Two Dimensions of Pragmatic Gestures Differentiate Early Developmental Trajectories

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Introduction and Literature Review

Topic gestures are interrelated with speech across the development of pragmatics. Children use pointing gestures and head gestures for multiple communicative intents when they lack the verbal lexicon necessary to encode intent entirely in speech (Bates et al., 1975; Butcher & Goldin-Meadow, 2000; Guidetti, 2005). Similarly, infants use iconic gestures to communicate about actions before they have the vocabulary to do so and later use iconics to augment, rather than replace, verbs once they enter the lexicon (Acredolo & Goodwyn, 1985; Bates et al., 1975; Özçalışkan & Goldin-Meadow, 2005).

However, a multimodal model of pragmatic development based primarily on the functions of topic gestures minimizes the role of an entire class of gestures that are pragmatic by definition. Like "pragmatic development," the term "pragmatic gesture" can be broad and ambiguous. For the purposes of the present study, we consider the essential characteristic of pragmatic gestures to be their function of communicating information about the interaction itself. They operate outside the topic of talk and provide conversational meta-comments about epistemics, attitude, and turn-taking instead of – or in addition to – contributing semantic meaning about the topic.

Children begin to produce pragmatic gestures very early in communicative development, but the ambiguity around how we talk about these gestures in adults' conversation likely contributes to a relative lack of research on their role in children's early interactions. Infants typically produce head nods, head shakes, palm-up gestures, and shoulder shrugs before their second birthday and before acquiring corresponding lexical terms (Beaupoil-Hourdel et al., 2015; Benazzo & Morgenstern, 2014; Guidetti, 2005). While these gestures frequently function pragmatically in everyday conversation, they also function emblematically as nonverbal translations of 'yes,' 'no,' and 'don't know.' Because these gestures commonly function as emblems in preverbal and early verbal communication, it can be easy to overlook where they may also serve pragmatic or interactive functions.

Existing research on children's earliest pragmatic gestures suggests they serve an important role in communicative development, but this work can face two limitations. First, these studies often compare pragmatic gestures to representational gestures but rarely look within the class of pragmatic gestures. (Colletta et al., 2015; Colletta et al., 2010; Esteve-Gibert & Prieto, 2014; Vilà-Giménez et al., 2020; also see Vilà-Giménez & Prieto, 2021 for a review). Second, pragmatic gestures are often subsumed under an umbrella category of nonverbal communication along with prosody, facial expression, pauses, and behavior (Borràs-Comes et al., 2011; Dijkstra et al., 2006; Hübscher et al., , 2017). One way to begin addressing these limitations is to highlight two particularly salient dimensions of gesture: gesture form and gesture-speech relation.

Gesture Form

Gesture form describes the key visual or physical characteristics of a gesture. Formal properties of gesture are those features which are recognizable and describable without any additional context, such as handshape, orientation in space, and temporal phases of movement (McNeill, 1992). The form dimension exists independently of function, even in cases where the two are tightly linked. For example, an outstretched index finger usually takes a deictic function, visually indicating the literal or metaphorical location of a referent. Less often, one outstretched finger might emblematically stand in for the number one, iconically represent a perch for a bird, or interactively signal to an interlocutor the desire to take the next turn. Divorcing form and function recognizes the possibility that a gesture form does not enter a child's lexicon via the most typical or predictable form-function associations.

Differences in form have been foundational to the study of topic gestures. Even within functional categories, formal categories matter. For both adults and children, the form of pointing gestures can vary based on the type of referent indexed and the pragmatic intentions of the speaker, such as referent individuation, discourse relevance of location, and imperative acts (Cochet & Vauclair, 2014; Kendon & Versante, 2003; Wilkens, 2003). Iconic gestures presented in character-viewpoint more

effectively communicate a referent's relative positioning than observer-viewpoint iconics, while the reverse is true for information about properties like speed and shape (Beattie & Shovelton, 2002). This differentiation between character- and observer-viewpoint is also relevant to the development of narrative production, where both spontaneously produced and trained character-viewpoint gestures are associated with better narrative structure (Demir et al., 2014; Parrill et al., 2018).

The form dimension of functionally pragmatic gestures can be a bit muddled. For example, Bavelas, Chovil, Lawrie, and Wade (1992) introduce interactive gestures as an entirely functional category of gesture but at the same time impose strict formal constraints. The authors' limitation of interactive gestures to addressee-indicating forms excludes gestures that perform the same interactive functions but differ in handshape, direction, or both (e.g., lateral palm-ups) and may include gestures that deictically indicate the addressee as topic-relevant rather then referencing the interaction. On the other end of the spectrum, the shrug family of gestures seems to have almost no agreed upon formal constraints, leading to a wide range of interpretations for their pragmatic functions in conversation (Boutet, 2018; Cooperrider et al., 2018; Debras, 2017; Givens, 1977; Jehoul et al., 2017).

Consequently, gestures labeled pragmatic, interactive, or discursive frequently discount formal features. This is not an unreasonable approach to answering questions exclusively about function, but as we study pragmatic gesture over development there may be much to learn from how gestures' emerging functions relate to their forms. Here we focus on two of the most commonly produced forms of pragmatic gesture in early childhood, *beats* and *palm-up gestures*.

McNeill (1992) describes *beats* as gestures that lack discernible meaning and are instead recognized by their prototypical movement. They are "small, low energy, rapid flicks of the fingers or hand" (p80) that emphasize the semantic content of temporally matched speech. Despite lacking

semantic meaning independent from meaning encoded in speech1, beats contribute pragmatic meaning by rhythmically aligning with prosodic cues to frame discourse.

Children begin producing beats around their second birthday alongside the emergence of multiword utterances (Nicoladis et al., 1999) and increase use of beats through the school-age years as discourse-pragmatic and narrative skills increase in complexity (Colletta et al., 2015, 2010; Mathew et al., 2018). A small body of recent work has investigated connections between children's production of beats and narrative. Training children to produce oral narratives with beats improves children's narrative structure and oral fluency (Vilà-Giménez & Prieto, 2020). Longitudinal observational studies of early spontaneous beat production and later narrative abilities have shown mixed results (Vilà-Giménez et al., 2020; Vilà-Giménez et al., 2021), but this may be explained by methodological differences in how the formal category of beat gestures was defined. See Vilà-Giménez and Prieto (2021) for a systematic review of beats' predictive role in early language development.

