Cross-situational learning of novel anaphors

Karen Clothier (kclothi1@jhu.edu)
Cognitive Science Department, 3400 N. Charles Street
Baltimore, MD 21218 USA

Satoshi Nambu (satoshi.nambu@monash.edu)
School of Languages, Literatures, Cultures and Linguistics, 20 Chancellors Walk
Clayton, 3800 AUSTRALIA

Hajime Ono (hajime@tsuda.ac.jp)
Faculty of Arts, 2-1-1 Tsuda-machi, Kodaira-shi
Tokyo, 187-8577 JAPAN

Akira Omaki (omaki@uw.edu)
Department of Linguistics, Guggenheim Hall Box 352425
Seattle, WA 98195 USA

Abstract

Word learning research has shown that learners constrain the hypothesis space for word meanings by using multiple sources of information, such as cross-situational regularities of word-context co-occurrences or syntactic cues, like the number of arguments. These studies typically focus on word meaning development where these cues can be helpful but not necessary. As such, it sheds little light on the acquisition of anaphors, which requires tracking syntactic dependencies across situations. To test whether or how learners track this information, we conducted a novel anaphor learning experiment with English and Japanese speakers, manipulating cross-situational regularities in anaphors and their syntactic dependencies. Results show both English and Japanese speakers closely track the frequency of interpretive possibilities for novel anaphors. However, they demonstrate difficulties learning long-distance reflexives, which are compatible with either local or non-local antecedents. This suggests that successful anaphor learning requires more than cross-situational regularities of interpretive possibilities.

Keywords: anaphors; binding; language acquisition; statistical learning; word learning

Introduction

Sentences (1) and (2) illustrate that the interpretation of local reflexives like *himself* and pronouns like *him* rely on structural relationships to their antecedents (the noun phrase that the reflexive or pronoun refers to, e.g. *himself* = John in (1), but *him* = Bill in (2)).

(1) Bill said that John kicked himself.
(2) Bill said that John kicked him.

This complementarity suggests that these anaphors respect different locality constraints; informally, English reflexives can only be bound by antecedents in the same clause, whereas pronouns must not be bound by antecedents in the same clause (Chomsky, 1981).

Other languages have different types of anaphors. For example, Japanese has a long-distance (LD) reflexive *zibun,* and replacing *himself* with this LD reflexive in the Japanese translation of (1) results in an ambiguous sentence, as *zibun* can refer to either Bill or John. This suggests that in Japanese and other related languages, the local domain for *zibun* is expanded to the whole sentence, thereby allowing both the local and non-local antecedents.

This cross-linguistic variation suggests that the interpretive possibilities for anaphors are not universally determined, and must be learned from language experience. Learning the interpretive possibilities of anaphors requires learners to infer the intended meaning of the utterance based on the utterance context. For example, the nature of the events described by (1) and (2) is different: one is reflexive, while the other is transitive. Thus acquiring anaphors requires the learner to simultaneously track the syntactic relations between the anaphor and its antecedent, as determined by the context of the utterance. Critically, learning that the LD reflexive can take either a local or non-local antecedent requires tracking such information across multiple situations in which the LD reflexive is used with either one.

Previous word learning research has investigated how learners use such cross-situational regularities or syntactic structures to learn word meanings. For example, 2.5 year-olds acquired the meaning of a novel verb (e.g. *pim*) dependent solely on the frequency with which the verb was presented with a particular video of a particular action (Scott & Fisher, 2012; for similar work on nouns see Smith & Yu, 2008). While there is an on-going debate over whether learners gradually update word meaning hypotheses across situations, or whether learners instead iteratively test and revise successive hypotheses across situations (see Medina, Snedeker, Trueswell, & Gleitman, 2011), both lines of work critically point to the fact that information across trials contributes to the word learning process.

Much work has also explored how learners use syntactic frames to constrain the meaning of novel words (*syntactic bootstrapping*; see Gleitman, 1990). For example, Yuan and Fisher (2009) showed that when infants heard a series of

transitive sentences with two arguments (e.g. *Jimmy blicked the cat*) in the absence of contextual information, they reliably interpreted the novel verb as referring to a causative event that requires two participants. On the other hand, presenting a series of intransitive sentences led infants to interpret the novel verb as referring to a single participant event. Such work shows that learners can use information from syntactic structures to narrow their hypotheses about word meanings.

