Environmental effects on parental gesture and infant word learning

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Abstract

How infants determine correct word-referent pairings within complex environments is not yet fully understood. The combination of multiple cues, including gestures, may guide learning as part of a communicative exchange between parent and child. Gesture use and word learning are interlinked, with early child gesture predicting later vocabulary size, and parental gesture predicting child gesture. However, the extent to which parents alter gesture cues during word learning according to referential uncertainty is not known. In this study, we manipulated the number of potential referents across conditions during a word learning task with 18–24-month-olds, and explored how changes in parental gesture use translated into infant word learning. We demonstrate that parents alter their gesture use according to the presence, but not the degree, of referential uncertainty. We further demonstrate that a degree of variability in the number of potential referents appears to benefit word learning.

Keywords: word learning; gesture; vocabulary development; parent-infant interaction

Introduction

Between 18–24 months of age, children's expressive vocabulary rapidly increases from approximately 90 to 320 words (Fenson et al., 1994). Children learn language in busy and variable environments containing multiple possible referents, but how they determine what the intended referent for a given word is remains under-investigated. Finding the correct word-referent pairing is a problem of substantial difficulty, as described by the well-known 'gavagai' problem (Markman, 1989; Quine, 1960), where a second language learner cannot know whether an unknown utterance – 'gavagai' – refers to a rabbit present in the scene, the rabbit bouncing, the rabbit's colour, or a range of other potential meanings. Infants face the same problem as the second language learner, with a further disadvantage – the lack of a first language to base their learning upon.

Recent attention has turned towards examining the multiple potential cues present in language learning environments that might help children to delineate referents of unfamiliar words (Monaghan, 2017). One of the earliest sources of information to support word-referent mappings is provided before children are able to speak: gestures in parent-child interactions. Within these interactions, gesture appears to be facilitative of word learning. For example, spontaneous pointing by the infant during a gaze-following task at 10–11 months predicted vocabulary growth at 24 months (Brooks & Meltzoff, 2008), and Fenson et al. (1994) found an increase in infants' gesture use between 8–16 months correlated with word comprehension. Parent and infant gesture use also appears to be reciprocal in nature. Rowe, Özçalışkan and Goldin-Meadow (2008) observed gesture use in parent-child dyads at four-month intervals between the ages of 14–34 months, then administered a vocabulary test at 42 months. They found that child gesture use at 14 months predicted vocabulary size at 42 months, and that parent gesture use predicted child gesture use at 14 months. Between 22–34 months, they found that child gesture use (number of gestures with or without speech) mirrored parent gesture use. Infant gesture therefore appears to predict language development and appears to be related to parental gesture use.

The nature of this relationship seems rooted in the informative role of gestures in word learning during active communication between parent and child, with gesture adding significant value to information exchange. The use of gesture as a response in perspective-taking tasks has demonstrated that infants use and adjust their gestures according to parent knowledge states. In a similar way to how older children (from 3.5-years) adjust their speech responses to actively incorporate a communicative partner's perspective (Nadig & Sevidy, 2002; Nilsen & Graham, 2009), when parents do not have the same information as infants, infants are more likely to gesture to support mutual understanding (O'Neill, 1996). Gesture thus may play a vital role in aiding effective communication when verbal ability is still being established. Infant gesture may also serve an interrogative function by acting as a signal to gain critical information from parents about a specific object (Iverson & Goldin-Meadow, 2005; Southgate, van Maanen & Csibra, 2007). Given that gestures are a vital means through which infants interact with and learn about their surrounding context, how might this assist children in navigating the complex environment surrounding word learning?

