bar graphs contrast gesture string length, complex sentences, and complex noun phrases for hearing family members (black) vs. homesigners (white)) in Nicaragua (left bars in each graph) and the USA (right bars). Error bars indicate standard errors. Bottom: Scatterplots of the same measures showing the relation between individual homesigners (x-axis) and their hearing family members (y-axis) in Nicaragua (white circles) and the USA (black trianglesblack).

In addition, although homesigners may have seen hearing family members produce complex sentences, there is strong evidence that homesigners themselves introduced complex noun phrases into their systems.

4. Discussion

Nicaraguan homesigners invented gesture systems containing two structural properties (complex sentences, complex noun phrases) found in the gesture systems of the USA homesigners. Even though Nicaraguan hearing gesturers displayed more complexity than USA hearing gesturers, there was no evidence that this difference had an effect on homesign: (*i*) On no measure did Nicaraguan homesigners display more complexity than USA homesigners, particularly when homesigner age is accounted for. (*ii*) As a group, homesigners in *both* cultures produced more complex noun phrases and more complex sentences than hearing family members. (*iii*) There was no correlation between individual homesigners and hearing family members on any gesture measure. We thus found no evidence that the structure of homesign is derived from the structure of gestures homesigners see hearing individuals produce, even in Nicaragua. This finding complements a study done by Carrigan and Coppola (2017) on homesign comprehension–Nicaraguan hearing family members understood homesigners' productions less well than would be expected if the family and homesigners co-generated the system.

4.1. Extending the original homesign findings

Our findings replicate previous work showing that the gestures hearing speakers produce do not offer an adequate model for the structural aspects of homesign. The study also goes beyond the current literature in three ways.

4.1.1. Nicaragua: an experiment of nature that varies richness of input

First, the study extends the homesign findings to a gesture-rich culture, Nicaragua. The Nicaraguan hearing family members produced more gestures without speech and longer gesture strings than the USA family members, and thus gave us an opportunity to assess the impact that gestural richness has on homesign. The fact that we did not find differences between the Nicaraguan and USA homesigners given these differences in input is a null finding, but it is a null finding with theoretical import. A priori there was every reason to believe that boosting the complexity of the input a homesigner receives would have a measurable impact on the complexity of the gestural system the homesigner creates. Not finding a difference between the structures developed by the homesigners in Nicaragua and the USA is therefore a compelling finding. Moreover, the increased numbers of gestures in the Nicaraguan sample made it possible for us to use more sophisticated statistical techniques than were used in the original homesign studies, lending credence not only to the differences found between homesigners and hearing family members, but also to the absence of differences between homesigners in the two cultures.

4.1.2. Complex noun phrases are created by homesigners

Second, the study extends the discovery of complex noun phrases to Nicaraguan homesign. Complex noun phrases were not included in the original descriptions of gestural input to homesign (Goldin-Meadow & Mylander, 1983, 1984, 1998) and, up to now, have been described in only one USA homesigner and his hearing mother (Hunsicker & Goldin-Meadow, 2012). The fact that the homesigners produced complex noun phrases, and their hearing family members did not, allows us to address an important question: Are homesigners introducing structure into their gestures, or are they amplifying structures already found in their input (as Hudson-Kam & Newport, 2009, have found in an artificial language-learning context)? The answer to this question may differ by linguistic property.

Homesigners and hearing family members both produced *complex sentences*, making it difficult to argue that homesigners were first to use these structures (but see Goldin-Meadow & Mylander, 1998, Fig.3, who found that 2 of our 4 USA homesigners used complex sentences before their hearing family members; the other 2 and families both used complex sentences when first observed). Some of the homesigners may then have gotten a model for complex sentences from their hearing family members. But the homesigners amplified their use of complex sentences and used them more consistently than their hearing family members. Once they began using complex sentences, all 4 of the USA

homesigners steadily increased production of these structures and used them at *all* subsequent sessions; their hearing family members used them only sparsely and erratically (Goldin-Meadow & Mylander, 1998, Fig.3).

The evidence is clearer for *complex noun phrases*: 8 of 11 homesigners (5 Nicaragua, 3 USA) produced complex noun phrases, but only one of these children's family members (in Nicaragua) produced complex noun phrases (Table 1). The absence of complex noun phrases in almost all of the hearing family members makes it difficult to statistically explore the difference between homesigners and their hearing family members. Note, however, that the hearing parents did produce many simple noun phrases in their gestures (in which only one gesture refers to an entity). In other words, the absence of complex noun phrases in the hearing family members did not stem from a lack of opportunity to produce complex noun phrases—their absence is likely to be a real omission. As a result, the complex noun phrase construction provides the most convincing evidence to date that homesigners, and not their hearing family members, are the ones who introduce structural properties into homesign.