In sum, the work reviewed above shows that learners make use of both distributional and linguistic cues. However, few studies have investigated the mechanism of anaphora acquisition, which requires tracking the cross-situational regularities of syntactic relations themselves. Research on anaphora acquisition mechanisms not only fills this empirical gap, but also provides a novel window into the constraints on cross-situational, statistical learning mechanisms.

The present study uses a novel anaphor learning experiment to investigate if and how participants use cross-situational co-occurrences of word form, contextual information, and syntactic structure. During the learning phase, participants are presented with sentence-picture pairs that contextually constrain the intended meaning of the target English sentence like (1) or (2) with a novel anaphor. We used three novel anaphors, following the interpretive possibilities of local reflexive (*botu*), pronoun (*sumu*), as well LD reflexive (*togu*). We included these three anaphor types for three reasons. First, this combination of anaphors is attested in Japanese and other languages, and therefore provides an ecologically valid anaphor system. Second, for English speakers, the Japanese LD reflexive is a new category of anaphor, so this allows us to simulate an actual learning process. Third, the local reflexive and pronoun are expected to be readily learnable for English speakers since both exist in English, and are also presented with a single interpretive possibility across trials. Thus, these anaphors can be used to validate this novel experimental procedure.

In order to probe the effectiveness of distributional information, we manipulated the frequency of two interpretive possibilities for the LD reflexive (i.e., *local antecedent*, akin to the meaning of (1), or *non-local antecedent*, akin to the meaning of (2)) by creating three between-subjects learning conditions: a Balanced condition where there were 50% local and 50% non-local antecedents; an LD-majority condition where 80% of the time the antecedent was non-local, and only local 20% of the time; and a Local-majority condition, where 80% of the time the antecedent was local, and only non-local 20% of the time.

If anaphor acquisition relies on accruing information and testing hypotheses across situations, then we would expect that a learner in the Balanced condition would be best able to learn the Japanese-style LD reflexive; encountering both interpretive possibilities should maximize learners' chances to realize the optionality of local and non-local antecedents.

However, there are two additional biases that may affect how learners use distributional information. For example, it has been proposed that in the absence of clear disambiguating information, learners are often biased to adopt syntactic structures that are easier to process in subsequent comprehension (e.g. Fedzeschkina, Newport, & Jaeger, 2016; Hawkins, 1999). With respect to processing LD reflexives, it has been found that at least in processing of Chinese LD reflexives, readers are biased to access local antecedents due to constraints on the working memory mechanism (e.g., Dillon et al., 2014). If this bias extends to anaphor acquisition, learners may struggle to learn the availability of the non-local antecedent with the LD reflexive, whereas even a relatively small percentage of input supporting the local antecedent may be sufficient to learn the availability of the local antecedent. Under this account, learners may in fact represent our LD-majority condition as if it were a 'Balanced' condition, because this local binding bias would enhance the availability of the local antecedent while dampening that of the non-local antecedent. If this is the case, then learners in the LD-majority condition – instead of the Balanced – should be best able to realize the optionality of local and non-local antecedents with the LD reflexive.

Another potential source of bias, which may be particularly relevant to the present study, is the influence of anaphors in the participants' native languages. The second language (L2) acquisition literature has found evidence for strong first language influence on the L2 acquisition of anaphors. For example, Yuan (1998) showed that Japanese speakers learning the Chinese LD reflexive were more likely to accept non-local antecedents than English speakers learning Chinese. Conversely, Japanese speakers learning English struggled to rule out non-local antecedents for English reflexives in a similar task (Hirakawa, 1990). Together, these results suggest that learners tend to 'transfer' and expect the same anaphors in their L2. Given that our study explores how adult learners acquire a novel anaphor, anaphors in the native language may constrain what can be learned within a single experimental session.

To investigate the native language influence on anaphor acquisition, we conducted this experiment with English native speakers and Japanese native speakers. If prior knowledge affects novel anaphor acquisition, then we would expect a contrast between the English and Japanese group: English speakers should struggle to learn the optionality in the LD reflexive, whereas Japanese speakers should be able to correctly learn the novel LD reflexive based on their knowledge of *zibun* in their native language.

Experiment

Participants

Fifty-seven native English-speaking members of the Johns Hopkins University community participated in the experiment. They were compensated with course credit or $10 cash. According to self-reports, none of the participants knew languages with LD reflexives. Participants were randomly assigned to one of the three learning manipulation

conditions. All participants completed a learning phase and then a test phase in the same session.