Palm-up gestures go by many names, including *palm-up open hand* (Müller, 2004), *palm lateral* or *palm-up presentation* in the open hand supine family (Kendon, 2004), *palm-up epistemic* (Cooperrider et al., 2018), *flips* (Harris et al., 2017; Vilà-Giménez et al., 2021), *palm-revealing* or *conduits* (Chu et al., 2014), and *hand shrugs* (Ekman & Friesen, 1969; Johnson et al., 1975; Morris, 1994/2015), among others. This range of terminology reflects some disagreement in what exactly "counts" as the palm-up form, but all these gestures share the fundamental formal features of outward wrist rotation with loose or extended fingers, with the palm exposed upward or outward at the gesture's peak. For the sake of simplicity, gestures that meet these basic formal criteria are referred to here as palm-up gestures or simply palm-ups.

[1] Though see Yap et al. (2018) for discussion of "hidden meaning" in some beats.

Though palm-ups are often considered emblematic or conventional gestures (Johnson et al., 1975; Morris, 1994/2015), they also perform pragmatic and interactive functions in spoken and signed languages across the globe, like epistemic stance-taking, distancing speaker from topic or interlocutor, managing the conversational floor, and metaphorically handling information (see Cooperrider et al., 2018 for a review).

Palm-up gestures are some of the earliest gestures produced by children, typically appearing before two years of age and often before an infant's first words (Acredolo & Goodwyn, 1985; Beaupoil-Hourdel & Debras, 2017; Harris et al., 2017; Iverson et al., 2008). Infants use palm-ups as emblems for literal absence ('all gone') and ignorance ('don't know') (English: Beaupoil-Hourdel & Debras, 2017; Harris et al., 2017; Italian: Caselli, 1983; Graziano, 2014). Toddlers use palm-ups to mark other epistemic states before they do so in speech (Catalan: Hübscher et al., 2019; German: Kim et al., 2016). By school entry children produce presentational palm-ups to mark discourse (Graziano, 2014). These studies have established that young children use palm-ups with multiple meanings, but do not speak to how different functions arise, persist, or mutate over development.

It is easy to recognize that beats and palm-ups share several key properties, such as acting in complement with prosody and emphasizing discourse content. As a result they are often grouped together functionally as "non-referential gestures" or simply as a looser category of "beats" (Dimitrova et al., 2016; McNeill, 1992; Shattuck-Hufnagel et al., 2016; Vilà-Giménez et al., 2020). The logic of treating beat and palm-up forms as one and the same is predicated on the fact that beats and palm-ups can be extremely similar in both form and function. However, it fails to account for the fact that despite this potential for similarity, many or most uses of beats and palm-ups serve entirely different functions with entirely different forms.

Gesture-Speech Relation

A second dimension of pragmatic gestures key to multimodal pragmatic development is gesture-speech relation, the way meaning in the nonverbal modality interacts with meaning in the verbal modality within a single communicative act (Özçalışkan & Goldin-Meadow, 2005). For example, pointing to a table *disambiguates* "that" in the utterance "look at that," *reinforces* the meaning of "table" in the utterance "sit at the table," and *supplements* the utterance "sit down" by adding information about where to take a seat.

Perhaps the most basic level of gesture-speech relation is *substitution*, where a communicative act exists only in the nonverbal modality. A speaker can respond to "which table?" by pointing to the table without any co-produced speech whatsoever. Both children and adults frequently substitute gestures for speech, but the substitution relationship may have special relevance in early childhood, when productive vocabulary is limited, overall speech production is low, and isolated gestures frequently serve as full communicative acts (Bates et al., 1975; Iverson & Goldin-Meadow, 2005).

This substitutive relationship is particularly useful for the comparison of beats and palm-up gestures because it highlights one of the most problematic issues with treating the two forms as one and the same. Palm-ups may be produced either with or without speech but beats are never produced without speech. As co-speech gestures, palm-ups perform a range of pragmatic functions, some very similar to beats, but they are also meaningful on their own. Using the example above, another communicative and valid response to "which table?" would be to indicate lack of knowledge by performing a palm-up instead of a speech act. Beats, in contrast, must be produced with speech by definition. Beats serve to add emphasis to some element of a verbal utterance. A beat without speech would not be a beat at all. Both palm-ups and beats may (at least in theory) take a reinforcing, disambiguating, or supplementing relationship to co-produced speech, but only palm-ups may take a substituting relationship.

Present Study

The present study explores how pragmatic gestures fit into a multimodal approach to the study of pragmatic development. We look at two dimensions of pragmatic gestures likely to reveal meaningful categorical distinctions within pragmatic gestures, if such distinctions are in fact worth making. First, we divide along gesture form between beats and palm-up gestures. Second, we divide communicative acts by the gesture-speech substitution relation: co-speech gestures produced simultaneously with a verbal utterance and "no-speech" gestures comprising a full communicative act which substitutes for a verbal utterance.

Focusing on these two dimensions of how children construct communicative intent with gesture and speech can illustrate the importance of giving pragmatic gestures the same considerations given to topic gestures. Is it sufficient to treat pragmatic gestures as a unified functional category? If not, what distinctions within this category are significant?

We ask three primary research questions. First, do gestures differing across these dimensions have different developmental onsets? Second, do differences across these dimensions relate to differences in frequency of use over development? Finally, do differences across these dimensions relate to differences in the pragmatic functions of communicative acts in early childhood, both overall and across early development?

Methods

Participants

Subjects were a subset of families participating in an ongoing longitudinal study of language development at the University of Chicago, which includes 64 typically-developing children and their families. Participants were recruited from the greater Chicago area through mailers to targeted zip codes and advertisements placed in a free, monthly parenting magazine. Responding parents were interviewed for background characteristics and to confirm a monolingual, English-speaking household.

The final sample was demographically representative of the greater Chicago area, as reported in the 2000 U.S. Census, in terms of race/ethnicity, household income, and parent education. See Rowe (2008) for additional information regarding participant recruitment and demographics of the full sample.

