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Successful communication does not drive language development: Evidence from adult homesign

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ABSTRACT

Constructivist accounts of language acquisition maintain that the language learner aims to match a target provided by mature users. Communicative problem solving in the context of social interaction and matching a linguistic target or model are presented as primary mechanisms driving the language development process. However, research on the development of homesign gesture systems by deaf individuals who have no access to a linguistic model suggests that aspects of language can develop even when typical input is unavailable. In four studies, we examined the role of communication in the genesis of homesign systems by assessing how well homesigners' family members comprehend homesign productions. In Study 1, homesigners' mothers showed poorer comprehension of homesign descriptions produced by their now-adult deaf child than of spoken Spanish descriptions of the same events produced by one of their adult hearing children. Study 2 found that the younger a family member was when they first interacted with their deaf relative, the better they understood the homesigner. Despite this, no family member comprehended homesign productions at levels that would be expected if family members co-generated homesign systems with their deaf relative via communicative interactions. Study 3 found that mothers' poor or incomplete comprehension of homesign was not a result of incomplete homesign descriptions. In Study 4 we demonstrated that Deaf native users of American Sign Language, who had no previous experience with the homesigners or their homesign systems, nevertheless comprehended homesign productions out of context better than the homesigners' mothers. This suggests that homesign has comprehensible structure, to which mothers and other family members are not fully sensitive. Taken together, these studies show that communicative problem solving is not responsible for the development of structure in homesign systems. The role of this mechanism must therefore be re-evaluated in constructivist theories of language development.

1. Introduction

The process by which children come to be mature members of a linguistic community has long been a subject of developmental research. Valian (2014) specifies four key components of a model of language development[1]: First, the initial state of the child (or endowment); second, the end-state of the language system—that is, the nature of the adult language system; third, the mechanism by which the learner transitions from the initial state and the end state, and fourth, the role played by any input the child receives. Although these can be (and are) studied independently, comprehensive theories of language development must address each component. In particular, any specification of the mechanism by which children acquire language must necessarily depend upon the conceptualization of the initial state, and the role of the input (as 'ingredients' to be used by the mechanism). Thus, in attempting to determine how mechanisms of language development operate, it is useful to precisely specify what these 'ingredients' are.

1.1. Language via 'target-matching' and 'communicative problem solving'

Constructivist theories of language development hold that children acquiring a language build linguistic representations on the basis of the input they receive (e.g., Ambridge & Lieven, 2015; Tomasello, 2000, 2009). Crucially, the construction of linguistic representations is accomplished through interactions with individuals who have fully developed language systems.

One constructivist account of language acquisition, known as a functionalist, or usage-based perspective, emphasizes the importance of communication as a mechanism of language development

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[1] We use the term "language" very broadly, to encompass phonological, morphological, lexical, and syntactic structure.

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(e.g., Bates & MacWhinney, 1982; Goldberg, 2006; Tomasello, 2000, 2007, 2009). These accounts define communication as interactions between individuals whose functional goal is the successful transmission of a message. Further, they suggest that in the 'end state' of language development, the learner matches the structure in the input or target language (we refer to this as 'target-matching'). Target-matching is accomplished via social interactions with more mature users of the target language (Tomasello, 2007). The more closely the learner's linguistic representations match the target language, the more successful communication will be.

Some strongly functionalist perspectives suggest that the specific forms of language have evolved in close relation with their communicative function (described, for example, in Bates & MacWhinney, 1982). Such perspectives hold that the form of a particular linguistic feature may be "inevitable" (Bates & MacWhinney, 1982, p. 178) given its communicative function as well as learner-internal and learner-external constraints on its emergence. Accordingly, the acquisition or construction of these linguistic forms results from children's attempts to solve particular communicative problems (like the need to understand what people around them are saying, e.g., Goldberg, 2006). Communicative problem solving is thus the means by which the child acquires the structure of the target language and achieves successful communication. As children age, their linguistic representations become increasingly abstract and independent of the context in which they are acquired (e.g. Ambridge & Lieven, 2011). Thus, once children have developed linguistic representations that fully match the target language, they are able to produce utterances that can be *understood based solely on the linguistic signal*.

Language and communication generally go hand-in-hand in the language-learning situation, and are difficult, if not impossible, to separate. In the vast majority of instances, in which the child has access to a target language, target-matching and communicative problem solving provide reasonable explanations of the mechanisms driving language acquisition. However, it is not clear that these mechanisms can account for the development of language structure under all circumstances, especially those in which a language model, or target, is absent.

1.2. Language emergence reveals mechanisms of language development

Along with a number of researchers from various areas of the study of language (e.g., Goldin-Meadow, 2003; Kiparsky, 1968, 2014; Senghas & Coppola, 2001) we argue that cases of present-day language emergence—the emergence of linguistic structure in the absence of linguistic input—parallel the language acquisition process. Both involve the development of complex linguistic representations using the language-learning mechanisms available to all humans. Given the similarities between language emergence and language acquisition, it is unparsimonious to posit different mechanisms for each phenomenon.

However, cases of present-day language emergence pose a challenge to these mechanisms. Both the target-matching and communicative problem solving explanations for language development in constructivist accounts assume that children receive language input that is structured, regular and complex. However, there exist situations in which individuals are exposed to input that is inaccessible, unstructured, or entirely absent—namely, the development of homesign systems.

Homesigners are situated at the intersection of acquisition and language emergence. Initially, they are young enough for their acquisition mechanisms to operate, but no input is available to feed those mechanisms. Goldin-Meadow (2015) argues that the natural variability in the input characteristic of these present-day cases of language emergence make them a unique means of teasing apart the learner-internal and learner-external contributions to language development.[2]

If 'communicative problem solving' is the primary means by which humans construct language, it should play a role in the development of linguistic structure in homesign systems. In the present paper, we evaluate whether this mechanism plays a role in the development of linguistic structure in four homesign systems used by adult deaf individuals in Nicaragua. Again, the term 'linguistic structure' encompasses morphophonological, morphological, lexical, and syntactic features of language—in the next section we review the evidence that homesign systems contain these features.

1.3. Homesign: Language without structured input

The cases of de novo genesis of language-like systems examined here occur in deaf individuals who are born free of cognitive and social impairments, and who can thus be considered typically developing. They are born into hearing, non-signing families who do not have access to early intervention or special education services for deaf children. Thus, they have little access to signed or spoken linguistic input. These individuals nevertheless develop and use systems of manual gestures, called "homesign," to use with their hearing family members (see Goldin-Meadow, 2003 and Morford, 2003 for reviews of work on homesign systems in childhood and adolescence).

Homesigners are unable to hear the spoken language around them, and are not exposed to conventional sign language; they also do not learn to read Spanish. Thus, their only input is what they can visually perceive of the hand, facial, and body gestures produced by the hearing people around them. Such gestures typically accompany speech, and do not contain independent linguistic structure (e.g., Goldin-Meadow, McNeill, & Singleton, 1996; Singleton, Morford, & Goldin-Meadow, 1993). This suggests that homesigners receive non-linguistic input, on which they then impose linguistic structure. Work with child homesigners shows that the gesture input they receive from their mothers is less patterned than what the deaf children themselves produce (e.g., Goldin-Meadow, Butcher, Mylander, & Dodge, 1994; Goldin-Meadow & Mylander, 1984, 1990).

Nevertheless, child and adult homesign systems exhibit many of the features of fully developed languages, such as basic syntax and morphology (e.g., Goldin-Meadow, 2003), hierarchical structure and complex phrases (Hunsicker & Goldin-Meadow, 2012), the grammatical relation of subject (Coppola & Newport, 2005), proto-pronouns (Coppola & Senghas, 2010), devices for expressing quantity (Coppola, Spaepen, & Goldin-Meadow, 2013), devices for establishing reference (Coppola & So, 2005) and emerging morphophonological and morphosyntactic regularities (Brentari, Coppola, Mazzoni, & Goldin-Meadow, 2012; Coppola & Brentari, 2014). Such research indicates that homesign is systematic and productive, and functions as a linguistic system.

1.4. Target-matching does not drive homesign development

The evidence discussed above (Goldin-Meadow & Mylander, 1984, 1990; Goldin-Meadow et al., 1994) shows that target-matching cannot account for the development of linguistic structure in homesign. Firstly, homesigners do not receive any fully

[2] While such natural experiments of language deprivation are highly informative regarding theories of language and cognitive development, the consequences of language deprivation are negative for the individuals who experience it. Researchers must do everything in their power to increase awareness about and reduce the occurrence and severity of language deprivation (Humphries et al., 2014).

structured input to match. No hearing parent of a deaf child in the literature thus far has spontaneously generated a full linguistic system of gestures to use with their deaf child. The mothers of the adult homesigners in Nicaragua who participated in the current study do produce utterances containing multiple gestures when describing simple events. However, only one mother produced a systematic word order pattern, and this pattern (Agent-Patient-Event) did not match the one produced by her son (Patient-[prosodic break]-Agent-Event) (Coppola, 2002).

Furthermore, the structure that exists in homesigners' productions exceeds any structure in the gestures they see around them. Not only are homesigners not attempting to match their target, they are in many cases going beyond the target. This accords with experimental and case-study research by Newport and colleagues (Hudson Kam & Newport, 2005, 2009; Singleton & Newport, 2004) showing that children impose structure on input that is inconsistent or variable. Goldin-Meadow (2014) similarly argues that children's statistical learning capabilities, which might be how target-matching operates, cannot account for the language development of child and adult homesigners.

Target-matching cannot be a necessary mechanism for developing linguistic structure, because structure in homesign exceeds the little (if any) accessible structured input homesigners receive. While target-matching might occur in typical language acquisition situations, we argue that other language development forces must be at play that result in language structure even in the absence of a target language. Given this finding, we next examine the communicative problem solving mechanism described in constructivist theories. Perhaps the interactions homesigners have with their hearing family members constitute the communicative problem solving that drives the development of homesign structure.

1.5. Might communicative problem solving drive homesign development?

Looking only at cases of typical acquisition, it is impossible to tell whether communicative problem solving drives the nature of the linguistic structures that children develop, or whether it merely acts as a catalyst for that development. Examining communication in circumstances in which no structured system is available to the learner, such as homesign, provides insight into this question.

Homesigners interact socially on a daily basis with the people around them—primarily their relatives who live with them. The social interactions of child and adult homesigners are functionally and pragmatically similar to those experienced by individuals in typical language acquisition situations (Coppola, 2002; Goldin-Meadow, 2003; Morford & Goldin-Meadow, 1997; Phillips, Goldin-Meadow, & Miller, 1999, 2001).

In over 20 years of interactions with the now-adult homesigners described in this paper, the authors have observed homesigners regularly engaging their hearing family members and friends in conversation (using gesture) about both present and non-present people and events (Coppola, 2002), discussing things such as jokes and politics, expressing their own feelings (Coppola, Carrigan, personal observations), and describing their dreams (Richie, personal communication, 2013). Even more importantly, the hearing communication partners (family members and friends) of adult Nicaraguan homesigners regularly respond to and initiate communicative interactions using gesture, an accessible modality for homesigners (Coppola, 2002). In short, homesigners participate in the socio-communicative environment around them, despite their lack of conventional linguistic input. The goal of this paper is to specify what about communicative problem solving might lead to the development of structure in homesign.