In addition, 57 native Japanese-speaking students from Tsuda College participated in the Japanese version of the same experiment. They were compensated ¥1000. Performance in an English cloze task (adapted from Kobayashi, 2002) revealed intermediate syntactic and semantic knowledge in English (maximum possible score: 25; M = 15.529, SE = 4.130), suggesting the relative dominance of Japanese over English.

Materials

Learning Phase Trials The 78 sentences for the Learning Phase were English sentences with clausal embedding (e.g. *John {said/remembered} that Susan combed {botu/togu/sumu}*), where *botu, togu* and *sumu* were the novel words used as the local reflexive, LD reflexive, and pronoun respectively. These anaphors were not marked for gender. Three main clause verbs (*comb, wash, fan*) were used once with both *said* and *remembered*. Using these six sentence frames, three male and three female character names were permuted to create 24 sentences containing the local reflexive and 24 containing the pronoun. For the local reflexive sentences, one sentence for each main clause verb was replaced with a mono-clausal sentence with the same verb. Taking these local reflexive sentences (including the mono-clausal sentences) and adding 6 additional embedded clause sentences following the same procedure described above created the 30 sentences containing the LD reflexive.

In order to make the intended interpretation of each sentence clear, throughout the experiment pictures were paired with each sentence to form a trial. Local reflexive sentences were depicted with pictures showing the syntactically local noun phrase as the antecedent of the anaphor; pronoun sentences were depicted with pictures showing the syntactically non-local noun phrase as the antecedent of the anaphor (as in Figure 1). Critically, LD reflexive sentences were depicted with either type of picture; referred to as the *local antecedent* in the former case, and the *non-local antecedent* in the latter.
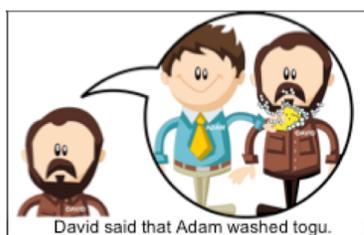

Figure 1: An example picture-sentence pair with *togu* (the novel LD reflexive), which illustrates the non-local antecedent (Adam washing David). The local antecedent version of this trial type would picture Adam washing himself inside the speech bubble.

Learning Conditions The picture-sentence pairs were used to create three different distributions of LD reflexive interpretations. For the Balanced condition, 15 LD reflexive sentences were paired with local antecedent pictures (including the necessarily local mono-clausal sentences, which appeared with a single character performing an action to themselves, with no speech bubble); the remaining 15 sentences appeared with non-local antecedent pictures. For the LD-majority condition, 24 sentences appeared with non-local antecedent pictures, while the remaining six sentences (including the three mono-clausal sentences) appeared with local antecedent pictures. For the Local-majority condition, 24 sentences (including the three mono-clausal sentences) appeared with local antecedent pictures, while the remaining 6 appeared with non-local antecedent pictures. This resulted in an 80%/20% distribution in the two unequally distributed conditions.

Picture Verification Test To create the sentences for the picture verification test, one set of six embedded clause sentence frames for each anaphor was reused with three new main clause verbs (*splash, paint, measure*). To create the trials, half the sentences were paired with their appropriate picture as described above to make *match trials*, and the other half was paired with the inappropriate picture (e.g. a non-local picture with a local reflexive sentence) to make *mismatch trials*, making sure that a roughly equal number of each anaphor, embedding and main clause verbs were in both sets of trial types. [1]

Materials for the Japanese experiment For the Japanese version of this experiment, the Japanese sentence materials were constructed in a very similar way as in the English experiment. However, because Japanese verbs are more selective in their argument structure, we were forced to change the events depicted in order to maintain natural sounding sentences, opting for a construction where the anaphor is marked with the dative particle *-ni*. The events depicted in the Japanese learning materials were: sticking tape to someone (__-*ni gamutepu-wo haru*), wrapping a ribbon around someone (__-*ni ribbon-wo makitsukeru*), and loading a log onto someone (__-*ni maruta-wo noseru*). In the test they were: spilling water onto someone (__-*ni mizu-wo kakeru*), putting paint on someone (__-*ni enogu-wo nuru*), and pinning an award on someone (__-*ni bajji-wo tsukeru*). All stimuli were presented in Japanese using hiragana and kanji, with novel anaphors spelled in katakana.