Capitalizing on annotation from prior research, these analyses are limited to a subsample of 18 children (8 girls). This cohort was first selected by Cartmill, Hunsicker, and Goldin-Meadow (2014) to maximize range of early verbal skill. Inclusion was determined by averaging children's mean length of utterance (MLU) across the first five observations (between 14 and 30 months), then selecting the 6 subjects with highest MLU, (M = 2.04 $\pm$ 0.10; 3 girls), lowest MLU (M = 1.22 $\pm$ 0.06; 2 girls), and median MLU (M = 1.52 $\pm$ 0.06; 3 girls).

The subsample of families was diverse in terms of household income, parent education, and race and comparable to the larger sample of 64 families (Table 1). The participants included 11 White Non-Hispanic, 1 White Hispanic, 4 Black/African-American, and 2 children of mixed/other race. Household income was reported in six brackets and ranged from less than $15,000 to more than $100,000 per year. Based on the bracket midpoints, approximate average yearly household income was $74,000. Maternal education ranged from less than 12 years (no high school diploma or equivalent) to more than 18 years (advanced or professional degree). The most commonly reported education level was completion of a Bachelor's degree.

Data Collection

Families were visited in their homes every 4 months when children were between 14 and 48 months of age. At each of the 12 home visits, 90 minutes of spontaneous interaction between children and their primary caregiver(s) was captured with audio and video recording. Families were instructed to behave as usual, as though the experimenter was not there. The videos capture a wide range of typical day-to-day activities from early childhood, such as reading books, playing with toys, doing jigsaw

puzzles, watching television, and eating meals. One family did not complete the home visit at 50 months. The remaining 17 families completed all 12 early childhood sessions.

Transcription & Annotation

Base transcription and gesture annotation

Annotation for this study was conducted using existing transcripts with base gesture annotation. For the original transcripts, all spontaneous speech by participant children and primary caregivers was transcribed in Microsoft Excel. Speech was transcribed verbatim but not phonetically and included conventionalized communicative sounds (e.g., “mmhm”, “ouch”). In the EC visits, caregiver speech directed to other adults was not transcribed unless the child was clearly attending to it. Speech was transcribed at the utterance level, with breaks between utterances decided by multiple criteria including pause length, grammatical structure, and intonational contour. To ensure high inter-coder reliability, agreement was calculated for both word units and utterance boundaries. Before independently transcribing videos, coders were required to reach 95% agreement with model transcripts for word and utterance metrics. Approximately one-third of transcripts were partially double-coded by a second expert transcriber. Transcripts with less than 90% agreement on either metric were rejected and re-transcribed until satisfactory agreement was reached.

Transcribers simultaneously annotated communicative gestures from both caregivers and children alongside speech transcription. This first-layer gesture annotation including codes for form (e.g., “point”, “thumbs up”, “iconic”, “beat”), body part(s) and side(s), and approximate gloss. Agreement for gesture annotation followed the same procedures as transcription reliability described above. See Huttenlocher et al. (2010) for full transcription procedures and reliability and Rowe and Goldin-Meadow (2009) for first-level gesture coding procedures and reliability.

Pragmatic gesture annotation

Using these transcripts, children's communicative acts produced with a beat or palm-up gesture were coded for pragmatic function using an annotation scheme adapted from Ninio et al. (1994) and originally described in Vilà-Giménez et al. (2021). Most communicative acts included a verbal utterance with co-speech gesture, but gesture-only acts produced in silence ("no-speech") were also included. Annotation was conducted using transcripts only, without access to audio or video. This method allowed coders to make judgments about pragmatic function at the utterance level, based solely on the speech and fundamental gesture characteristics of a communicative act rather than cues from prosody, facial expression, or visual information in the physical context.

Coding included four broad categories of pragmatic function with an additional six subcategories, following the commitment space semantics framework from Krifka (2015):

1. *Unbiased assertions.* Communicative acts in this category were those with declarative or explanation illocutionary force and no markers of modality.
2. *Biased assertions or questions.* These acts express a degree of commitment to the truthfulness of the proposition, often in relationship to an interlocutor's contribution. Subcategories of biased assertions were epistemic uncertainty (including questions and requests for information), epistemic agreement, and negation.
3. *Requesting speech acts.* These acts include both imperative and interrogative forms of requests for action (rather than information).
4. *Expressive speech acts.* These acts included exclamations and utterances primarily serving to convey emotion ("hooray!", "ouch!") as well as performative markings (e.g., "the end", "sorry").

Coding occurred at the level of the gesture, so that single utterances containing multiple co-speech gestures had multiple pragmatic function codes. Judgments about communicative intent were based on the communicative acts and the immediate conversational context, including five acts before

and after the target act. The "unclear" code was used for cases with insufficient context to determine the pragmatic function of an utterance or gesture, for example, when the child talked to a non-caregiver adult who was not transcribed.

All transcripts were annotated for pragmatic function by one coder. Inter-rater reliability was determined by having a second coder double code 20% of the transcripts. Inter-rater reliability for pragmatic function was high (Cohen's κ=.846, $p<.001$). Annotation disagreements were resolved by coder consensus.

Data Analysis

We performed a longitudinal analysis examining the relationships between children's pragmatic gesture form, co-presence with speech, and pragmatic function between 14 and 58 months of age. All analyses were conducted using R (Version 4.1.3; R Core Team, 2022) and the R-packages lme4 (Version 1.1.28; Bates et al., 2015), nnet (Version 7.3.17; Venables & Ripley, 2002), rstatix (Version 0.7.0; Kassambara, 2021), and tidyverse (Version 1.3.1; Wickham et al., 2019).

Results

Children's gestures were compared along two dimensions: (1) gesture form (beat vs. palm-up) and (2) presence or absence of co-produced speech (co-speech vs. no-speech). Theoretically this two-by-two analysis creates four possible constructions for communicative acts. However, a defining characteristic of beat gestures is a rhythmic marking of speech. Beat forms are therefore necessarily co-speech. In order to avoid problems of multicollinearity, the analyses that follow combine the two dimensions into the single variable of gesture construction for the communicative act. The three possible gesture constructions were no-speech palm-ups, co-speech palm-ups, and co-speech beats. Figures are formatted to clearly differentiate gestures along both dimensions, but all analyses were performed using the single gesture construction variable. Full models and statistical tables are included in the supplemental materials.