One possibility is that the structure is present because it is understood by the communication partner. Perhaps the communication partner has shaped the structure in homesign by understanding, and therefore responding appropriately to, one set of structures versus another. Goldin-Meadow and Mylander (1984) tested this with hearing parents of homesigners in the US, and found no evidence for the hypothesis. Here we build on previous data by testing the parents many years later in a decontextualized comprehension paradigm. The additional years of interaction between adult homesigners in Nicaragua and their communication partners may have given communicative problem solving more opportunity to influence the development of homesign structure. Constructivist theories predict that we should observe successful communication between homesigners and co-participants in the communicative problem solving process. According to this view, hearing communication partners (relatives) of the homesigner should comprehend the homesign productions of their deaf family member.

The current set of studies assesses how well hearing communication partners of adult Nicaraguan homesigners understand the homesigners' gesture productions. We first consider the homesigners' mothers, who have served as the primary caregivers for their now-adult deaf children, and who have interacted with them for at least 20 years. We then examine the comprehension of other family members (one homesigner's father, as well as several siblings). Study 1 examines mothers' comprehension of homesign relative to their comprehension of Spanish, the native language that they share with their hearing children. In Study 2, we looked at how well the homesigners' other family members comprehended homesign productions, and the factors that affect this comprehension (e.g., age of exposure to the homesign system). In Study 3 we asked whether the productions themselves contained sufficient information for a receiver to succeed at our task, and in Study 4 we asked whether the homesign descriptions could be comprehended by a group other than homesigners' family members—namely, native Deaf users of American Sign Language.

2. Study 1

Mothers are often primary caregivers for, provide significant linguistic input to, and serve as primary interlocutors for their children. It is thus reasonable to expect that the mothers of homesigners might play the same role. Each of the mothers in the current study has served as the primary caregiver for her deaf child, and has known and lived with her now-adult child for a minimum of 20 years. Here we ask whether homesigners' mothers co-generate their deaf child's homesign system via communicative interactions by assessing how well these mothers understand the gesture productions of their offspring.

We compare mothers' comprehension of their deaf child's homesign productions to their comprehension of spoken Spanish descriptions of the same events that were produced by one of their hearing children. If mothers serve similar roles in their children's development of homesign and spoken Spanish, we would expect their comprehension to be comparable for these two tasks. If we find that mothers do not comprehend their deaf child's homesign productions to the same degree that they comprehend their hearing child's spoken Spanish productions, it would suggest that mothers' communicative interactions with their deaf child are *not* the driving force behind the development of their deaf child's homesign system.

2.1. Participants

The homesigning participants and their families were recruited between 1996 and 2004 by the second author through personal visits to rural and urban areas of Nicaragua and via community contacts. They have participated in a variety of research tasks since their recruitment, and are familiar with both the authors and the research procedures employed.

2.1.1. Homesign producers

Four deaf adult Nicaraguan homesigners (1 female), ages 16–26 years at the time of production, produced the homesign descriptions used as stimuli for this task. All four homesigners were deaf, with very minimal knowledge of spoken or written Spanish. Some could produce and/or comprehend a limited number of common spoken Spanish words, such as "mamá," "papá," and "agua" (water). All found writing their names effortful, if not impossible. They have had little to no formal education, and have not acquired Nicaraguan Sign Language or any other conventional sign language. They each use their homesign system as their primary means of communication with family and friends. Crucially, they do not interact with each other, which means that their homesign systems developed independently, and are thus distinct from one another (although they share some general properties, as noted in the introduction).

2.1.2. Spoken Spanish producers

Four hearing siblings of homesigners (1 female), ages 17–43, produced spoken Spanish descriptions of the same events. The siblings were native monolingual Spanish speakers, had an average of 8.5 years of education (range: 0–14 years), and had not acquired Nicaraguan Sign Language or any other conventional sign language.

2.1.3. Receivers

The mothers of the four adult homesigners described above were hearing native monolingual Spanish speakers ranging from 45 to 60 years of age, and had an average of 2.25 years of education (a typical level for hearing Nicaraguans of this age who live in rural areas). The mothers had not acquired Nicaraguan Sign Language or any other conventional sign language.

2.2. Materials

2.2.1. Events described by homesigners and spoken Spanish producers

We used descriptions of simple events produced by homesigners to assess their communication partners' comprehension of homesign. The stimuli used to elicit both Homesign and spoken Spanish descriptions were 83 simple videotaped events involving live actors and real everyday objects (6 were practice items; see Appendix A for descriptions of all items). Spoken Spanish descriptions were produced for a subset of these 83 events (41 or 42, with 3 practice items). The events featured one or two entities in a variety of thematic roles; the two-entity events included combinations of animate and inanimate entities. The two animate entities in the events were the same man and woman throughout, and the inanimate entities were objects such as a cup, a banana, and a flower. Example events included "A man kisses a woman" and "A sheet of paper burns." In the events containing two animate entities, the thematic roles of the entities could be reversed. For instance, in the event "A man kisses a woman," the man is the agent and the woman a patient; however, a woman is equally likely to act as an agent and kiss a man (who is, in that case, a patient). This is relevant for the discussion of the picture foils in the picture arrays, described below.

The picture arrays used to assess comprehension each included four pictures. One picture always depicted the target event. Fig. 1 (top left) shows a sample picture array for an inanimate one-entity event ("A piece of paper burns"), and (in the top right) a sample picture array for an animate one-entity event ("A woman sneezes"). For one-entity events, the non-target foil pictures could depict: (a) the target entity involved in a different action or state ("Other Event"); (b) a different entity involved in the same action/state ("Other Entity"); or (c) a different entity involved in a different action/state, that is, there was no overlap with the target event ("Unrelated"). Picture arrays for some items contained one of each type of foil, and arrays for other items contained one of the (a) or (b) foil types along with two (c, unrelated) pictures.

For two-entity events, the non-target foil pictures could depict: (a) the two target entities involved in reversed thematic roles ("Reverse"); (b) one of the target entities involved in the same action with a different entity ("Other Entity"); (c) the two target entities involved in a different action or state ("Other Event"); or (d) one of the target entities involved in an unrelated action (either with or without a second entity; "Unrelated"). Fig. 1 (bottom left) shows a sample picture array for "Reversible" two-entity event ("A man kisses a woman"), and (in the bottom right) a sample array for a two-entity event "Non-reversible" event ("A man pushes a chair").

2.2.2. Homesign descriptions

Homesign descriptions were produced by the homesigners described above to a communication partner who was physically present[3] in 2002 (Homesigners 1, 2, and 3) and 2004 (Homesigner 4). The productions of Homesigners 1, 2, and 3 in the current study were originally analyzed in Coppola and Newport (2005). They found that the vast majority of the target noun phrases produced by each homesigner (88–93%) appeared in clause-initial position in both agentive and non-agentive contexts. This pattern constitutes evidence that each homesign system contains the grammatical relation of subject. Thus, the homesign utterances selected for the current task display a high degree of systematicity. The original task was not designed as a comprehension task, but as a targeted elicitation task. The intent of asking the receiver to select a picture matching the homesigner's description was primarily to encourage production of the target nouns, that is, the nouns most likely to be treated as subjects crosslinguistically. Thus, the original design did not include systematic training regarding how to produce a "complete" description of the event.[4]

2.2.3. Spoken Spanish descriptions

One hearing sibling of each homesigner (see participant information above) produced spoken Spanish descriptions of one subtest (half) of the events to his/her mother live in 2011.[5] As was the case for the homesign productions, we did not systematically train siblings to produce "complete" descriptions, but relied on the comprehension component mothers completed to serve as an incentive for siblings to produce complete descriptions.

2.3. Procedure

2.3.1. Homesign comprehension task

Each mother watched the previously videotaped homesign descriptions produced by her own deaf child. Mothers watched

[3] Homesigner 1 described the vignettes to his older brother for half the items, and to an older cousin for the other half of the items. Homesigner 2 described all items to his younger brother; Homesigner 3 to his mother (see General Discussion for comparison of this mother's comprehension of live vs. videotaped homesign descriptions); and Homesigner 4 to her younger sister.

[4] For a small number of stimulus events, a homesigner produced multiple descriptions—for this task, we clipped the videotaped description that contained the maximum number of gestures expressing the event action and entities for each stimulus event and compiled each homesigner's productions into a single QuickTime video file. The set of descriptions included in the stimuli are representative of each homesigner's internal system (see General Discussion).

[5] In the General Discussion we address the methodological difference between the live spoken Spanish comprehension task and the videotaped homesign comprehension task. Briefly, we conclude that this difference does not undermine our conclusions.

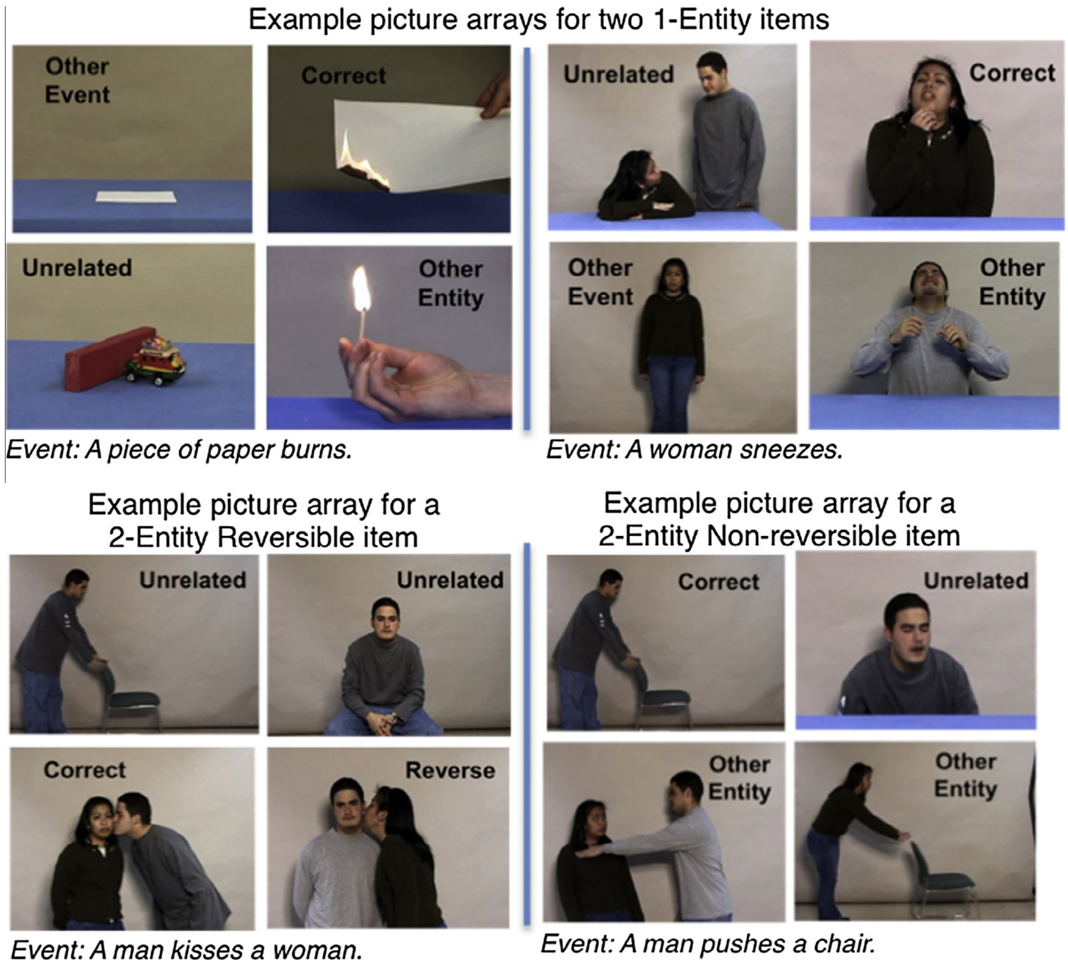

Fig. 1. Example picture arrays for the comprehension task, by item type.

each description as many times as they wanted, then selected the matching picture (see Materials section for detailed description of Comprehension Arrays).