On the other side of this communicative partnership, gesture use by caregivers may provide valuable information about intended referents during rapid vocabulary development. In particular, parental gestures such as pointing serve as a useful tool for identifying a referent when learning word-referent pairs. Iverson et al. (1999) reported parental pointing during 15% of exchanges related to word learning. Furthermore, the quality of parental gesture appears to have

an effect on word learning. Cartmill et al. (2013) assessed parental input quality during parent-child interactions at 14–18 months by asking adult participants to guess words from muted observational videos. This provided a measure of input quality by indicating how informative non-verbal and gestural communication was in determining word meaning. When correlated with child vocabulary at 53 months, children whose parents produced higher quality input had higher receptive vocabulary.

Thus, both the frequency and quality of parental gesture are related to infant word learning and provide valuable cues that enable the child to predict the referents for their growing vocabulary. However, it is not yet known how adaptive parental gesture is to the information present in the environment, or what kind of gestures are most helpful to infants under conditions of differing referential uncertainty.

In verbal communication, we know that speakers adjust their phonology, prosody, word selection, and syntax in accordance with the context of communication and the listener's perspective (Bannard, Rosner, & Mathews, 2017; Brown-Schmidt & Duff, 2016; Gorman et al., 2013). We also know that children can adapt their gesture and speech to accommodate the perspective of adults (Bahtiyar & Küntay, 2009). Parents also adapt their spoken labelling behaviour according to infant familiarity with objects (Cleave & Kay-Raining Bird, 2006; Masur, 1997) and how conventional the label is (where conventionality refers to there being a culturally agreed referent for a specific word; Luce & Callanan, 2010). However, we do not know the extent to which parents adjust their gesture use contingently based on referential uncertainty during infant word learning.

In this study, we address this issue, testing whether parents would offer a higher number of gestural cues when a target item was amongst more, rather than fewer, distractor objects. Furthermore, we measured whether the type of gestures that occur, and their correspondence with speech, affected children's learning of novel words. Greater referential uncertainty, as determined by a higher number of potential referents for a novel label, has led to less reliable and slower word learning in previous studies (Smith, Smith, & Blythe, 2011; Trueswell et al., 2013). Consequently, we would expect parental gesture to play a stronger role in delineating referents when there is a higher degree of referential uncertainty. In a word learning task, we manipulated the number of potential referents for a novel word between one, two, and six referents. We hypothesised that parental gestural cues would increase with the frequency of potential referents from the one- to the six-referent condition, particularly for deictic cues (gestures directing attention to a specific object). We predicted the same pattern for the co-occurrence of speech with gesture, in particular for speech that used the target label. We then examined whether these cues translated into infant word learning accuracy by testing infants on their knowledge of the novel label. We hypothesised that infants of parents who offered more gestural cues would show higher word learning accuracy.

Method

Participants

Fifty-three monolingual English infants aged between 18–24 months-old (M = 20.9 months, SD = 1.7, 25 female) were recruited from a database of families who had registered interest in study participation at Lancaster University Babylab. Infants were from middle-class families (determined via parental education level). During training, six parent-infant dyads were excluded due to infant fussiness. Twenty-seven infants (M = 20.8 months, SD = 1.6, 14 female) also completed the testing phase, with the remaining sample excluded due to infant fussiness (n = 4) or incomplete trials (n = 16; less than 5 of 6 test trials).

Materials

Nine novel objects were used as referents for the novel words. Each novel object was a different colour and shape. Three novel words, selected from the NOUN database (Horst & Hout, 2016), were used as labels (*noop*, *darg*, and *terb*). Three objects were chosen as targets randomly for each participant, with all other objects serving as foils, and each novel label was randomly paired with each target per participant. Stimuli position, target, and condition order during training and testing were counterbalanced across participants using a Latin square. Parents also completed the UK-CDI (Alcock, Meints, & Rowland, 2017), a measure of receptive, expressive, and gesture (communicative and symbolic) vocabulary. Communicative gestures are declarative (deictic and imperative gestures) and symbolic gestures form a larger subset of actions with objects, games, and pretend play (representative gestures).