Age of Onset

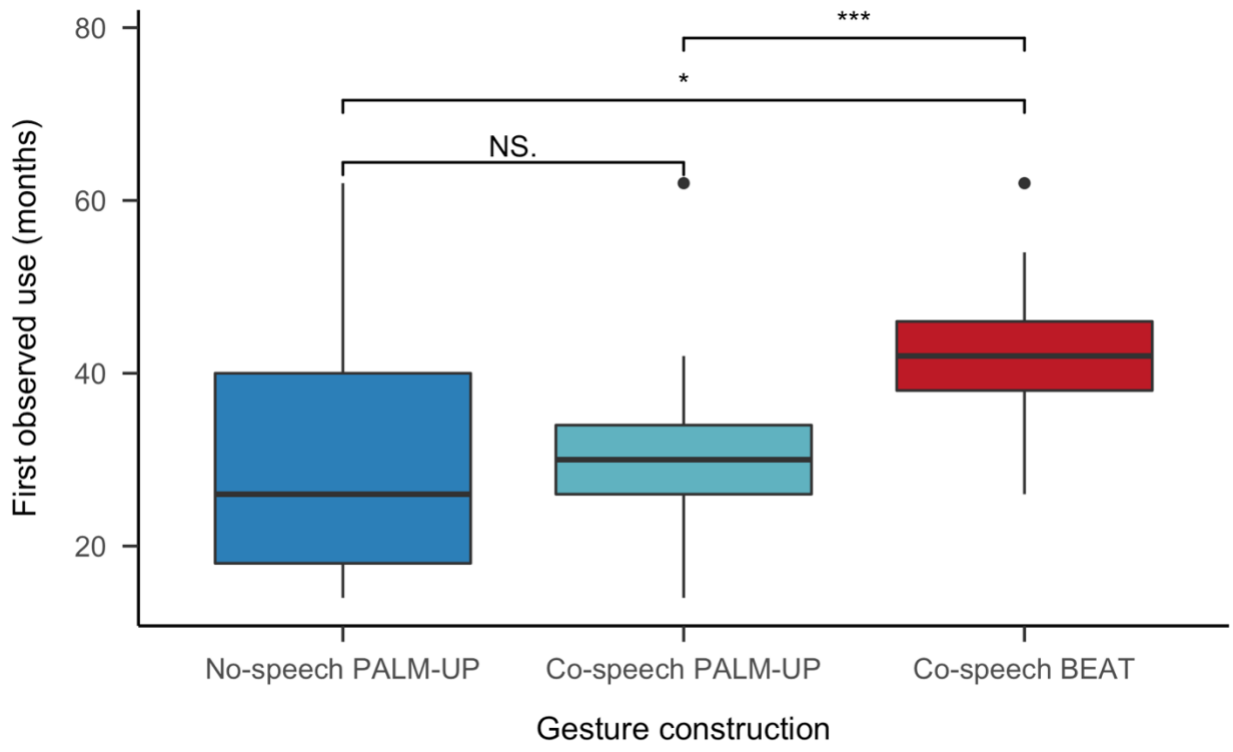
A first descriptive analysis compared age of production onset for each of the three possible gesture constructions: no-speech palm-ups, co-speech palm-ups, and co-speech beats. Age of onset was defined as the child's age in months at the session where the child was first observed to produce the gesture.[2]

Both co-speech and no-speech palm-ups were typically first produced around the 30-month visit. Mean onset for no-speech palm-ups was 30.44 months (*SE* = 3.71) and 31.11 (*SE* = 2.44) for co-speech palm-ups. Average onset for beat production was one year later, at the 42-month visit (*M* = 42, *SE* = 2.10; Figure 1).

Figure 1

Distribution of mean production onsets for pragmatic gesture constructions. Palm-up gestures with and without speech onset one year before beats.

[2] The overall rarity of pragmatic gestures in children's spontaneous interaction necessitated loose criteria for onset. Using stricter criteria (e.g., requiring the gesture construction to be produced at two sessions in a row) resulted in a similar but non-significant trend.



A one-way ANOVA showed significant variation in mean age of onset ($F(2, 51) = 5.23$, $p = .009$). Pairwise comparisons using t-tests with Bonferroni adjustment revealed significant differences in mean age of onset between co-speech beats and co-speech palm-ups ($p = .004$) and between co-speech beats and no-speech palm-ups ($p = .030$). There was no significant difference in age of onset between the two palm-up forms.

The results indicate the onset of these pragmatic gesture constructions is more tied to gesture form than the presence or absence of speech.