2.3.2. Spoken Spanish comprehension task

Each mother listened to spoken Spanish descriptions of the events produced by one of her hearing children in real time. She then chose, from the same picture arrays described above, the matching picture. The order of administration of the Homesign and spoken Spanish tasks was counterbalanced.[6]

2.4. Coding and analysis

All tasks were videotaped, and each picture choice was coded for correctness and foil type chosen. The 6 practice items were excluded from the final analyses. Four items required producers to describe the spatial configurations of items (e.g., "a circle of wooden blocks surrounds a banana"); because we were more interested in how homesigners described semantic roles, we excluded these from the final analyses. An additional 5 items were excluded because the photographic stills of the target event in the picture array were difficult to comprehend (four of these contained change of state events, like "the ball appears", that occur over time and are difficult to depict in a single image).

[6] Mothers of homesigners 1 and 2 completed the spoken Spanish comprehension task one day after the homesign comprehension task. Mothers of homesigners 3 and 4 completed the spoken Spanish comprehension task prior to the homesign comprehension task, on the same day.

2.5. Results and discussion

All four Mothers comprehended homesign descriptions at rates better than chance, which is 25% (exact Binomial test, $p < 0.001$[7]), but no mother performed above 75% (and three mothers did not perform above 53%). It is difficult to know what the threshold of "comprehension" would be in the absence of data from a fully shared language. Therefore, we directly compared each mother's comprehension of the same 31–35 events described in homesign and in spoken Spanish (Fig. 2).

The homesigners' mothers comprehended spoken Spanish descriptions at rates significantly better than chance (again, 25%; $p < 0.001$). However, mothers comprehended spoken Spanish descriptions better than they comprehended homesign descriptions of the same events (for three mothers, $p < 0.05$, McNemar's Test for Correlated Proportions; Homesigner 3's mother, $p = 0.07$). Mothers thus did not have trouble with the task itself, but rather with the content of the homesign descriptions.

The error patterns displayed by the homesigners' mothers suggest that the mothers lack understanding both of the semantic roles

[7] Due to the small number of participants and the structure of these data, parametric analyses that compare the average proportion correct *across* homesign families for two conditions (such as *t*-tests or ANOVAs) are not appropriate. We instead use an exact binomial probability test to compare each participant's proportion correct to chance performance, and McNemar's Test for Correlated Proportions (somewhat analogous to a Chi-square test) to compare the performance of ASL signers to that of Mothers on comprehension of Homesign descriptions in Study 2, and to compare Mothers' comprehension of Homesign versus spoken Spanish descriptions (in Study 3).

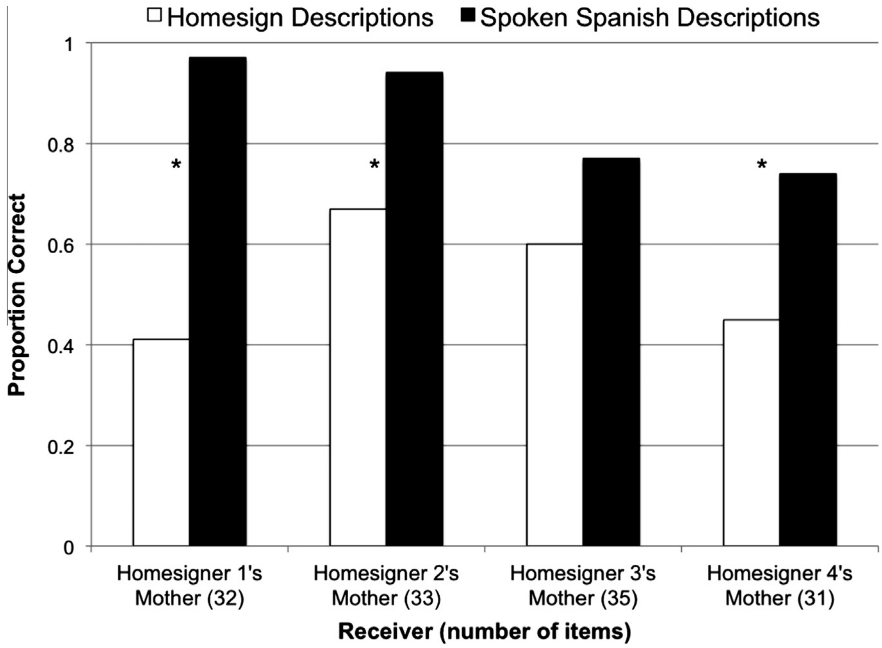

Fig. 2. Homesigners' mothers comprehended spoken Spanish descriptions better than they comprehended homesign descriptions of the same events. $^{*}p < 0.05$.

linked to a particular gesture, as well as an understanding of some of the homesigners' gestures representing arguments and predicates. This is particularly surprising given that the same man and woman were the only two animate characters across all the vignettes and that the vast majority of events could be (and were) represented iconically. When mothers erred on 2-entity reversible items, they most often selected the "reverse" foil, in which the target characters engage in the target action but in reversed semantic roles. This suggests that mothers did not make use of the systematicity in the homesigners' gesture ordering patterns established by Coppola and Newport (2005). The grammatical relation of subject serves as a device for linking arguments and predicates (and thus designating the semantic roles of the characters).

Mothers' errors on 1-entity and 2-entity non-reversible items indicate that their poor comprehension stems from even more basic misunderstandings. For both event types, it is possible to select the correct picture provided that one understands the gestures for the arguments and predicates themselves. The majority of mothers' errors consisted of selecting foils in which either a non-target entity performed the target action, or a foil in which a non-target entity performed a non-target action. For 2-entity non-reversible events, about a quarter (20–30%) of mothers' errors were another type of foil, in which the the target entity performs a non-target action. These errors suggest that mothers did *not* understand the homesigners' gestures for arguments and predicates.

The mothers of Homesigners 3 and 4 performed less well than one might expect on the spoken Spanish task, given that Spanish is their native language. While these mothers experienced some difficulty, they performed well above chance. Their difficulty with the task format does not undermine our conclusions, because the spoken Spanish task serves a control for the homesign task. The difference in homesign comprehension and spoken Spanish comprehension is the relevant comparison, and the data demonstrate that even these two mothers understood homesign less well than spoken Spanish.

Over a 25-year period, mothers have certainly developed ways of communicating with their deaf child, and in day-to-day life their communicative interactions are not entirely without success. Although context and shared history support communication, they are not required for successful communication. For instance, two strangers who share a common language would succeed at this referential communication task, even in the absence of a shared history and context. We wanted to measure mothers' comprehension of the homesign system itself, rather than their ability to use context and shared history to interpret homesigners' descriptions. The task used here was intentionally decontextualized, and forced participants to rely only on the homesign gestures produced to access the intended meaning. The pattern of results in Study 1 suggests that successful communication between mothers and their deaf child cannot have been the motivation for the development of the homesign systems.

Mothers' superior comprehension of their hearing children's spoken Spanish descriptions suggests a different role for mothers in the communicative development of their hearing and deaf children. While they share, and were likely a main source for, spoken Spanish with their hearing children, they do not share or co-generate homesign with their deaf children in the same way. This finding accords with previous studies of the systematicity in child homesign systems, which is also not attributable to the deaf children's mothers (e.g., Goldin-Meadow & Mylander, 1984).

It may be that other members of homesigners' families play the role of co-participant in the communicative problem solving process. Communication partners who began using a homesign system at younger ages than homesigners' mothers may have developed skills—like processing homesign in real time—that mothers lack. These skills may then have allowed them to engage in communicative problem solving with their deaf sibling in a way mothers did not. Homesigners' siblings, who are closer in age to the homesigner and have been gesturing with their deaf sibling from a young age, might show better homesign comprehension than their mothers, constituting evidence for a critical period effect in homesign. In Study 2, we tested additional family members to examine the effects on homesign comprehension of number of years of communicative experience and age of exposure to the homesign system.

3. Study 2

The homesigners in this study regularly interact with family members other than their mothers. If someone besides their

Table 1
Description of the homesigners' family members and their interactions with the homesigners.

Family group	Relation	Age at testing	Years interacting with homesigner	Age at which interactions began	Proportion correct
1	Brother (older)	27	25	2	0.62
	Father	63	25	38	0.56
	Mother	62	25	37	0.46
2	Brother (younger)	25	25	0	0.71
	Sister (younger)	22	22	0	0.71
	Mother	45	29	16	0.75
3	Brother (older)	43	34	9	0.57
	Mother	60	34	26	0.53
4	Brother (younger)	17	17	0	0.72
	Sister (younger)	28	28	0	0.71
	Mother	60	33	27	0.48

mother has served as their primary communication partners, that person might be more likely to understand the homesigners' productions. Siblings are closer in age to the homesigner (and sometimes even younger), conferring the advantage of gesturing with the homesigner from their birth.

3.1. Participants and method

Six siblings of the four homesigners and the father of Homesigner 1 completed the same homesign comprehension task that Mothers completed in Study 1. Table 1 summarizes each participant's: (1) relation to the homesigner, (2) age at the time of testing, (3) approximate number of years spent interacting with the homesigner (if they are a younger sibling, that value is the same as their age at testing), and (4) age at which they began interacting with the homesigner (for younger siblings, this is the time of their birth, age "zero").

3.2. Results

To determine whether homesigners might co-generate their systems with other family members, we compared the performance of other family members to that of homesigners' mothers. Only Homesigner 4's two siblings performed significantly better than their mother, scoring 71% and 72% correct. The scores of all other relatives did not differ significantly from the homesigners' mothers. All family members in Homesigner 2's family comprehended the homesign system equally well, although Homesigner 2's mother still comprehended the spoken Spanish descriptions significantly better than she comprehended the homesign descriptions.