4.1.3. Gestural precursors of an emerging language

Third, by extending homesign studies to Nicaragua, the study offers insight into the gestural precursors of an emerging language. Language acquisition takes place over ontogenetic time—children are typically exposed to a language by their parents and acquire that language during childhood. Passing language through the minds of young children via language acquisition is how all languages reproduce and change, yet remain learnable. In contrast, language emergence takes place over historical time—describing how language is created and evolves in the absence of prior language. Although language emergence must have occurred in the oral modality at some point, the oral modality no longer supports the study of language emergence. But the manual modality still does (Brentari & Goldin-Meadow, 2017).

Homesigners like those we have studied here first came into contact in Nicaragua 40 years ago, and established a communication system that served as a foundation for the iterative application of learning and communication processes that have led to the emergence of a new sign language, Nicaraguan Sign Language (NSL, Senghas, 2003). NSL displays the two structural properties that we have described here—complex sentences and complex noun phrases (Senghas, Newport, & Supalla, 1997). Our findings thus suggest that these properties were likely to have been brought to NSL by the original homesigners, and to have served as a foundation for additional linguistic properties contributed by subsequent generations. Our study thus sheds light on the types of structures that an individual can introduce into communication before that communication is shared within a community of users, and therefore sheds light on the roots of linguistic structure.

4.2. The biases children bring to language-learning

The finding that children go beyond their input when inventing homesign systems builds on a body of work showing that deaf children also exceed their input when exposed to language by signers who do not have a complete grasp of that language (Singleton & Newport, 2004) and when exposed to an emerging and thus not fully-formed sign language (Senghas, 2003; Senghas & Coppola, 2001). The fact that, in all of these situations, children go beyond the input they receive underscores the active component children play in shaping their language when it is given to them, and in creating their language when it is not. However, the input homesigners get represents a more extreme case as it does not serve as the primary linguistic system for anyone other than the homesigner. The leap homesigners make thus represents a more significant move beyond input than the leap made by children learning language from impoverished models and, as a result, provides clearer evidence of the biases children bring to language-learning.

We know that language input, when present and usable, influences child language-learning. However, finding a tight relation between parent input and child output does not mean that children come to language-learning without biases. It is precisely these biases that homesign sheds light on. Child homesigners are as ready to learn language as any child, but they do not receive input from an established language, and the gestures their hearing parents use do not display linguistic structure. If homesigners are using their hearing parents' gestures, they must be taking those gestures and turning them into linguistic form. Homesign thus offers a window onto the internal processes that children apply to the input they receive to arrive at linguistic structure. Note these internal processes are obscured in typical language-learning because linguistic structure is already present in the input, and need not be reinvented.

Nevertheless, we might be able to see these processes at work in typical language-learning situations in the speed with which children exposed to language models acquire particular linguistic structures—structures found in homesign may be acquired earlier, or with less input, than structures absent from homesign. This hypothesis can be tested against language-learning data in typical environments. However, our data do not tell us whether these processes are language specific or domain general (but see Gershkoff-Stowe & Goldin-Meadow, 2002, for a test of language specificity in one homesign construction, and also Goldin-Meadow, So, Ozyurek, & Mylander, 2008); our data tell us only that the processes are recruited when a child is faced with the task of language-creation. Nor can we say whether the biases to create a language with the properties of homesign are unique to child learners, as we did not examine homesign creation in adults. We thus argue, on the basis of positive evidence (i.e., the presence of a linguistic structure in homesign), that structures present in homesign are evidence of internal biases child learners bring to language-learning. We also speculate, albeit on the basis of negative evidence (i.e., the absence of a linguistic structure in homesign), that structures common in established languages (spoken or signed) but rare or unattested in homesign are likely an outgrowth of communicative/functional pressures (see, for example, Rissman et al., 2020).

We have found linguistic structure can be *created* (as opposed to learned) by a child in the absence of structured input. The homesign gesture systems in Nicaragua and the USA contained structural devices found in all natural languages even though homesigners did not have access to linguistic input. Moreover, these structures could not easily be traced back to gestures the homesigners' hearing family members used, suggesting that the structures were created by the homesigners.[3] Language creation is the first step in language emergence. It provides starting materials that can be shaped by other key factors involved in language emergence—sustained *communication* using a shared system, repeated *transmission* of that system to child learners. Our findings make it clear that some aspects of linguistic structure do not require these key factors to appear in human communication. These linguistic structures are thus fundamental to human language and likely to be universal.

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Informed consent

Informed consent was obtained for experimentation with human subjects.

[3] Attempts to explain structural properties of homesign by looking at hearing family members' *responses* to homesign have also failed (Goldin-Meadow & Mylander, 1984:94–104).

Author contributions

All authors developed the study concept and contributed to its design. Data collection was performed by Flaherty and Hunsicker. Flaherty performed the data analysis and interpretation under the supervision of Goldin-Meadow. Flaherty and Goldin-Meadow drafted the manuscript, and Hunsicker provided revisions. Flaherty and Goldin-Meadow revised the initial draft to produce this Revision. All authors approved the final version of the manuscript.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2021.104608.

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