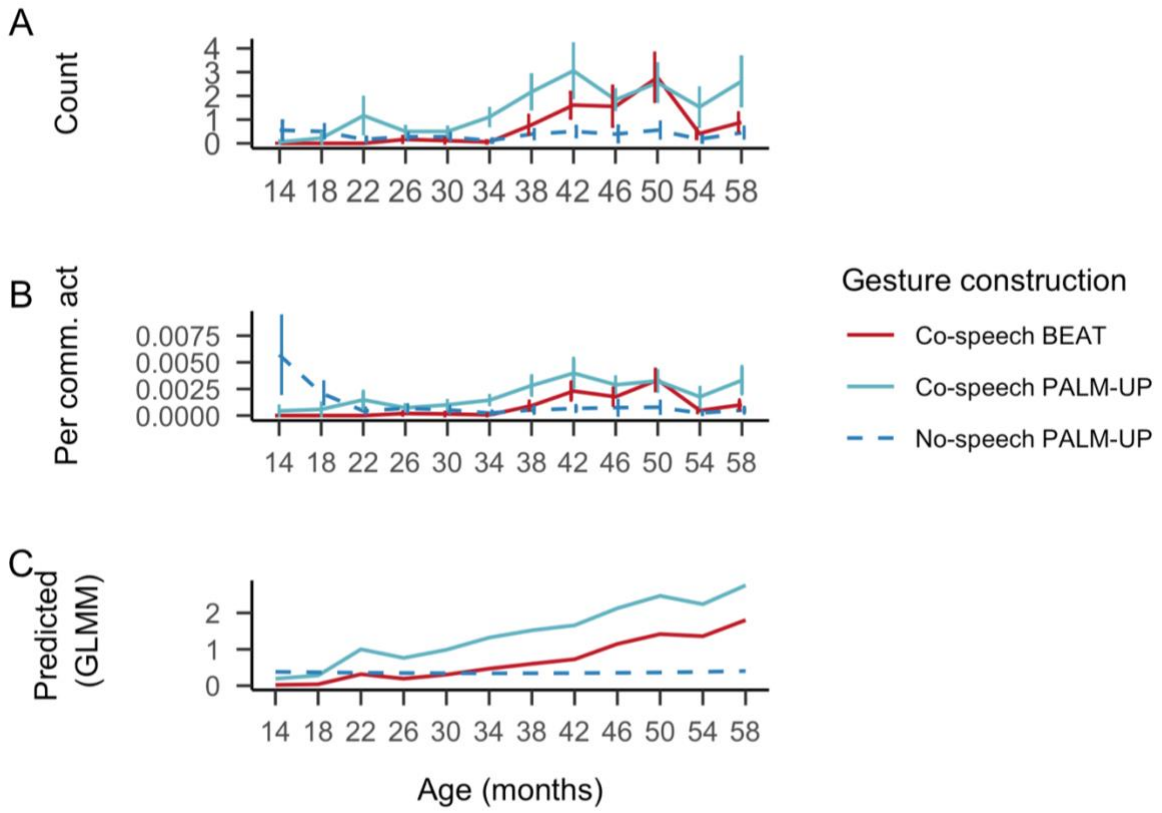
Frequency of Production

We next built a Poisson mixed-effects regression model to compare children's frequency of use for each gesture construction across the twelve sessions. The final model included fixed effects for gesture construction (factorial; no-speech palm-up, co-speech palm-up, or co-speech beat), child age in months (numeric), number of communicative acts produced by the child at each session (numeric,

centered) and interactions between gesture construction and both age and number of communicative acts and a random slope for age by subject.

Figure 2

Actual and predicted frequencies of gesture across time. Children produce more co-speech beats and palm-ups, but not no-speech palm-ups, between 14 and 58 months. These trends are similar for raw frequency of observed gestures (A), gestures as a proportion of communicative acts (B), and frequencies predicted by GLMM (C).



Generally, children increased production of both co-speech gesture constructions over time and with increasing amount of communicative acts but did not increase production of no-speech palm-ups (Figure 2A). These trends were similar for observed gestures as a proportion of each child's total number of communicative acts at each session (Figure 2B) and for predicted frequencies using the GLMM regression (Figure 2C). There were significant interactions of co-speech beats with age (β = 0.07, *SE* = 0.01, $p < .001$) and number of communicative acts (β = 0.96, *SE* = 0.12, $p < .001$). Similarly, there were

significant interactions of co-speech palm-ups with age (β = 0.04, *SE* = 0.01, *p* < .001) and number of communicative acts (β = 0.68, *SE* = 0.08, *p* < .001). Conversely, production of no-speech palm-ups did not vary across age or number communicative acts.

Critically, the increases in production across time for both co-speech constructions existed above and beyond overall increases in amount of talk. That is, children do produce more co-speech gesture as they produce more verbal utterances, but this predictable increase does not fully explain the observed upward trajectories of co-speech gesture frequency across early childhood (see Table 5 and Figure 6 in supplemental materials for model comparison).

Gesture Construction and Pragmatic Function

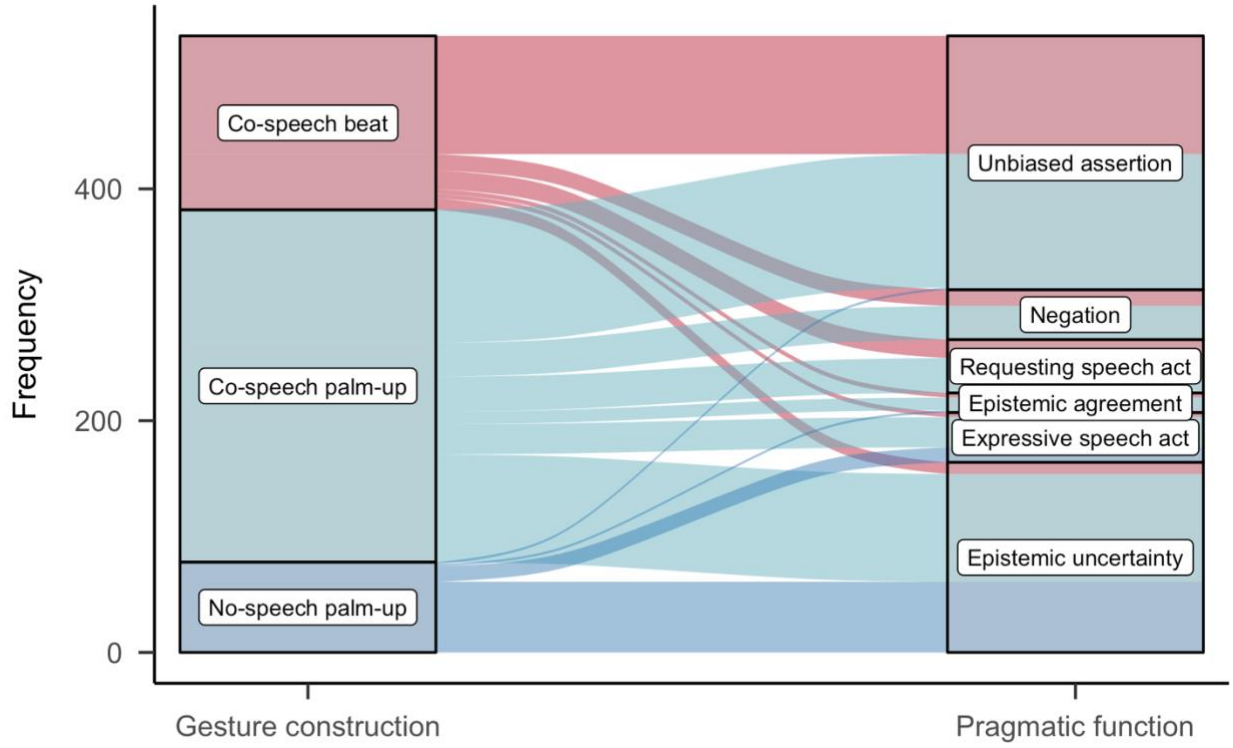
The final research question asks whether differences in gesture construction are associated with particular pragmatic functions in children's early communication. In a first analysis, we compare overall relationships between constructions and functions. In a second analysis, we use a multinomial logistic regression to model how these relationships change across development.