Three Spearman rank correlations were performed on the comprehension scores of the homesigners' relatives to determine whether the age of the receiver, the length of their interaction with homesigner, or the age of their initial interaction with the homesigner related to their level of homesign comprehension. We found that homesign comprehension decreased with age, such that older communication partners comprehended homesign more poorly than younger communication partners ($r_S(9) = -0.6995$, $p = 0.02$; Fig. 3, upper left panel). Age of initial interaction was significantly correlated with homesign comprehension, such that relatives who were older at the time of their initial interaction with the homesigner showed poorer comprehension of homesign descriptions ($r_S(9) = -0.7325$, $p = 0.01$, Fig. 3, lower center panel). However, crucially, there was no relationship between length of interaction with the homesigner (measured in number of years) and homesign comprehension ($r_S(9) = -0.3624$, $p =$ n.s., Fig. 3, upper right panel).

3.3. Discussion

This task measured family members' comprehension of the actual gestures produced in homesign utterances, without relying on context and/or routines. These results indicate possible maturational effects on the comprehension of homesign: Relatives who were younger at the time of the task performed better than relatives who were older, and those relatives who were younger when they first began interacting with the homesigner comprehended homesign better than individuals who were older when they were first exposed to homesign. Despite the better comprehension by younger relatives and relatives who were younger when they began interacting with the homesigner, no communication partner comprehended homesign *fully*. If these homesign systems were co-generated via communicative interactions with any communication partners, we would expect comprehension levels to be much closer to 100%. This finding is even more striking given the extensive interactions that all family members have had with the homesigners through childhood and well into the homesigners' adulthood. Thus, the results of Study 2 further support our conclusion that successful communicative interactions between homesigners and their family members do not primarily drive the development of homesign structure.

Younger relatives, on average, have more education, which might confer an advantage on the homesign comprehension task. However, in Study 1 we found that all mothers (who span a variety of ages) performed better on the same task when asked to comprehend spoken Spanish descriptions than when comprehending homesign descriptions. This suggests that formal education is not a requirement of the task itself.

One other possibility for communication partners' relatively poor comprehension of homesign is that the homesign productions provided insufficient information to allow their communication partners to succeed. We explore this further in Studies 3 and 4.

4. Study 3

Study 3 reports two additional analyses aimed at ensuring that the homesign descriptions that family members watched in Studies 1 and 2 contained enough information for receivers to respond correctly. For example, if a homesign description of an event in which a man breaks a pencil contained only a 'breaking' gesture, a receiver could not reliably select the picture depicting a man as the agent rather than a foil showing a woman as the agent.

Specifically, we assessed whether homesign descriptions contained gestures expressing key event elements (the entity or entities in the event, and the event itself). If homesign descriptions were incomplete, mothers' poor performance comprehending homesign descriptions is reasonable. If homesigners produced complete descriptions, then family members' poor comprehension

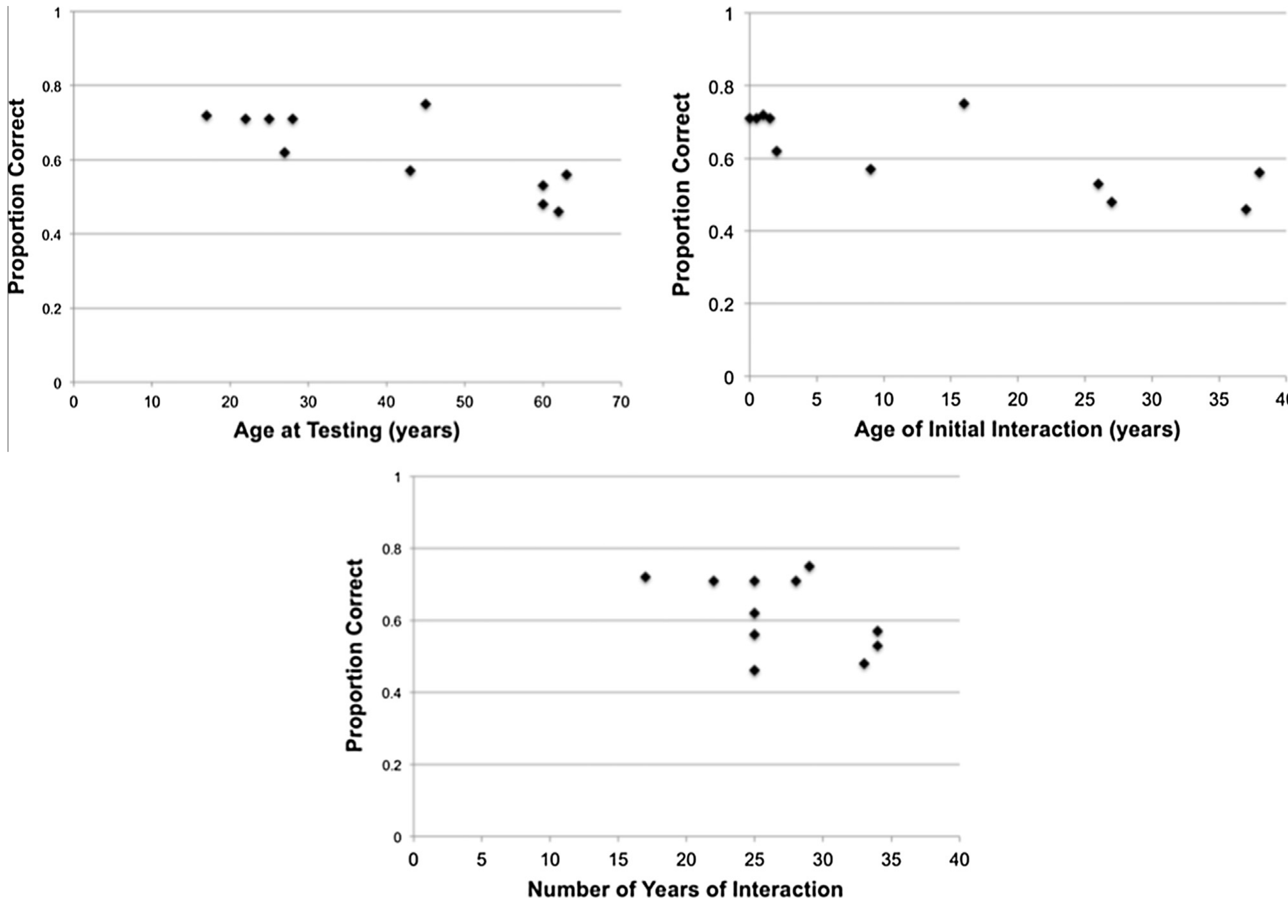

Fig. 3. Performance on the homesign comprehension task of homesigners' relatives by (a) age at testing: Older relatives of homesigners comprehended homesign less well than younger relatives (upper left panel); (b) age of initial interaction with the homesigner: Relatives who were younger when they began interacting with the homesigner comprehended homesign better (upper right panel); (c) length (number of years) of interaction with the homesigner: Relatives who have interacted with the homesigner longer did *not* comprehend homesign better (lower center panel).

cannot be attributed to insufficient/incomplete descriptions, offering further evidence that these homesign systems have developed without relying on successful communication. Note that this is a very simple way of assessing the information content of productions—this coarse measure doesn't take into account various linguistic devices (e.g., word order, use of space, non-manual markings) that indicate relationships between arguments and predicates. The design of the task is such that only 21% of the items (16 2-entity reversible items out of 77 total items) require comprehension of any device linking arguments and predicates. The remaining 61 items can be understood based solely on the referential content. Homesign systems have been shown to use such devices (e.g., word order as a device for expressing argument structure; Coppola & Newport, 2005), but these devices are not necessarily used in all productions, and we do not want to assume *a priori* that mothers are aware of or can make use of these devices. By limiting our coding to the referential content of homesign descriptions, we do not assume that mothers can successfully interpret such devices.

4.1. Coding and analysis

To reduce the potential for over-attributing meaning and structure, the information content of the homesign descriptions was coded by a research assistant who was naïve to the nature of lexical and grammatical structure in sign languages. Recall that the structure of the events is quite simple: Vignettes contained either one or two animate (a man or woman) or inanimate (a ball, a pencil, etc.) entities. We are confident that sign-naïve coders *can* interpret the referential content of homesign descriptions for two reasons. First, as an elicitation task, the set of possible referents of any gesture is limited to the entities and events in the stimulus event. Second, the gestures that homesigners used to represent people, objects, and events tended to resemble their referents, or they were known to the authors from previous work.

4.1.1. Which event elements were expressed?

Each description was coded for whether it contained a gesture for the primary entity, the event, and secondary entity (if applicable). "Complete" descriptions contained gestures for each of these elements; we present our definitions and an example of the coding below. In a vignette with a single entity, such as "A woman cries," the woman is considered the primary entity, and "cry" is the event. In a vignette like "A man breaks a pencil," the man is the primary entity, the pencil is the secondary entity, and "break" is the event. In a vignette like "A man kisses a woman," the man (or agent) is considered the primary entity, the woman (or patient) is considered the secondary entity, and kiss is the event. Entities or events were coded as "Present" in the production if the homesigner produced one or more gestures that uniquely picked out the entities or events in the context of the comprehension array. For example, in a description of the vignette, "A woman hits a pillow," the second entity, "pillow," was considered "Present" because it was described using the gesture string "SLEEP SQUARE" and no object in any of the foils could be picked out by the same gesture string. Entities or events were coded as "Non-present" if there was no gesture produced describing them, or if the gesture(s) describing them did not uniquely pick out the referent in the context of the comprehension array, or depended on context that was difficult to access given the video. For example, a description glossed as "WIPE-NOSE CLOTH" (indicated by pointing at the cloth of the homesigner's own skirt) was considered a "Non-present" description of "handkerchief" because it did not uniquely distinguish the handkerchief depicted in the target from a bandanna in a distractor foil. Some gestures coded as "Non-present" were indexical points or gestures toward people or objects in the homesigner's environment (e.g., one homesigner pressing both hands on the arms of the chair in which he was sitting to mean "Chair" in describing the vignette "A man pushes a chair"). Twenty percent of each homesigner's productions were coded for reliability by the first author (initial reliability was between 85% and 95%), and disagreements were resolved via discussion.

4.1.2. Was it possible to select the correct picture from the description?

We coded the referential content and gesture ordering of each homesign description and evaluated it with respect to the comprehension array. For non-reversible items, selecting the correct picture was coded as 'possible' if the description contained "Sufficient Information" – that is, if it contained at least one explicit gesture was produced for each entity, as well as the event. Additionally, the form of the gestures had to successfully disambiguate the correct picture choice from the three foils. For example, the comprehension array for the item "a man eats a banana and dislikes it" (evidenced by the man's facial expression) contained a foil in which a man is eating a banana with a neutral facial expression. If a homesigner produced MAN EAT BANANA without a negative facial expression, selecting the correct picture would not be possible, and the description would be coded as having "Insufficient Information."

For reversible items, selecting the correct picture entails not only recognizing the referential content of the description, but understanding how arguments and predicates are linked. Therefore, a description was coded as having "Sufficient Information" if the description was complete, and/or the gestures for a single entity and corresponding event were clearly associated. These criteria required that each argument be linked to a unique predicate, and that the gesture for the predicate immediately followed the gesture for the argument to which it related. Such a description for the event "a man hits a woman" could be glossed as: (1) MAN HIT WOMAN GET-HIT, (2) WOMAN GET-HIT, or (3) MAN HIT (the latter two are only coded as having "Sufficient Information" provided there are no foils showing the man hitting a non-target second entity, or the woman getting hit by a non-target primary entity). The description MAN WOMAN HIT (in which one cannot unambiguously assign semantic roles based solely on gesture ordering) would be coded as having "Insufficient Information".[8] Twenty percent of each homesigner's productions were coded for reliability by the first author, with disagreements resolved via discussion, resulting in 100% agreement.