Procedure

The procedure was identical for the two language groups, but the Japanese version was carried out in Japanese by trained native Japanese-speaking research assistants.

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[1] Since both local and non-local antecedents are acceptable for the LD reflexive, there were no mismatch trials for this anaphor in the embedded clause sentence types discussed here.

Learning Phase This experiment was implemented in PsychoPy (Pierce, 2007). During the Learning Phase the participant was presented with one picture-sentence trial at a time. They were instructed to read the sentence aloud, and take as long as they needed to figure out the meaning of the novel word. They used the space bar to progress to the next trial, working at their own pace.

Participants were instructed to infer the meaning of novel words they would encounter in the experiment. The instructions explicitly stated that the novel words may or may not correspond to existing words in their native language. After the instructions, there were three blocks of learning trials, consisting of 26 trials each, with eight sentences each for the local reflexive and pronoun, and 10 LD reflexive sentences (including 1 mono-clausal local and one LD reflexive sentence).

In order to motivate participants during the learning phase, these learning blocks were interspersed with two quiz blocks containing 12 picture verification test trials, four for each anaphor. At the start of the first quiz block participants were given brief instructions telling them to respond 'match' if the sentence appropriately described the picture based on what they thought the novel words meant. There were two practice trials. No feedback was provided.

The order of these learning blocks, and of the quiz blocks was counter-balanced across participants to control for any list order effects. The trial presentation order was randomized within each block using PsychoPy's trial randomization function. Participants typically completed this phase in 20-30 minutes.

Test Phase Participants were given the picture verification test as described above for the quiz trials. Again, they were told to indicate if the sentence described the picture by pressing either 'f' for match or 'j' for mismatch. The trials were presented randomly, with a break halfway through. Participants typically completed the test phase in 20-30 minutes.

Results

For statistical analyses of the data, the picture verification responses from each language group were entered into a mixed logit model (Jaeger, 2008) with the acceptance response (i.e. the picture and the sentence description match) as the dependent variable. We used learning condition, picture antecedent and anaphor type, and the two- and three-way interactions as predictors, and participant and item as random effects.

English Figure 2 shows the results for the English-speaking participants. On average, participants in all three learning conditions were more likely to accept the local reflexive with a local antecedent ($\beta = 1.568$, $z = 13.239$, $p < .000$) and less likely to accept the pronoun with a local antecedent ($\beta = -1.531$, $z = -12.833$, $p < .000$). This was an expected pattern given that local reflexives and pronouns exist in English, and the input provided consistent information. This
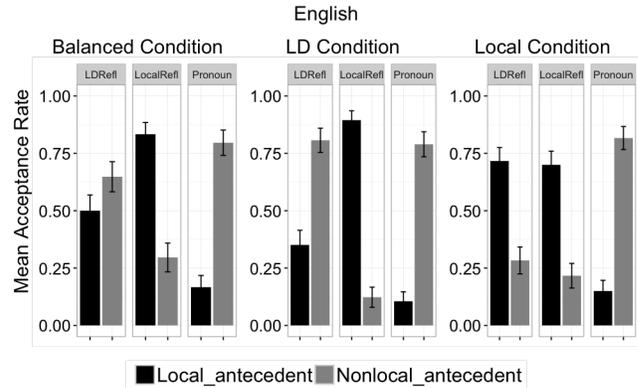

Figure 2: Mean acceptance rates, split by each anaphor given a particular antecedent, across the three learning conditions, from English speaking participants.

reassured us that the task was achievable given consistent input. We turn now to the optionality in the LD reflexive.