Procedure

Infants were seated on their parent's lap and viewed stimuli from 70 cm away. Each group of stimuli was presented for 30 seconds, with a moveable opaque screen shielding objects from view in-between trials. Parents were asked to imagine they were teaching real words for real objects. Familiarisation with the objects took place outside of the experimental room with the parent only. The labels and a three-word object description were visible to the parent throughout training to eliminate the need for parents to remember the novel label and paired target.

Participants began with one warm-up trial, where the experimenter placed a ball as a familiar object on a tray and instructed the parent to teach the infant the word as if it were novel. The aim was to familiarise parents with the procedure without increasing task demands. Parents then proceeded to the training phase, where they taught infants novel label-referent pairs with unfamiliar objects as stimuli. In the one-referent condition, only the target was presented; in the two-referent condition, one target and one foil were presented; and in the six-referent condition, one target and five foils were presented (see Figure 1). Each participant received each of the three conditions once.

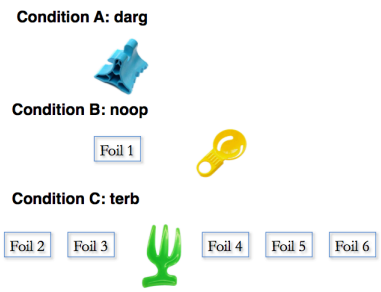

Figure 1: Training trials example.

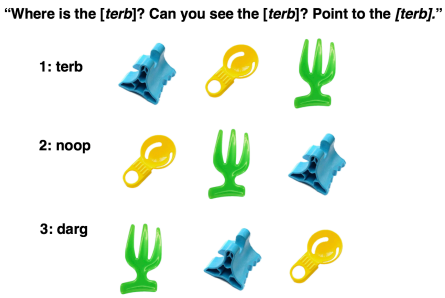

Figure 2: Testing trials example.

After completing all three training conditions, participants were then administered six testing trials, with each target word tested twice (see Figure 2). At the start of each trial, the infant was asked by the experimenter "Where is the [*target*]? Can you see the [*target*]? Point to the [*target*]." The trial ended when the infant made a response or the prompt had been repeated twice without a response.

Coding

All sessions were video-recorded and then coded for gestures and speech with gesture per utterance according to Rowe et al.'s (2008) coding scheme. A second coder coded 20% of the videos with an overall inter-rater reliability $\kappa = 0.78$ for gesture ($N = 284$) and $\kappa = 0.86$ for speech with gesture ($N = 160$).

Gesture types were split into three main groups (Rowe et al., 2008): *representational* gestures, indicating properties of the target referent such as size, shape, or function; *deictic* gestures, singling out the target referent by pointing with the arm and index finger extended or with the arm extended and the palm exposed and *other* gestures, which included all gestures not aimed towards the referent (those aimed at foils and related to caregiving interactions such as hugging).

The co-occurrence of speech that indicated properties of the target referent (e.g. size, shape, or function) with gesture was coded as *supplementary*. The co-occurrence of speech that singled out the target referent with gesture was coded as *complementary*. The frequency of referent label use was also recorded.

Results

A series of linear mixed effects models (lmer; lme4 in R, v3.4.1, 2017) were used to predict parents' use of gestures during training (gesture subtypes and co-occurring speech with gesture subtypes were dependent variables). These models were built up progressively with the addition of fixed effects of condition and child vocabulary (scores of communicative gesture, symbolic gesture and expressive subscales of CDI), comparing each model to a null model or previous best-fitting model using log-likelihood comparison after the addition of each new term (Barr et al., 2013). Random effects of subject and infant age were included in each analysis.

Environmental uncertainty effects on parental gesture use

The linear mixed effects models demonstrated a significant effect of condition on overall gesture count ($\chi^2(2) = 11.73$, $p = .003$). Consistent with our hypothesis, parents gave more gestural cues when they were faced with a higher number of potential referents (see Figure 3), with a significant difference between one- and two-referent conditions ($t(94) = 2.12$, $p = .037$), and one- and six-referent conditions ($t(94)=3.51$, $p = .001$), but not two- and six-referent conditions ($t(94) = 1.39$, $p = .167$). The addition of child vocabulary measures did not improve model fit (communicative gesture: $\chi^2(1) = 0.38$, $p = .539$; symbolic gesture: $\chi^2(1) = 0.28$, $p = .598$; expressive: $\chi^2(1) = 0.34$, $p = .560$). No significant interactions between fixed effects were found.