4.2. Results and discussion

Homesigners produced complete descriptions 67–83% of the time, collapsing across all item types. Homesigners always produced at least one explicit gesture expressing the event depicted in each item, and sometimes used multiple predicates. For example, for an event described in English as "A man walks in and wakes up a woman," with the intended target event "wake up," a homesigner might produce a description like MAN WALK WOMAN SLEEP LOOK-UP.

Homesigners almost always produced an explicit gesture for the primary entity in each video vignette. Fig. 4 (left panel) shows the proportion of items in which each homesigner produced a gesture for the primary entity, by Item Type (on average, 84–100% of the time). For 1-entity vignettes (white bars), in which mentioning the primary entity is crucial, all homesigners produced a gesture for the primary entity 94–100% of the time.

Fig. 4 (right panel) shows the proportion of items in which each homesigner produced a gesture for the secondary entity, by Item Type. Homesigners never produced a gesture describing a second entity (which did not exist) in 1-entity vignettes. For 2-entity non-reversible events (grey bars), homesigners produced an explicit gesture for the second entity between 59% and 85% of the time. However, only 6 of the 34 items (18%) of this type contained a foil that depicted a non-target secondary entity. Thus, homesigners produced gestures for the secondary entity much more often than was strictly required.

For 2-entity reversible events, homesigners mentioned the second entity between 75 and 100% of the time (black bars). Six of the 16 items (37.5%) had foils in which the target primary entity performed the target action with a non-target secondary entity. Homesigners produced an explicit gesture for the secondary entity much more often than 38% of the time, which suggests that their descriptions were, at least in content, as complete as they needed to be given the communicative goal of the task.

Generally speaking, homesigners' descriptions of the vignettes were complete. They always produced an explicit gesture describing the event in each vignette, and although they occasionally did not produce explicit gestures for the entities involved in each vignette, their descriptions overall were not significantly lacking information. Recall that comprehension of 2-entity reversible events depends not only on whether all elements of the vignette are described, but also on their relationship. We therefore also coded whether it was possible to select the correct picture, based on the content of the homesigner's description presented here, and the nature of the comprehension foils.

For all homesigner's descriptions, and across all item types, we determined that it was possible to select the correct picture based on the description having "Sufficient Information" between 50% and 94% of the time. Descriptions of one-entity items were more likely to have "Sufficient Information" and were coded as such 82–94% of the time (Fig. 5, white bars). Descriptions of two-entity non-reversible items were coded as having "Sufficient Information" 56–76% of the time (Fig. 5, grey bars), and descriptions of two-entity reversible items were coded as having "Sufficient Information" approximately 50–81% of the time (Fig. 5, black bars).

The Study 3 results make clear that homesign descriptions often did contain enough information for the receivers in Studies 1 and 2 to respond correctly, and thus to have shown higher overall comprehension levels than they did. In Study 4 we determined whether our assessment of a production having "Sufficient Information" in fact allowed correct picture choice for any live receiver performing the task—that is, whether the gestures were in fact communicative. Although homesigners' family members comprehended homesign descriptions relatively poorly, given that the descriptions generally contained the required information, perhaps another receiver would be able to succeed. To measure whether the homesign descriptions were in fact communicative, in Study 4 we compared homesigners' mothers comprehension of the homesigners' descriptions to that of native users of American Sign Language who did not

[8] It might be possible to assign semantic roles to each gesture if the homesigner produced a standard gesture ordering pattern (i.e. if the homesigner had a word order rule). However, we did not assume *a priori* that any homesign employed such a rule, nor did we assume that any receiver would be able to recognize/interpret such a rule. Thus, a coding of this production as containing "Insufficient Information" is extremely conservative, and in fact gives works in favor of receivers (by setting the bar for 'potential comprehensibility of homesign productions' lower than it might actually be).

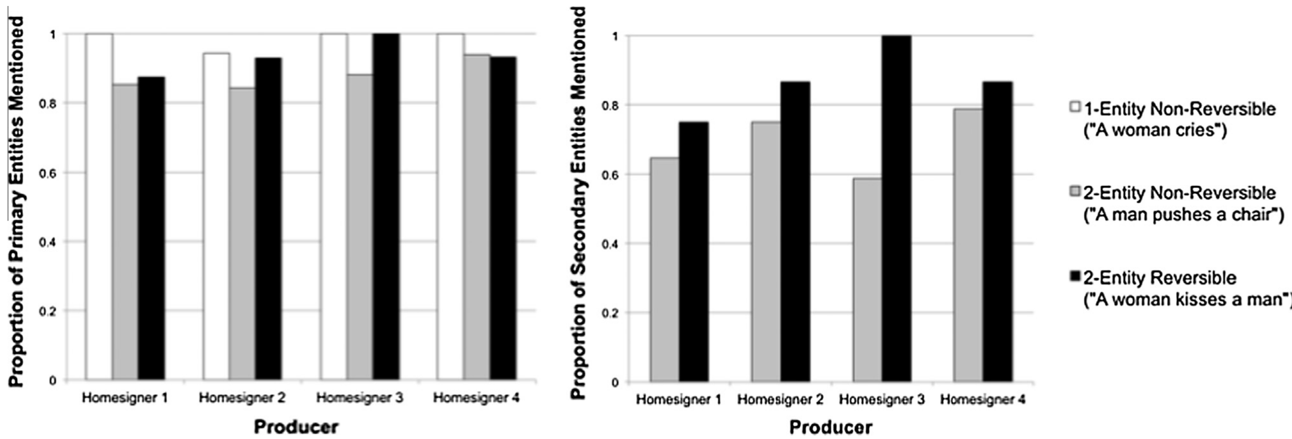

Fig. 4. Left, Proportion of productions in which the primary entity was explicitly mentioned, by Item Type. Right, Proportion of productions in which the secondary entity was explicitly mentioned, by Item Type.

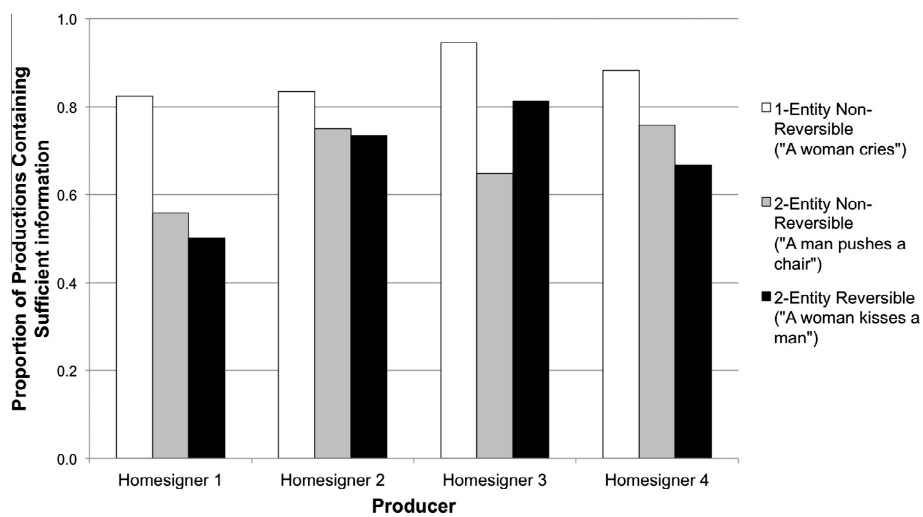

Fig. 5. Proportion of homesign descriptions containing sufficient information for receivers to select the correct picture from the comprehension array, by Item Type.

know any of the homesigners or their respective homesign systems. We also compared our "Sufficient Information" measure to the actual comprehension performance of these two groups.

5. Study 4

Here we asked whether the homesign descriptions we assessed in Study 3 contained a communicative message that could be comprehended in real time by any receiver. We wanted to: (1) determine whether a naïve receiver with less experience with the particular homesign productions used in this task than the authors or the coders could nevertheless process and comprehend the productions in real time, and (2) compare this comprehension to that of homesigners' mothers.[9]

To this end, we asked native users of American Sign Language (ASL signers) to watch homesign descriptions and perform the same comprehension task mothers performed. ASL signers have experience perceiving and using a visual communication system, like the mothers of the homesigners, but would not be expected to know *a priori* the lexical items or the grammatical structures in the four homesign systems under study.[10] Sign languages in different countries are not mutually intelligible (Sandler & Lillo-Martin, 2006), and each of these homesign systems was developed in unique circumstances, without significant influence from any natural sign language (increasing the likelihood that they will be different from one another, and different from ASL). If ASL signers comprehend homesigner descriptions more poorly than or to the same degree as homesigners' mothers, perhaps those productions are not comprehensible to any receiver. If, however, ASL signers comprehend homesign descriptions better than homesigners' mothers, the descriptions do contain enough information for a live receiver to succeed at the task.

5.1. Participants and method

The participants were four fluent Deaf users of ASL (3 females), ages 23–62 years (M = 38), who did not know the homesigners or their homesign systems. All had been exposed to ASL before the age of five, used ASL every day, and had an average of 15.25 years of education. They also knew and used written English to varying

[9] We selected mothers as the comparison group, even though they were not always the best comprehender within a family group, in order to maintain consistency in the role of the communication partner with respect to the homesigner – each family group contained a mother.

[10] Other differences exist between ASL signers and Mothers, which are examined further in the General Discussion.

degrees daily and were functionally bilingual (as is common for most ASL signers). Each ASL signer was randomly matched with one homesigner's mother; that ASL signer watched the same homesigner's productions as did the mother, and chose, from the same picture array, the photo that matched each description. The task was videotaped, and each choice was coded.

Unlike homesigners' mothers, the ASL signers saw all six practice items at the start of the task (mothers completed three practice items at the beginning of each of the two subtests). We did this to ensure that they had learned the homesigner's lexical items for "Man" and "Woman" (as the practice items all involved the man and/or the woman[11]). ASL signers were, like mothers, allowed to watch each description as many times as they wanted (though they watched most descriptions only once). ASL signers and mothers thus had equal exposure to the homesign productions (although each mother still had vastly more experience with her deaf child's homesign system, and with the video stimuli homesigners described, than did the ASL signers).[12]

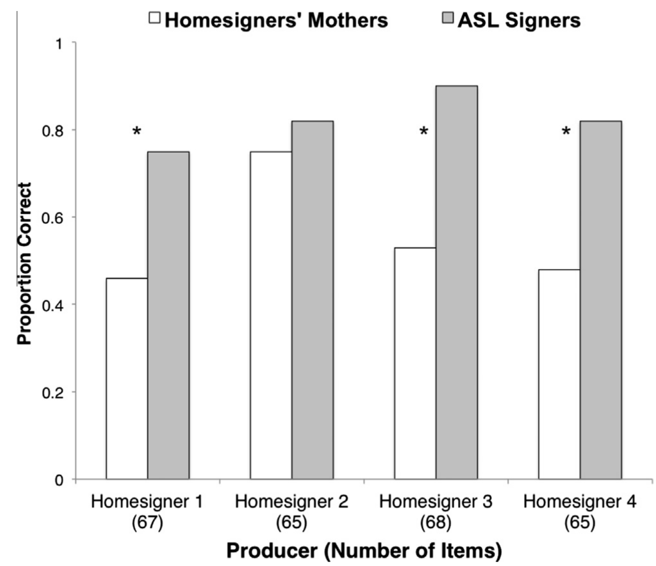

Fig. 6. Comprehension of homesign descriptions by homesigners' mothers and ASL signers. ASL signers comprehended homesign descriptions better than homesigners' mothers ($^{*}p < 0.01$, McNemar Test for Correlated Proportions).