Overall construction-function associations

We first explored relationships between types of gesture act construction and the pragmatic functions for all child-produced beats and palm-ups in the data. A Chi-square Test of Independence revealed a significant relationship between a communicative act's pragmatic function and gesture construction (X^2 = 168.91, p < .001). The majority of co-speech beats were produced with unbiased assertions (68%) and the majority of no-speech palm-ups communicated epistemic uncertainty (78.21%). Co-speech palm-ups accompanied acts with a range of pragmatic functions and had no clear primary function. **Error! Reference source not found.** visualizes these relationships as an alluvial plot, where band widths represent the frequency that gestures within each category of construction serve each pragmatic function.

Figure 3

Overall associations between gesture constructions and pragmatic functions. Co-speech beats are primarily associated with unbiased assertions. No-speech palm-ups are primarily associated with epistemic ignorance. Co-speech palm-ups are not associated with a primary pragmatic function.



Post-hoc analyses with Bonferroni adjustment confirmed a strong positive association between co-speech beats and unbiased assertions (Std. residual = 7.88, $p < .001$) and a strong positive association between no-speech palm-ups and epistemic uncertainty (Std. residual = 9.81, $p < .001$). There was no significant positive or negative association between co-speech palm-ups and any category of pragmatic function (see Table 6 and Figure 7 in supplemental materials).

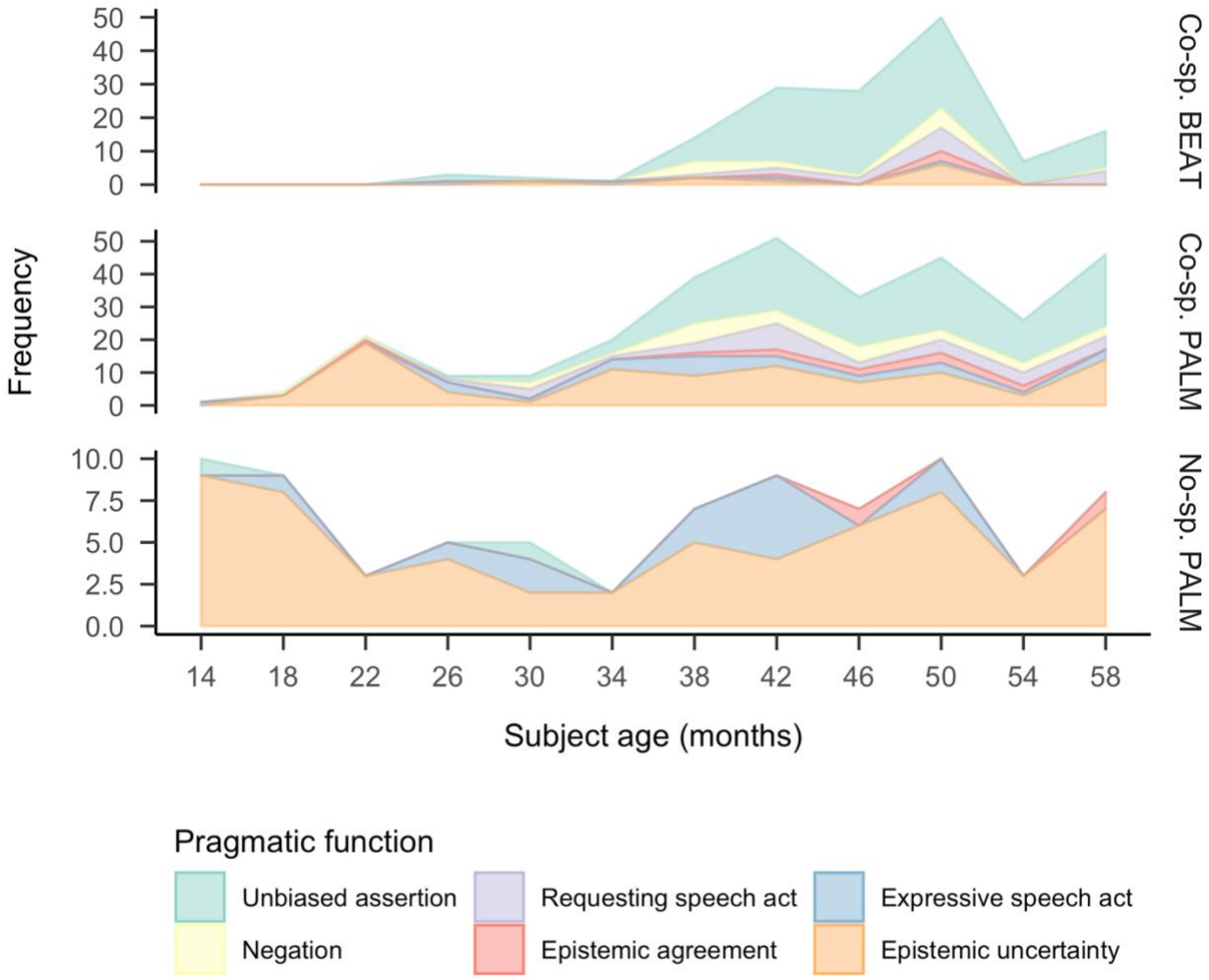
Functional change over development

A follow-up analysis modeled how these overall relationships between gesture construction and pragmatic function changed across early childhood. Figure 4 plots how often each of the three gesture constructions was produced with the six pragmatic functions, where frequency is summed across all

children at each of the 12 visits. The overall associations between co-speech beats and unbiased assertions and between no-speech palm-ups and epistemic uncertainty appear to hold across time.