The relation between gestural cues and number of referents was particularly notable in deictic gestures, in-keeping with our hypothesis. There was a significant effect of condition on deictic gesture number ($\chi^2(2) = 8.35$, $p = .015$, see Figure 3), with significant differences between one- and two-referent conditions ($t(94) = 2.21$, $p = .030$), and one- and six-referent conditions ($t(94) = 2.80$, $p = .006$), but not two- to six-referents ($t(94) = 0.60$, $p = .553$). Adding child vocabulary did not improve model fit (communicative gesture: $\chi^2(1) = 0.001$, $p = .973$; symbolic gesture: $\chi^2(1) = 0.05$, $p = .832$; expressive: $\chi^2(1) = 0.01$, $p = .917$). No interactions between fixed effects were found.

For representational and other gestures, there were no significant effects or interactions.

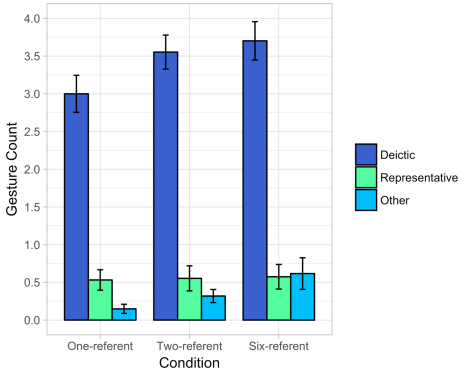

Figure 3: Mean count and standard error of gesture type generated by parents per condition.

Environmental uncertainty effects on co-occurring parental speech and gesture

When testing the co-occurrence of complementary speech with gesture, linear mixed effects models showed significant main effects of condition and child symbolic gesture vocabulary ($\chi^2(3) = 8.28$, $p = .041$; see Figure 4). There was a significant increase from one to two referents ($t(80) = 2.57$, $p = .012$), but no significant difference between one and six referents ($t(80) = 1.68$, $p = .096$) or two and six referents ($t(80) = -0.89$, $p = .376$). There were no other significant main effects of child vocabulary measures and no significant interactions between fixed effects.

When testing the co-occurrence of supplementary speech with gesture, we found condition was not significant as a main effect alone. There was a significant interaction between condition and child expressive vocabulary ($\chi^2(5) = 17.96$, $p = .003$), which showed that children with larger vocabularies were offered more information in the one- and two-referent conditions, but less in the six-referent condition, than children with smaller vocabularies. There were no other significant main effects or interactions between fixed effects.

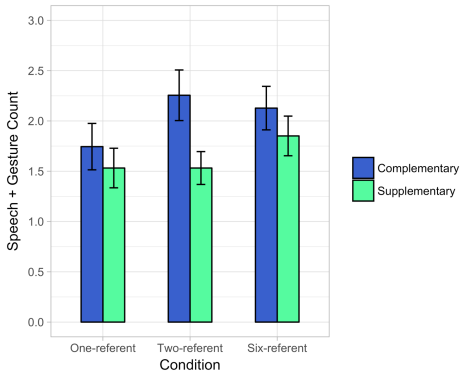

Figure 4: Mean count and standard error of types of speech with gesture generated by parents per condition.

Effect of parental gesture use on word learning

A series of binomial general linear mixed effects models (glmer; lme4 in R, v3.4.1, 2017) were used to predict accuracy. These models were built up progressively with the addition of fixed effects of condition and child vocabulary (scores of communicative gesture, symbolic gesture and expressive subscales of CDI), comparing each model to a null model or previous best-fitting model using log-likelihood comparison after the addition of each new term (Barr et al., 2013). Random effects of subject and infant age were included in each analysis.