5.2. Results and discussion

Like homesigners' mothers, ASL signers comprehended homesign descriptions at rates significantly better than chance (25%; exact Binomial test, $p < 0.0001$). Furthermore, each ASL signer comprehended the homesign descriptions they viewed better than that homesigner's mother did, and this difference reached significance for 3 of the 4 ASL signer-mother pairs (Fig. 6). This suggests that the homesign descriptions *did* contain sufficient information to allow a receiver to successfully complete the task, and that mothers did not succeed for other reasons.

Note that ASL signers did not score at ceiling on this task—this is understandable, given that the homesign systems are *not* related to American Sign Language, and ASL signers had no previous experience with the homesign system they viewed. It is however surprising that given this lack of experience, ASL signers still comprehended homesign descriptions better than homesigners' own mothers, who had significant experience using the system via extensive interactions with the homesigners.

In Study 3 we measured the information content of a homesign description to determine whether it was possible to select the correct picture. Considering only items for which it should have been possible to respond correctly, ASL signers selected the correct picture 82–100% of the time overall. Mothers, in contrast, only selected the correct picture 18–80% of the time (Fig. 7).

We conducted a logistic regression to predict the likelihood of selecting the correct picture using two factors: (1) Type of Receiver (ASL signers, mothers, and other communication partners) and (2) Sufficient Information (yes/no). The model showed that ASL signers were significantly more likely to select the correct picture when the homesign description contained sufficient information (Table 2). Furthermore, mothers and other communication partners were both significantly *less* likely than ASL signers to respond correctly when the homesign description contained sufficient information.

These results indicate that even when homesign descriptions contained enough information to select the correct picture, mothers often could not do this. This suggests a serious breakdown in communication between homesigners and their mothers, which supports our conclusions from Study 1 that mothers do not share their deaf child's homesign system, and that successful communication between parents and children is not crucially necessary in the development of a language system.

ASL signers and mothers differ in many ways, which will be discussed further in the General Discussion. However, one of the ways in which they differ—namely, the use of a visual language from an early age—might explain mothers' poor comprehension relative to ASL signers. Poor comprehension of the 2-Entity Reversible descriptions indicates that mothers do not understand how homesign descriptions link gestures for entities and actions. Furthermore, mothers' poor comprehension of 1-Entity Non-Reversible descriptions seems to suggest that they do not understand homesigners' gestures for the entities themselves. This is unlikely, however, because (a) these are fairly standard gestures for the homesigners (they use the same gestures to mean "man" and "woman" for all items necessitating mention of these participants); (b) mothers used some of the same gestures when *they* described these events in gesture on other occasions; (c) and mothers do show some understanding of the gestures (by picking the correct picture on other items in which the man or woman is the target participant). We suggest that, instead, mothers may encounter more difficulty processing the homesign gestures in real time than do ASL signers. This is likely because mothers began using homesign as adults, and have had less cumulative experience using and perceiving visual language than ASL signers (see Study 2). Despite having lived and communicated with their deaf child for a minimum of 25 years, mothers do not depend on the homesign system as a primary means of communication; they only use the visual system to communicate with their deaf child, and do not frequently have extended conversations in the visual/gestural modality.

The fact that ASL signers comprehended homesign descriptions to a greater degree than homesigners' mothers tells us that homesign descriptions contained structured, comprehensible information. Mothers' inability to understand or process these descriptions confirms that their communicative interactions with their deaf child cannot be entirely responsible for the development of structure in homesign.

[11] We made this decision based on observations in previous experiments and informal settings that each homesigner's mother used and/or understood their deaf child's gestures for man and woman. The results of item analyses on Mothers' errors seemed to indicate that Mothers sometimes did *not* understand these gestures, or were unable to process them in real time—see Section 6.2.1 in the General Discussion for our explanation of this finding.

[12] Homesigner 3's Mother had in fact been the original live receiver/comprehender for the homesign productions clipped for this task when Homesigner 3 first produced them in 2002, and so had seen approximately the same productions twice. Her comprehension did not significantly change from 2002 to 2011, when she completed the comprehension task for the second time.

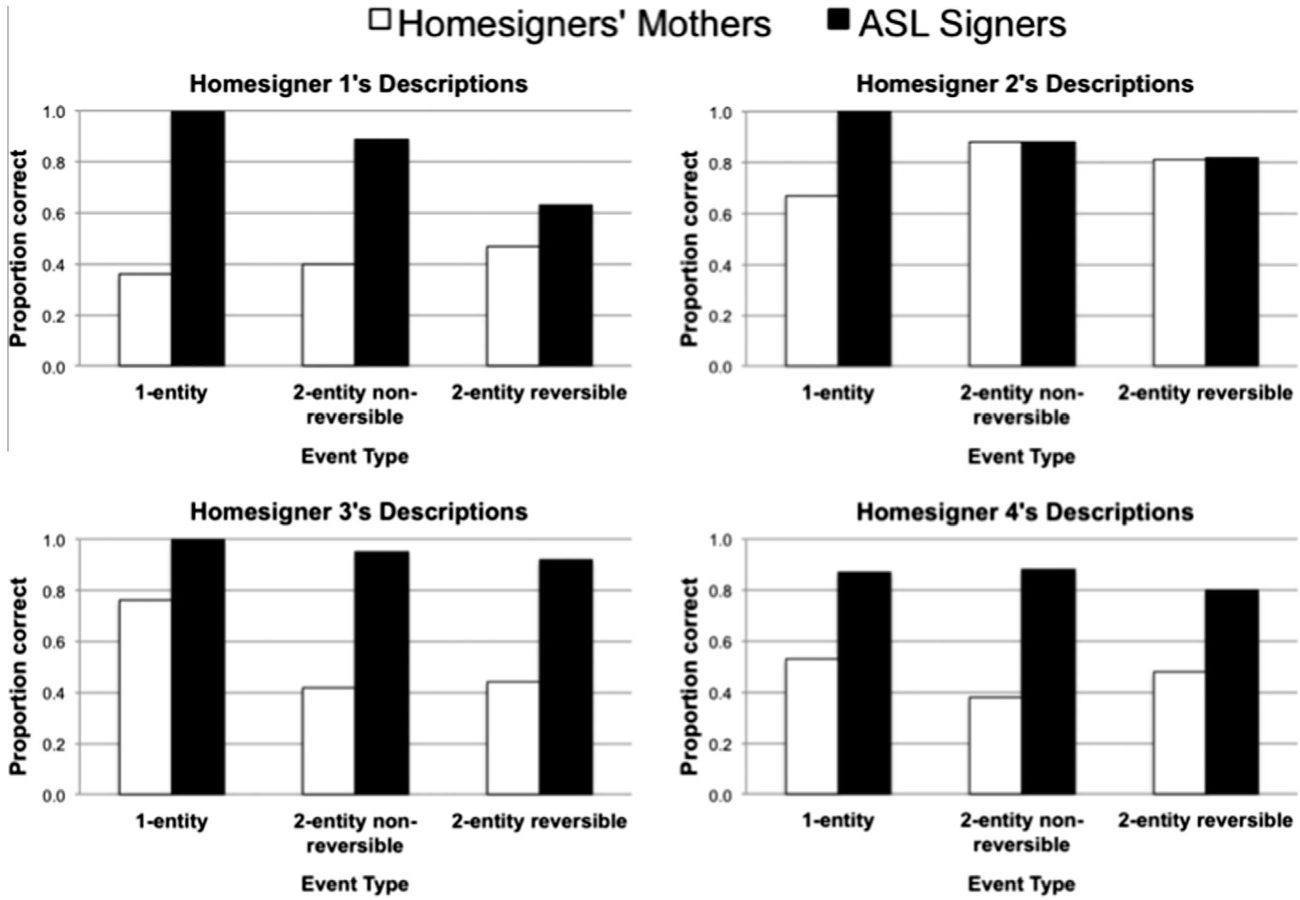

Fig. 7. Proportion of correct responses when homesign descriptions contain sufficient information. Every ASL signer (black bars) comprehended homesign descriptions as well as or better than that homesigner's mother (white bars) for all item types.

Table 2
Results of the logistic regression predicting the likelihood of selecting the correct picture based on the type of receiver and the information content of homesign descriptions. ASL signers are the reference group.

	Coefficient	Std. Error	*p*-value	Odds ratio
ASL Signers (Reference)				
Mother	−0.2269	−0.3372	n.s.	0.797
Other Relative	−0.4252	0.2983	n.s.	−0.654
Sufficient Info	1.8207	0.3407	<0.001	6.176
Mother × Sufficient Info	−1.7483	−0.4394	<0.001	0.174
Other Relative × Sufficient Info	−0.8223	−0.4029	<0.05	0.439

6. General discussion

In the studies reported here, we have assessed whether approximately twenty years' worth of communicative problem solving interactions drive the development of the linguistic structure present in four independently-generated family-based homesign gesture systems. Constructivist perspectives on language development emphasize the importance of communication between language models and language learners (e.g., Tomasello, 2008). If the development of linguistic structure in homesign systems is driven by the goal of achieving successful communication, homesigners' communication partner should understand homesign productions. Our results indicate that *successful communication between homesigners and their communication partners is not a primary driving force in the emergence of homesign structure*.

Despite engaging in daily gestural interactions for an average of 20 years prior to our testing, mothers comprehended homesign productions extremely poorly. In Study 1, we did not observe successful communication based on the linguistic signal alone between mothers and homesigners (as measured by mothers' comprehension of decontextualized homesign descriptions). The communicative problem solving interactions homesigners have engaged in with their mothers during their lives have not resulted in successful communication, but the different homesign systems under study nevertheless do contain linguistic structure.

Study 2 found that both age at testing and the age at which a communication partner began interacting with their deaf relative related to comprehension. Younger communication partners performed better than older communication partners on the homesign comprehension task, and those communication partners who were younger when they began interacting with their deaf relative comprehended homesign better than those communication partners who were older when they began interacting with their deaf relative. Despite this, no communication partner showed complete comprehension of homesign descriptions of simple events. This further indicates that, although homesign comprehension improves with earlier exposure to homesign, the development of homesign structure does not result primarily from successful communicative interactions between homesigners and any of their relatives.