Figure 4

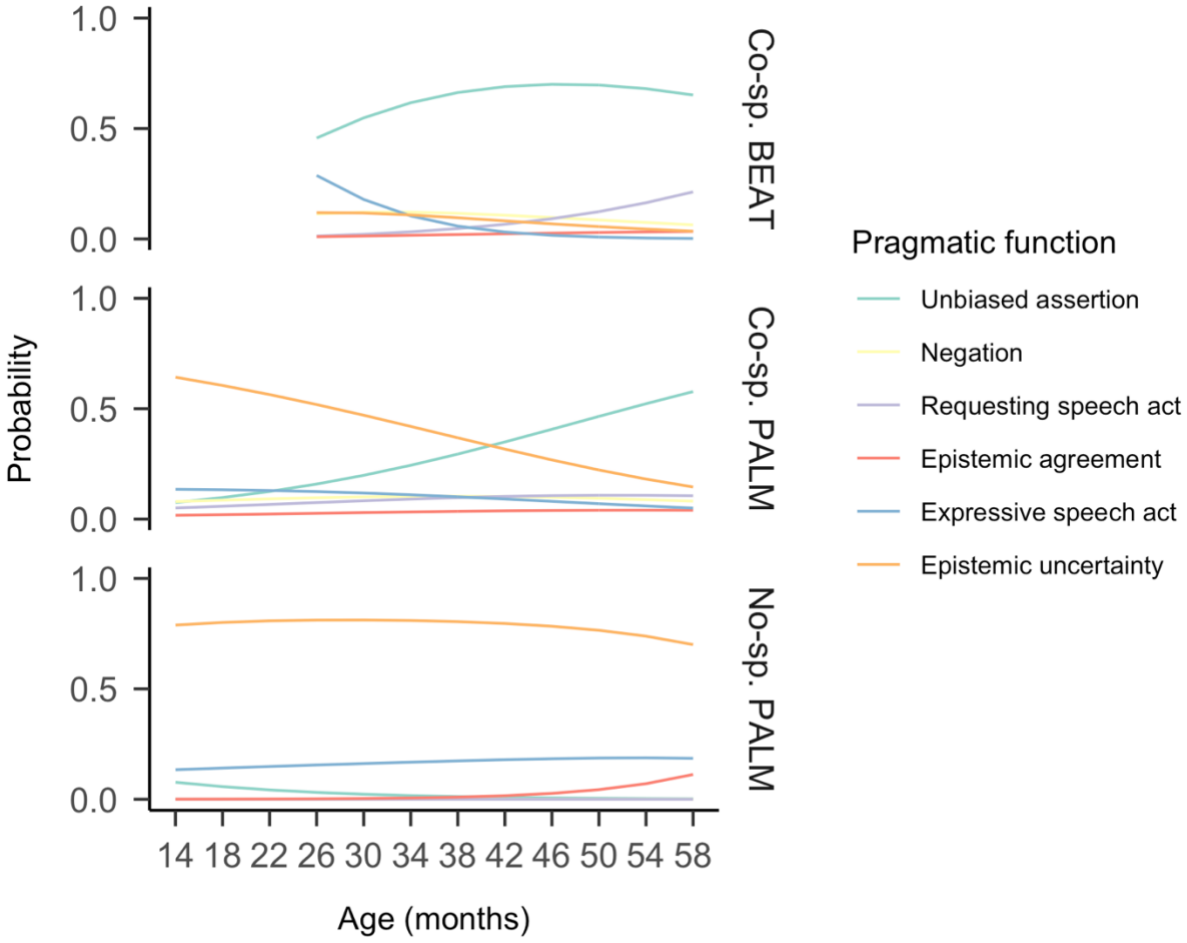
Pragmatic function by gesture construction across time. Overall associations between co-speech beats and unbiased assertions and between no-speech palm-ups and epistemic uncertainty hold across time.



We used a multinomial logistic regression to model the likelihood of a communicative act serving each pragmatic function predicted by the type of gesture construction (factor) and the interaction between gesture construction and age in months (numeric, recentered; Table 7). The predicted trends are modeled in Figure 5, where the y-axis represents the probability that a given gesture construction serves each pragmatic function across the observation period.

Figure 5

Predicted likelihood of pragmatic function for shrugs across early childhood. Curves represent the likelihood a communicative act will serve the pragmatic function based on the act's gesture construction across EC, predicted by multinomial logistic regression. As children develop, their co-speech palm-ups are less associated with epistemic uncertainty and more associated with unbiased assertions. Most associations between gesture construction and pragmatic function are consistent over time.



To test the significance of these trends, we performed a logistic regression for each pragmatic function, predicted by type of gesture construction, child's age in months, and their interaction. Most gesture construction/pragmatic function relationships did not have statistically significant change over time, but there were several exceptions, consistent with the multinomial model.

Between 14 and 58 months, co-speech beats were decreasingly associated with expressive acts (β = -0.16, *SE* = 0.06, *p* = .014). Co-speech palm-ups were increasingly associated with unbiased

assertions (β = 0.06, *SE* = 0.01, $p < .001$) and decreasingly associated with epistemic uncertainty (β = -0.06, *SE* = 0.01, $p < .001$).

Discussion

These analyses show that two simple dimensions of gesture use relate to differences in how young children use pragmatic gestures, with consequences for how we understand gesture's role in pragmatic development. We identified a group of gestures produced frequently by infants and young children which are inconsistently defined and relatively understudied. We focused on two dimensions of gesture, form and presence of co-produced speech, which may be clearly recognized and differentiated among gestures in this group. The three analyses in this study illustrate how these dimensions of pragmatic gesture feature in early language development.

First, the form of the gesture construction, but not presence of speech, was related to the age children first produced these gestures. Children began using palm-up gestures about a year before beat gestures. Given that beat gestures must be produced with speech while palm-up gestures may be produced alone, one intuitive explanation for this is that because beats are necessarily co-speech there is simply no opportunity for co-speech gestures before children have sufficiently advanced verbal abilities. However, the fact that children produced co-speech palm-ups as early as they first produced no-speech palm-ups means children do have the opportunity and capability for co-speech gesture acts. The difference in productive onset is driven by form, not gesture-speech relation.

If the difference in onset of beats and palm-ups is not explained by whether or not the forms can be produced without speech, what else might be driving this effect? Perhaps it is due to specific physical features of these forms. If the palm-up form was less complex than beats or required less manual dexterity, infants could produce them earlier in motor development. In reality, however, just the opposite is true. In this system of gesture annotation, the identifying features of a palm-up are significantly more physically involved than a beat. A palm-up is identified by a specific handshape and

specific movement, where the fingers are extended away from the palm and there is a visible outward rotation of the wrist. The only identifying characteristic of a beat gesture (in this annotation scheme) is a pronounced and punctuated movement. A beat may take any handshape and the movement may be in any direction. The variation in onset then is not sufficiently explained by dexterity limitations.