Analysis using general linear mixed effects models revealed the addition of condition improved model fit ($\chi^2(2) = 6.08$, $p = .048$; see Figure 5), indicating a significant increase of accuracy from one to two referents ($\beta = 0.91$, $z = 2.19$, $p = .028$) and from one to six referents ($\beta = 0.86$, $z = 2.02$, $p = .044$), but no significant increase in accuracy from two to six referents ($\beta = -0.05$, $z = -0.13$, $p = .893$). However, this varied by parent, as the addition of a slope of condition per parent as a random effect removed the significant main effect of condition ($\chi^2(2) = 1.8$, $p = .406$).

Given that complementary speech with gesture was highest in the two-referent condition during training and accuracy was highest in this condition during testing (see Figure 5), we postulated that there might be some relationship between the two. However, the inclusion of total gestures, gesture subtype, and types of co-occurrence of speech with gesture did not improve model fit, suggesting there was no significant prediction of accuracy when these effects were taken into account. This did not support our hypothesis that increased parental gesture use during training would predict increased accuracy of infant word learning. A separate model examining these training response variables without an effect of condition did not demonstrate any significant improvement of model fit, suggesting any significant difference in accuracy was the result of differences in condition alone, without any demonstrable effects of training response.

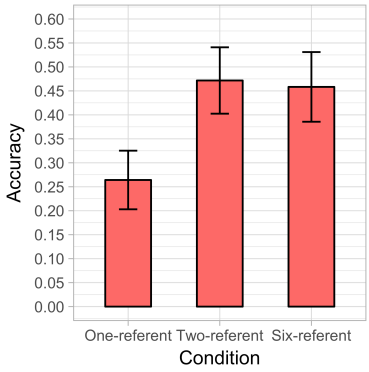

Figure 5: Mean infant word learning accuracy and standard error per condition.

Discussion

By varying referential uncertainty, we explored how parental gesture might aid infants in learning correct word-referent pairings within complex environments. Our training results demonstrated that parent gesture can be manipulated by altering the immediate environment around infant word learning. This was particularly notable in deictic gesture use. The results showed that parents use deictic gestures most in the presence of referential uncertainty, as parents gestured most in the six- and two-referent conditions compared to the one-referent condition. Deictic gestures have previously been found to be highly informative when determining word-referent pairs (Cartmill et al., 2013). Children also have been found to follow the direction of deictic gestural cues over linguistic cues in referent-selecting tasks (Grassmann & Tomasello, 2010). Thus, although it is possible that our findings related to deictic gesture use were influenced by task-demands (requesting parents to teach specific novel words for objects, and objects being out of reach), they are in line with other research that points towards the usefulness of

deictic gestures when delineating referents in naturalistic and laboratory settings.

The mechanism by which gesture adds information to speech may be a reduction of cognitive load for the infant, providing a visual component to learning resources alongside the verbal component (Goldin-Meadow, 2000; McGregor et al., 2009). This has been found particularly useful in situations of high task demands (McNeil, Alibali, & Evans, 2000) – consistent with parents using the most gestures in the six-referent condition. However, there was no significant difference in gesture use between the two-referent and six-referent conditions, which did not support our hypothesis that the higher the number of potential referents, the higher the number of parental gestures to assist the child in coping with referential uncertainty. One might also expect a higher number of potential referents to confer a higher task-demand, and thus perhaps a need for a greater reduction of cognitive load due to an increased amount of distracting information.