Studies 3 and 4 demonstrated that the poor comprehension of communication partners is not due to insufficient information in the homesign descriptions. An analysis of the content of homesign descriptions showed that these descriptions were generally complete (Study 3), and that naïve receivers—ASL signers—*could* comprehend these descriptions to a greater degree than did homesigners' mothers (Study 4). We conclude that the homesign descriptions *do* contain comprehensible, structured information, to which mothers are not fully sensitive. Furthermore, none of the communication partners with relatively high homesign comprehension scores performed significantly better than the ASL signer who watched the same homesign productions. If the system were co-generated by homesigners and any of their family members via communicative interactions, family members should have performed better than strangers who had extremely minimal experience with the homesign system. Note that ASL signers' relatively high comprehension does *not* signify that the homesign systems studied here are entirely transparent—if that were the case, all homesign communication partners should have performed at higher levels than we observed.

As previously mentioned, the homesign comprehension task is *intentionally decontextualized* because we want to know what message is being conveyed by the gestures themselves. Recall that according to constructivist theories, children's linguistic representations increasingly abstract away from the context in which they are acquired (e.g. Ambridge & Lieven, 2011). Thus, once children have abstract linguistic structures, *those structures ought to be interpretable to other mature users of the language even in a decontextualized situation* like the task used in the present studies. The fact that mothers comprehended spoken Spanish descriptions at higher rates than they comprehended homesign utterances (Study 1) provides evidence that this was possible for mothers to some extent. Furthermore, the results of Studies 3 and 4 indicated that there *is* information in the homesign descriptions themselves—it was simply not fully accessible to homesigners' relatives.

6.1. Structure in homesign productions

Although we do not present an analysis of the structure in the homesign productions used in the present studies, we are confident such structure exists. A number of prior studies have demonstrated a range of linguistic structures in the homesign systems of the *same four homesigners* who produced the homesign descriptions used here.[13] These include: the grammatical relation of Subject (Coppola & Newport, 2005); a systematic distinction between arguments and predicates (Goldin-Meadow, Brentari, Coppola, Horton, & Senghas, 2015); proto-pronouns (Coppola & Senghas, 2010); plural morphology that is incorporated into homesign syntax (Coppola et al., 2013); and morphophonological patterns in handshape like those of established sign languages (Coppola & Brentari, 2014 (child homesigner); Brentari et al., 2012; Brentari, Coppola, Cho, & Senghas, in press) (adult homesigners). In particular, the productions analyzed in Coppola and Newport (2005) constitute 62.3% of the actual homesign productions included in the current studies. Given that these homesign descriptions were elicited using the same methodology as the data described above, it is reasonable to conclude that these descriptions exhibit similarly linguistic structure. The ability of ASL signers to comprehend the homesign utterances in Study 4 also constitutes independent evidence of their systematicity.

[13] In fact, our results do not hinge on demonstrating structure in these particular productions.

The evidence for language structure in adult homesign systems accords with a significant body of research characterizing the language-like properties of child homesign systems. Likewise, the current results with adult homesign systems corroborate earlier findings with child homesign systems demonstrating a gap between the knowledge and/or use of the homesign system by the homesigners themselves and the hearing people they interact with (e.g., Goldin-Meadow & Mylander, 1983, 1984; Goldin-Meadow, Mylander, & Franklin, 2007; Morford & Goldin-Meadow, 1997). The fact that homesign structure exists despite poor comprehension by communication partners means that the structure in homesign does not develop so that homesigners can be understood by their communication partners.

6.2. Factors affecting homesign comprehension

6.2.1. Why do communication partners perform poorly?

No communication partner showed complete comprehension of the homesign descriptions produced by their deaf relative. Even the mother who showed the highest rate of homesign comprehension nevertheless showed significantly higher comprehension of the same descriptions when produced in spoken Spanish. The mothers' difficulty comprehending the descriptions of even one-entity events—the events with the fewest demands: the least amount of content, as well as the simplest relationship between the elements (i.e., the entity and the predicate)—strongly suggests that mothers do not share the homesign system in its truest form (that is, when it is produced without significant contextual support, numerous repetitions, etc.).

Observational and experimental evidence reveals homesigners' awareness that their productions are not well understood, and provides ecological validity of the generally poor comprehension of decontextualized homesign productions shown by the communication partners in the current work. For example, in typical conversations, homesigners often repeat information or express the same information in slightly different ways. Furthermore, experimental evidence has found that homesigners were more consistent in the handshapes they used to label an object the first time they described it relative to subsequent productions (Goldin-Meadow et al., 2015). This suggests that communication partners' poor comprehension decreases homesigners' internal consistency across a task. This is not to say that homesign productions lose their structure, but they may become simpler in order to accommodate their interlocutor.

We propose that communication partners have difficulty processing homesign descriptions in real time. This hypothesis accounts both for the generally poor comprehension of homesign, and for the finding that communication partners who began interacting with their deaf relative at an earlier age showed better comprehension of homesign than those who began interacting with the homesigner at a later age. Our proposal accords broadly with work showing critical period effects on language acquisition (e.g. Newport, 1990). More specific to the present work, Mayberry and Eichen (1991) found that the later signers were exposed to American Sign Language (ASL), the more poorly they performed on a sentence recall task. They conclude that age of exposure to a sign language affects deaf individuals' ability to perceive and reproduce phonological, lexical, and grammatical elements of signed sentences. More recently, Morford, Grieve-Smith, MacFarlane, Staley, and Waters (2008) argued that the timing of exposure to a sign language leads to different allocation of attentional resources during the perception of signing. These data further support our argument that communication partners—and especially mothers and other older relatives—are learners of their deaf child's homesign system rather than active contributors to its creation.

6.2.2. Why do ASL signers perform relatively well?

The Deaf native users of American Sign Language comprehended homesign as well as the best communication partners, and better than each homesigner's mother. Here we discuss the characteristics of ASL signers that might explain their surprisingly good comprehension of systems with which they had extremely limited experience. ASL signers differ from the homesigners' family members in a number of respects: they have had more formal education, more experience using a visual language, and may have more familiarity with this type of task. It is certainly possible that increased familiarity with the type of task might have facilitated ASL signers' performance in this task, but it is difficult to see how having more formal education would improve performance. The results of Study 2 and the data referenced in the previous paragraph support the notion that ASL Signers' experience using a visual language—both from a younger age and with a greater number of signers than homesigners' relatives—likely helped them perform well in the task. ASL signers are also likely more used to perceiving videotaped signing, given their increased access to technology relative to the families with whom we work in Nicaragua.

It might be argued that ASL signers performed as well as they did because of their lifelong experience interacting with individuals who do not sign, making them more skilled at inferring meaning from non-linguistic gestures.[14] However, three pieces of evidence argue against this possibility. First, native-signing deaf individuals possess equivalent (not superior) "mind-reading" abilities as hearing individuals (O'Reilly, Peterson, & Wellman, 2014). Second, in the kind of "mind-reading" process described above, ASL signers would be relying heavily on context to infer meaning. Because the stimulus events used in the present studies are decontextualized, and no stimulus event/participant role is inherently more likely than another, the experimental context does not support an advantage for ASL signers in comprehending homesign descriptions in this task. Finally, if the structure in homesign were a product of communicative problem solving between homesigners and their communication partners, *any* advantage ASL signers possess in deciphering homesign communication ought to be outweighed by communication partners' years of experience with the homesigner and their system.

6.2.3. Does reduced common ground cause poor comprehension?

For methodological reasons, we used videotaped productions to ensure that receivers saw exactly the same homesign descriptions (so differences in comprehension would *not* be attributable to differences in the specific production a receiver viewed). Perhaps by eliminating the possibility of interaction in the comprehension task (e.g., 'participatory sense-making,' De Jaegher & Di Paolo, 2007), our methodology prevented mothers from accessing common ground with the homesigner, which in turn impaired their performance. However, the events being described in the task are intentionally independent, unrelated, and decontextualized. We thus intended for there to be very little accessible common ground in the task generally, as we wanted to measure communication partners' comprehension of the linguistic signal alone. If the system were co-generated via interactions between homesigners and their relatives, relatives should have been able to complete the task without having to rely on context or common ground.

Furthermore, to the extent that common ground *is* less accessible in videotaped versus live descriptions, this factor should have equally affected ASL signers' performance. In fact, a lack of common ground should have had a greater impact on ASL signers' performance, as they did not have the years of experience interacting with the homesigner (from which mothers might possibly infer common ground). ASL signers' better performance despite their increased inability to access common ground (relative to mothers) indicates that this factor likely did not play a significant role in comprehension of videotaped homesign descriptions. Additionally, Homesigner 3's mother was the original receiver for the descriptions we used in this task when the homesigner produced them live in 2002; she comprehended these descriptions equally poorly in both the live and videotaped formats. Taken together, these points support our conclusion that lack of common ground cannot explain mothers' poorer comprehension of homesign descriptions in these studies.

6.2.4. Does the limited expressive capacity of homesign cause poor comprehension?

It might be the case that communication partners demonstrated limited or outright poor comprehension of homesign because the homesign systems themselves are limited in their expressive power. Our own interactions with the homesigners and their family members suggest that it is certainly difficult for them to communicate successfully about many things. However, the results of Study 3 showing that the homesign descriptions are generally complete suggest that any limitations on their systems do not extend down to expressing these types of simple events. Homesigners' descriptions of the simple events are generally complete and efficiently expressed (that is, without a great deal of extraneous information within a single utterance).

Although homesign descriptions of simple events are generally complete, it might nevertheless be the case that they are limited in their communicative effectiveness. In Study 4, we attempted to measure the communicative effectiveness of homesign descriptions by asking naïve receivers (ASL signers) to comprehend them. ASL signers did comprehend homesign descriptions surprisingly well given that their limited experience with the systems. However, as discussed above, ASL signers may possess certain characteristics that conferred an advantage in their comprehension of homesign descriptions relative to their mothers and other communication partners. The notion that homesign is not as communicatively effective as a full language might explain why even the best communication partners did not *fully* comprehend homesign descriptions.

However, this possibility does not undermine the broader conclusions we make in this paper. Our results showing that the homesign systems themselves do not support communication between homesigners and their relatives do not challenge the results of previous research showing that such systems have many elements of linguistic structure (see Introduction). If, in fact, homesign is somehow less effective than established languages at transmitting messages, this further supports our claim that communicative problem solving has not led to the structure present in homesign systems.

6.3. Implications for constructivist theories of language development

The focus of this study is assessing the role of communication in developing a shared language system. The research presented here indicates that, even when social interaction is present, successful communication between a language learner and ostensible language models is not guaranteed. Nevertheless, the deaf individuals who participated in this work did each develop and use a system of manual gestures (homesign) to express themselves, which contain many of the features of established languages (again, see introduction for a partial list of linguistic devices in homesign). Thus, contrary to claims of constructivist and other accounts of language development (e.g. Bates & MacWhinney, 1982; Everett, 2015; Goldberg, 2006; Tomasello, 2000, 2007, 2009) linguistic structure can and does emerge even in the absence of successful communication.

[14] We thank a reviewer for raising this possibility.