With respect to the acquisition of the LD reflexive, we had initially expected participants in the Balanced condition to show the best ability to accept the LD reflexive in both local and non-local antecedent trials. However, this expectation was not confirmed, as the acceptance rate for the LD reflexive was not high in either local or non-local antecedent trials (Figure 2). In order to explore the impact of distributional regularities, we conducted planned pairwise analyses and compared response rates for the LD reflexive across the three learning conditions. Participants in the Local-majority condition and LD-majority condition showed a reliable preference to accept the LD reflexive with the antecedent that was frequently presented in the input (Local-majority condition: $\beta = 1.211$, $z = 6.336$, $p < .001$; LD-majority condition: $\beta = -1.024$, $z = -5.201$, $p < .001$). Finally, when response rates for the LD reflexive were compared across the three conditions, participants only showed a strong preference for an antecedent in the Local condition ($\beta = 1.211$, $z = 6.336$, $p < .001$) and the LD condition ($\beta = -1.024$, $z = -5.201$, $p < .001$), not the Balanced condition. Furthermore, in a model considering only acceptance rates of the LD reflexive in the Balanced condition, there was no significant preference for either antecedent ($\beta = 0.614$, $z = 1.547$, $p = .122$), suggesting that participants in the Balanced condition truly were responding at chance on a given LD reflexive trial. This pattern of responses suggests that participants' behavioral response patterns reproduced the distributional regularities they observed in their input.

Moreover, participants in the LD-majority condition were less likely to accept the local antecedent with the LD reflexive compared to those in the Local-majority condition ($\beta = -0.823$, $z = -6.119$, $p < .000$), or those in the Balanced condition ($\beta = -0.347$, $z = -2.593$, $p = .010$). Similarly, participants in the Local-majority condition were more likely to accept the LD reflexive with local antecedents compared to those in the Balanced condition ($\beta = 0.340$, $z =$

2.775, p = .006), and the LD-majority condition (β = 0.823, z = 6.119, p < .000). These patterns suggest that participants in the unequally distributed learning conditions also reproduced the rate at which the local or non-local antecedents appeared in their input.

Japanese Figure 3 shows the results for the Japanese-speaking participants. Overall, Japanese speakers' response patterns were very similar to those of English speakers. Participants across the three learning conditions accepted the local reflexive more often with local antecedents (β = 1.196, z = 10.524, p < .001) and rejected the pronoun with local antecedents (β = -1.275, z = -10.519, p < .001). Japanese speakers were also sensitive to the distributions in their learning condition. When participants in the Balanced condition were compared to those in the Local-majority condition, there was no significant difference in their acceptance rates for the two antecedents with the LD reflexive (β = 0.208, z = 1.378, p = .168)[2]. But like English speakers, participants in the LD condition compared to the Balanced were less likely to accept the LD reflexive with a local antecedent (β = -0.637, z = -4.757, p < .000).

Pairwise analyses of the LD reflexive data at each group level again reveal the similarity between English and Japanese speakers. Participants only showed a strong preference for a local antecedent in the Local-majority condition (β = 0.787, z = 4.065, p < .001) and non-local antecedent in the LD-majority condition (β = -1.062, z = -5.228, p < .001), but no clear preference was observed in the Balanced condition. Furthermore, in comparison to participants in the Local-majority condition, those in the LD-majority condition were less likely to accept the LD reflexive with local antecedents (β = -0.679, z = -5.228, p < .000). Finally, when response rates for the LD reflexive were compared across the three conditions, participants only
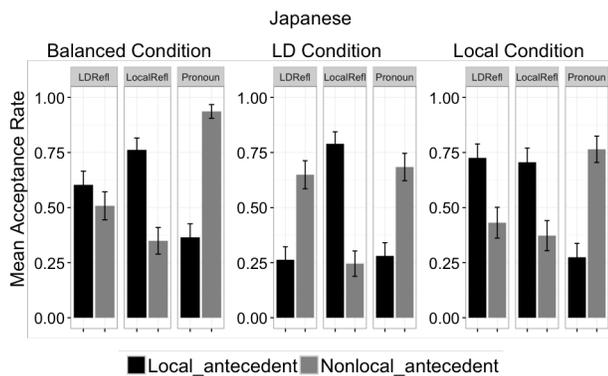

Figure 3: Mean acceptance rates, split by each anaphor given a particular antecedent, across the three learning conditions, from Japanese speaking participants.

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[2] However, the main model shows that overall participants in the Local condition were more likely to accept the LD reflexive with the local antecedent (β = 0.517, z = 3.444, p = .001).

showed a strong preference for an antecedent in the Local condition (β = 0.787, z = 4.065, p < .001) and the LD condition (β = -1.062, z = -5.228, p < .001), not the Balanced condition. In the model considering only acceptance rates of the LD reflexive in the Balanced condition, there was again no significant preference for either antecedent (β = -0.493, z = -1.215, p = .224).