This result may demonstrate that the more important factor in referent-identification is whether there is referential uncertainty or not, rather than the degree of uncertainty. It is possible that the additional information conveyed in gesture is not as valuable in reducing cognitive load when there is more than one choice to be had. This interpretation is consistent with children's actual learning of novel words – infants demonstrated the highest accuracy in the two-referent condition, and performed marginally worse in the six-referent condition which had the highest frequency of parent gestural information and referent label use. Infants performed worst in the one-referent condition. This might be unexpected given the lack of referential uncertainty, although there was also the least amount of information available (provided in speech and gestural cues).

These learning results suggest that some referential uncertainty might actually be beneficial for learning, and that perhaps too much uncertainty begins to remove that benefit. In Monaghan's (2017) computational study of multiple cue integration in word learning, the model predicted that a small amount of variability in the cues available in the word learning environment yielded superior learning in comparison to conditions where cues were perfectly reliable and invariable. But when this variability became substantial, learning of novel words began to decline. In Monaghan et al. (2017), this prediction was supported in a study of adults learning novel word-referent mappings from multiple cues: variability was helpful. However, in these studies, the referential uncertainty was kept constant – in all cases, there were two possible referents from which to select. In the current study, we further show that a small degree of variability in referential uncertainty led to the best novel word learning.

The presence of two competing alternatives in the environment ties in with studies of children's application of mutual exclusivity (Markman & Wachtel, 1988). In these studies, children are shown to actively use a general principle of 'this, not that' to map unknown words to unknown objects in relation to known objects. Although this mechanism works primarily by prior knowledge, it is possible that having one choice enables some sorting of the available referents that makes word learning more efficient.

However, our results did not show a significant direct effect of parents' behaviour in driving children's word learning performance – the amount of gestural information with and without speech during training was not predictive of more accurate infant word learning as we had predicted. Any effect of condition on accuracy also disappeared with the addition of a random slope for condition per parent, suggesting that there was a high degree of variability in how parents used gestures across the conditions.

The lack of an effect may be partly due to limitations in our sample. All parents were of mid-socioeconomic status (SES), recruited from a database of families who had actively signed up to take part in child development studies. Families from mid to high SES backgrounds are known to use gesture more (Rowe & Goldin-Meadow, 2009). Kirk et al. (2013) suggest that the added benefit of gesture may be most prevalent in cases where there is general diminished parental input, providing a compensatory effect, and in mid to high SES families, parental input is less likely to be reduced. Gains in child vocabulary following training that involved increased gesture use have previously been found primarily in low SES environments (Hirsh-Pasek et al., 2015). Although parents in our study did gesture more with increased referential uncertainty, it is possible that any added benefit of gesture in this sample reached something of a ceiling effect when it came to word learning – infants were already subject to a level of parental input that meant gesture did not add to their learning.

Finally, given prior evidence that children's vocabulary and gesture use are positively related, and child gesture is linked to parental gesture (Rowe et al., 2008), child gesture vocabulary might be expected to have some effect on parental gesture use during training. However, this was not the case in our study. Our models of gesture alone did not identify an effect of child expressive and gesture vocabulary. We did find that these effects played a role in the amount of speech with gesture. We found that child gesture and expressive vocabulary were significant effects when referential uncertainty was increased. This may indicate that child gesture and expressive vocabulary are related to parental gestures co-occurring with speech, instead of parental gesture in isolation. This aligns with the idea of gesture playing a supplementary role to speech, rather than one supplanting the other (O'Neill, 1996; Iverson & Goldin-Meadow, 2005).

In summary, we found that referential uncertainty affected parents' gestures. Parents were affected by the number of potential referents in the environment, and adapted their gestures, and co-occurrences of gestures with naming of the target object, offering more cues when the child's environment became more complex. However, parental gesture use was only affected by whether there was referential uncertainty or not, rather than the degree of referential uncertainty. In terms of children's accuracy when testing their knowledge of novel labels, referential

uncertainty was again found to affect learning, and actually promoted it. The results add to a broad picture of communicative exchange where interlocutors are sensitive to the context and informational requirements of the situation, and also to growing evidence that variability, within speech and within the environment, is beneficial for learning.

Acknowledgments

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