These data argue against one of the central claims of some constructivist accounts of language development. Namely, that communicative problem solving drives the development of linguistic structures in learners; or, put another way, that such linguistic structure develops in order to facilitate communication. In the case of the genesis of homesign, this cannot be true: there are no existing target structures for the learner (the homesigner) to acquire, and homesign is nevertheless linguistically structured despite the lack of successful communication between homesigners and their family members.

We acknowledge that *engaging* in communicative problem solving, even if it is unsuccessful, is likely important for the development of homesign structure. Indeed, sociocommunicative interaction with others may be necessary for a homesign system to develop. For instance, Ferjan Ramirez et al. (2013) reported on three deaf adolescents who did not appear to have developed homesign systems like those used by the homesigners whose systems are examined here, perhaps as a result of not experiencing regular social engagement.

However, we argue that communicative problem solving cannot be the *source of the structure itself,* as strong functionalist or usage-based perspectives suggest. If linguistic structure in homesign emerged as a result of communicative problem solving between homesigners and their relatives, that structure should be comprehensible to the individuals who participated in the process. Our data show, in contrast, that none of the homesigners' relatives—the primary individuals who have engaged homesigners in communicative problem solving—comprehend homesign fully. It is especially striking that the ASL signers who participated in our task, who have never met the homesigner, comprehend homesign at least as well as homesigners' siblings, and significantly better than homesigners' mothers. The finding that homesign is comprehensible to someone who has never engaged in communicative problem solving with the homesigner further underscores our conclusion that homesign structure does not emerge from the process of communicative problem solving.

The conclusions of this work do not depend on homesign being *fully* comprehensible to any party (including the homesigners themselves). Homesign structure may reflect the way homesigners cognitively organize the world when trying to communicate about it (e.g. Goldin-Meadow, So, Özyürek, & Mylander, 2008; Hall, Ahn, Mayberry, & Ferreira, 2015). This would not require that either homesigners or communication partners recognize that structure. Our data specifically show that homesign structure has not emerged in order to facilitate communication with homesigners' communication partners.

Reviewing behavioral and neurophysiological evidence, Willems and Varley (2010) conclude that language and communication are served by neurally distinct systems. They take this as evidence against the proposal that some communication depends on language. The present work further supports the distinction between communication and language, and indicates that some aspects of language do not depend on communication. We find that linguistic structure exists in homesign systems despite poor communication between homesigners and their primary communication partners.

One might point out that although some linguistic structure develops, homesign systems do *not* resemble fully established languages in all respects, and perhaps, then, the lack of successful communication explains why homesign systems do not develop into "full" languages. This point does not constitute a counter-argument to the position taken in the current paper. It is certainly possible that a lack of successful communication between homesigners and their frequent communication partners (family members) is one reason why homesign systems do not develop further than they do (suggested, e.g., by Hoff, 2006). However, the fact that any linguistic features can develop in the absence of successful communicative interactions means that such communicative interaction cannot be the sole or primary factor necessary for language development.

In her 2006 review of a large body of research assessing the role of the social environment in language acquisition, Hoff concludes that social interaction can be divided into two types: communicative interaction, which serves as a "catalyst" for the language development process; and nonlinguistic "communicative understandings" (p. 78), which provide children with access to the structure in the linguistic model. The present work supports Hoff's claim that communicative interaction is a "catalyst" for language development. Taken together with other work on language emergence, our data indicate that communicative problem solving is a motivational force in the development of structure, but it is not the mechanism by which that structure is created. The current work enlarges the discourse regarding the factors that support language development. We further elucidate how the social context contributes to this process, noting that successful communication is neither necessary for nor sufficient to explain language development.

7. Conclusions

These data are unique: no other research has systematically assessed the degree to which adult homesign utterances are understood by homesigners' family members. Our extensive informal observations of homesigners interacting with their family members over the last 20 years accord well with the experimental data presented here: miscommunications occur frequently, especially when discussing events beyond the here and now, or events that particular interlocutors have not themselves experienced. This in turn suggests that communication partners' performance on our comprehension task is representative of communication between homesigners and their relatives in daily life. Taking these observations together with the reported experimental findings, we argue that a large proportion of the successful communication that takes place between homesigners and their family members relies on reference to objects that are present, routines that are observable or experienced in common, and knowledge of shared experiences.

Our results indicate that the role of communication in constructivist accounts of language acquisition and language emergence should be significantly de-emphasized. Such theories place too much importance on social interaction (via communicative problem solving) as the primary mechanism of language development, taking for granted both the presence of a linguistic model, and the notion that successful communication (using that linguistic model) is eventually achieved between the learner and the model. Taken together with previous work on homesign systems, the data presented here reinforce the idea that linguistic devices can develop in the absence of a linguistic model, and crucially, that successful communication is not necessary for their development. Chomsky (1965) wrote that communication "may be required to set the language-acquisition device into operation," but "may not affect the manner of its functioning in the least" (p. 33). We find that although communicative *engagement* may be necessary to support the emergence of linguistic systems, communicative *success* is not in itself sufficient to explain their structure.

The notion that successful communication alone cannot fully explain the development of language need not lead us to a strongly nativist account of language acquisition that posits innate knowledge of grammatical categories and/or syntactic structures. Indeed, even studies of homesign and emerging languages, arguably the most extreme cases of the emergence of linguistic structure in the absence of linguistic input, have thus far failed to reveal the precise source of language structure. Namely, we still do not know whether such structures are themselves innate (as in Valian

(2014)'s first component) or whether they result from learning mechanisms that are biased to produce linguistic structure (as in Valian's third component) (e.g., Senghas & Coppola, 2001). The results presented in this paper clearly point to a very prominent role in language development for both biology and social interaction, though neither of these alone adequately explains the course of language development. Our findings are compatible with theories of language development in which features of language (in both typical acquisition cases and in the larger case of language evolution/emergence) emerge partly as a result of experience (communicative attempts, or input from others) and partly as a result of learner-internal constraints or biases (which explains why we see convergence across languages, as well as across typical and atypical language development contexts).

The present research cannot elucidate the relative contributions of learner-internal and learner-external factors to the process of language development. These data provide significant evidence against a constructivist account of language development that depends heavily on successful communicative interactions as a mechanism of language development. However, the data are compatible with accounts that include a less primary role for communicative interactions. The present work suggests that learner-internal factors (i.e., any innate content and mechanisms), the natures of which have yet to be fully specified, are at the heart of language development. Such learner-internal mechanisms likely require communicative engagement to operate, but the structure that develops does not require access to a structured linguistic model, nor is it driven by communicative problem solving, or the desire to achieve communicative success.

A comprehensive description regarding precisely how the language development process unfolds is still needed. Future research on spontaneous cases of language emergence (e.g., homesign, and village or emerging sign languages) should be paired with experimental work (e.g., gesture creation paradigms and computational modeling) to address questions such as: What kind of input is necessary for any language structure to emerge? How do learner-internal mechanisms transform non-linguistic input into linguistic devices? and What sorts of social structures and communicative interactions are necessary to support this process?

For example, it is important to separate the effects of vertical (older-to-younger cohort) and horizontal (peer-to-peer) interactions on language genesis (Senghas, Senghas, & Pyers, 2005). Recent and ongoing work addresses these questions using a variety of methodologies. Gagne, Senghas, and Coppola (in preparation) compared children of first-cohort users of Nicaraguan Sign Language to second-cohort users of the language. Unlike a group of second-cohort users of Nicaraguan Sign Language, who regularized the inconsistent productions of first cohort users of the language, individual children of the first cohort do not regularize inconsistent productions of their parents. Computational modeling work paired with naturalistic data collected from adult homesigners and their families indicates that the structure of a group—who communicates with who—affects the speed of conventionalization of vocabulary (Richie, Yang, & Coppola, 2014). Work is currently underway examining whether child learners are in fact necessary to the genesis of certain linguistic structures. Using methodology that draws from experimental semiotics and gesture creation paradigms, we ask whether spatial agreement systems can be innovated by a single "generation" of interacting, hearing adults (e.g. Carrigan & Coppola, in preparation; Carrigan, Coppola, & Tabor, 2014). As urged by Newport (2011), researchers going forward must reach across theoretical divides and draw from a range of perspectives to uncover the true nature of language development.

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Appendix A. Items by number of entities and reversibility

Number of Entities	Reversible?	Description	Subtest
1	N	A woman faints	A*
1	N	A woman faints	B*
1	N	A man faints	A
1	N	A woman is happy	A
1	N	A piece of paper burns	A
1	N	A man stands up	A
1	N	A cup is blue	A
1	N	A man is hurt	A
1	N	A rug flaps	A
1	N	A woman cries	A
1	N	A woman falls	A
1	N	A woman sneezes	B
1	N	A man is afraid	B
1	N	A woman limps	B
1	N	A piece of paper falls	B
1	N	A woman runs	B
1	N	A woman is angry	B
1	N	A woman is sad	B

(continued on next page)

Appendix A (*continued*)

Number of Entities	Reversible?	Description	Subtest
1	N	A man yells	B
1	N	A man sleeps	B
2	N	A woman breaks an egg	A*
2	N	A woman breaks an egg	B*
2	N	A woman sits in a chair	A
2	N	A candle is in a bowl of water	A
2	N	A man pushes a chair	A
2	N	A woman breaks a pencil	A
2	N	A man is a cowboy	A
2	N	A rug is on the floor	A
2	N	A gift surprises a man	A
2	N	A man smells some shoes	A
2	N	A woman loses her sunglasses	A
2	N	A woman likes some flowers	A
2	N	A woman is a teacher	A
2	N	A man misses a ball	A
2	N	A man eats a banana	A
2	N	A woman drops a ball	A
2	N	A woman fears a spider	A
2	N	A woman talks on the phone	A
2	N	A woman loses a bracelet	B
2	N	A man sits in a spotlight	B
2	N	Carrying a suitcase makes a man tired	B
2	N	A man is a doctor	B
2	N	A man throws a ball	B
2	N	A cup is in the spotlight	B
2	N	A man loses some keys	B
2	N	A woman hits a pillow	B
2	N	A flower is in a bowl of water	B
2	N	A woman stands in the corner	B
2	N	A mask frightens a woman	B
2	N	A man loses a handkerchief	B
2	N	A man smells some flowers	B
2	N	A man dislikes a banana	B
2	N	A ball is in the corner	B
2	N	A woman sees a mask	B
2	N	A man is a farmer	B
2	Y	A man hits a woman	A*
2	Y	A man hits woman	B*
2	Y	A man makes a woman angry	A
2	Y	A man fears a woman with a mask	A
2	Y	A man wakes up a woman	A
2	Y	A woman sees a man	A
2	Y	A woman smells a man	A
2	Y	A woman touches a man	A
2	Y	A man kisses a woman	A
2	Y	A man sees a woman	B
2	Y	A woman is afraid of a man with a mask	B
2	Y	A woman pushes a man	B
2	Y	A woman wakes up a man	B
2	Y	A man surprises a woman	B
2	Y	A man chases a woman	B
2	Y	A man smells woman	B
2	Y	A woman frightens a man	B
2	Y	A woman hits a man	B

* These items were practice items and were excluded from final analyses.

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