Overall, participants across both language groups show strikingly similar response patterns. They were only willing to accept each anaphor following the distribution of antecedent co-occurrences provided in their input, even when the optionality presented there resembled their native language (i.e. Japanese speakers). Results also suggest that the chance responding in the Balanced condition across both language groups was not the result of different individuals preferring different antecedents, rather as a group these participants are simply reproducing the statistical regularities in their input.

Discussion

The present study used a novel anaphor learning paradigm to investigate cross-situational learning of novel anaphors. Overall, we found that participants in our study appear to track the distribution of syntactic structures across situations to constrain their anaphor acquisition. The fact that learners reproduced the distribution of local vs. non-local interpretations for the LD reflexive indicates that the input distribution was guiding the process of anaphor acquisition. This kind of probability-matching behavior, which has been reported in other statistical learning paradigms (e.g. Hudson Kam & Newport, 2005), further illustrates humans' ability to reproduce and learn regularities in their input from simple frequency tracking (c.f. Estes, 1976). Furthermore, the fact that there was little difference between the two language groups – specifically the fact that Japanese speakers, like English speakers, treated the LD reflexive as a local reflexive or pronoun based on their learning condition rather than following the interpretive possibilities of their native *zibun* – suggests that biases to copy and reproduce regularities in the input distribution played a more important role than other potential biases (e.g. processing biases or L1 influence).

One of the main research questions in this study concerned how participants handle the optionality in the interpretive possibilities of the LD reflexive, and how manipulating the distribution of those two options would affect acquisition. The results demonstrate that learners struggle to acquire the optionality of the LD reflexive, regardless of their native language. Participants in the unequally distributed learning conditions appeared to treat the antecedent that only appeared 20% of the time as noise, ignoring it during learning, and accepting roughly that same rate of 'noise' during test (for all three anaphors). In other words, participants in the LD-majority and Local-majority conditions simply treated the LD reflexive as another form of either the pronoun or local reflexive, respectively.

Participants in the Balanced condition appear to be roughly at chance in accepting or rejecting the provided antecedent.

These results and conclusion raise an important question for future research: if distributional regularities are not useful in acquiring anaphors that allow for more than one interpretation, how do speakers of languages like Japanese acquire the interpretative optionality of their LD reflexives?

One possible explanation is that learners must first be confident about one possible antecedent before allowing optionality. For example, learners in the two unequally distributed learning conditions may have settled on one interpretation, without having received enough evidence to allow optionality. Learners in the Balanced condition, however, were not confident about either antecedent. To test this, an on-going follow-up experiment is exploring the effect of presentation order and the frequency of particular antecedents, e.g. presenting a majority of either local or non-local antecedents before introducing the kind of optionality we presented in the Balanced condition.

Alternatively, this difficulty could be explained by a uniqueness principle, i.e., bias against many-to-one meaning-form mappings. Learners must learn that both multiple semantic and syntactic mappings are acceptable for LD reflexives, so future work should investigate this bias at both levels. For example, highlighting the distinctiveness of the LD reflexive's interpretive optionality may increase learners' acceptance of optionality. To this end, sentences with relative clauses may help learners disambiguate between anaphor types: in "The woman standing next to Susan splashed her/herself," *zibun* is only interchangeable with *herself*, not *her* because Susan does not c-command the anaphor. The current data can only address the acquisition of the locality constraint, and not the c-command requirement on the structural relation between antecedent and anaphor, but learning both in tandem may be critical for successful acquisition of an LD reflexive.

Sentences where the reflexive is in the subject position of an embedded clause could also provide evidence that the LD reflexive differs from the local reflexive in its syntactically constrained interpretive possibilities (e.g. "John said that *zibun-wa* awesome."). While such a sentence is not possible with a local reflexive, it is grammatical for *zibun* precisely because the LD reflexive can take an antecedent outside the local clause (in contrast to the local reflexive's more restricted locality constraint). Providing these sentences in the learning input may provide further evidence to learners about the distinctiveness of the LD reflexive, and increase their confidence that optionality is integral to the LD reflexive type anaphor itself and not noise in the input.

In short, findings from the present study provide an important step towards understanding the constraints on cross-situational learning of anaphoric expressions. We suggest that successful acquisition of an LD reflexive may require that learners incrementally acquire interpretive possibilities in sequence, or that they are presented with an additional syntactic cue that unambiguously indicates the availability of the non-local antecedent interpretation.

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