One important difference between palm-ups and beats is that palm-ups often serve lexical or emblematic functions while beats generally do not carry semantic meaning. The palm-ups children produced before the onset of beats did not exclusively function emblematically, with co-speech palm-ups in particular serving a range of pragmatic functions soon after onset. Still, these earliest co-speech palm-ups were much more likely to communicate epistemic uncertainty than co-speech palm-ups in the later sessions. It may be that the mere possibility for palm-ups to take topical meanings encourages children to more easily add them to their gesture lexicon, allowing pragmatic functions to grow from early emblematic use. Beats, on the other hand, never function emblematically and are always produced in complement to meaning in speech. It may be more difficult for children to add this exclusively pragmatic gesture to their repertoire from scratch.

Though the substitution gesture-speech relation, determined solely by presence or absence of speech, was not associated with productive onset, other relationships between co-speech gestures and speech might explain the observed differences. Beats are, definitionally, rhythmic with a reinforcing relationship to speech. They are tied to prosody and add emphasis but not meaning. Co-speech palm-ups are often similar to beats in these ways, linked to prosody and emphasizing linguistic meaning, but frequently have a supplementing relationship to speech rather than a reinforcing relationship. Gesture and prosody work as “sister systems” in communicative development (Hübscher & Prieto, 2019) and children’s gesture-speech “mismatches” (i.e., gesture supplementing speech with additional meaning) can indicate transitions between stages of language development (Butcher & Goldin-Meadow, 2000; Özçalışkan & Goldin-Meadow, 2005). Given the differences in gesture-speech relation expected

between co-speech beats and co-speech palm-ups, a closer look at these relationships might address why these forms differ in onset in ways unexplained by the characteristics of the physical forms themselves.

In general, the results of the first analysis indicate that differentiating along the dimension of form is necessary to avoid misinterpreting observations about functional use of pragmatic gestures. Without this categorical division, the onset for a broad category of "pragmatic gestures" or "non-referential gestures" would be considerably earlier than when children actually begin producing rhythmic, reinforcing beat gestures. Separating along the form dimension allows us to ask what properties of beats lead to them entering children's gesture lexicons later in pragmatic development.

The second analysis in this study compared how frequencies of gesture production changed across early development. Differences in frequency trajectories differed by presence or absence of co-produced speech. Use of co-speech gestures, both palm-ups and beats, increased after onset. Use of no-speech palm-ups decreased across the observation period, with the steepest decline appearing at the earliest visits, between 14 and 22 months of age. Although it may seem intuitive that co-speech gestures increase across the span of early development marked by dramatic growth in vocabulary and syntax, increases in co-speech gesture use are not fully explained by increases in overall quantity of speech. Co-speech beats and co-speech palm-ups were produced at increasing rates even as a proportion of overall amount of talk. Although it is true that children have more opportunities to produce co-speech gestures as they produce more speech acts, children in this study increasingly integrated beat and palm-up gestures with speech acts above and beyond what would be expected from increased opportunity.

While it may come as no surprise that no-speech gestures did not increase at rates comparable to co-speech gestures, there is no reason to presume they should not increase at all. The rapid increase in the number of speech acts young children produce in spontaneous interaction means an increase in the higher-order category of communicative acts as well. Conversation is not a zero-sum game between

verbal and non-verbal turns. As children contribute more to a dialogue, they have every opportunity to contribute more gesture-only communicative acts, but this was not the case. Not only did children not increase their production of no-speech pragmatic gestures, no-speech gestures decreased in use as a proportion of overall number of turns. It seems that the frequency with which children produce these gesture constructions is tied to developing pragmatic skills *in speech*.

Dividing along the dimension of gesture-speech relation brings this stark contrast between co-speech and no-speech pragmatic gestures to light. In this early stage of pragmatic development, children are changing how they integrate verbal and nonverbal modalities, not simply how much they communicate in each. Without the distinction between speech presence and absence, co-speech and no-speech gestures are at odds with one another in an analysis of frequency of use, obscuring or mitigating the relationship between verbal and non-verbal development. With this distinction, we see that children's use of pragmatic gesture is not simply hitching a ride with speech. Instead, children's use of pragmatic gesture is intertwined with – but not perfectly parallel to – pragmatic changes in the verbal modality.

The final analyses showed that both form and substitutive gesture-speech relation relate to the pragmatic functions of communicative acts in early childhood and to how those functions change over time. Co-speech beats and no-speech palm-ups each tended to serve one primary pragmatic function at onset, unbiased assertion and epistemic uncertainty respectively, and maintained a strong bias toward these functions across early childhood.

Co-speech palm-ups were not associated with a single primary function. Instead, they seemed to be influenced by both form and gesture-speech relation. Co-speech and no-speech palm-ups "flocked together" in the first half of the observation period. These two variations on the palm-up form shared a productive onset and both tended to perform epistemic uncertainty. In the later visits, the function of co-speech palm-ups shifted to more closely "flock" with co-speech beats. The association with epistemic

uncertainty decreased as co-speech palm-ups became more likely to accompany acts of unbiased assertion.

Despite an increasing alignment with beats along the dimension of gesture-speech relation, co-speech palm-ups never took on a primary function. They continued to frequently accompany acts of epistemic uncertainty and were more likely than either co-speech beats or no-speech palm-ups to serve other pragmatic functions.

Adults use palm-up gestures with tremendous flexibility in function (Cooperrider et al., 2018; Debras, 2017; Jehoul et al., 2017). This analysis hints at what properties of these gestures allow for this flexibility and where in language development it begins to emerge. By the final observation at 58 months, children's co-speech palm-ups were pulled in two directions by these two dimensions of form and gesture-speech relation. If no-speech palm-ups largely operate emblematically as a non-verbal stand-in for "I don't know" and beats exclusively function pragmatically, co-speech palm-ups find multiple meanings somewhere between the two extremes.

Failing to break apart these pragmatic gestures into constructions based on both form and gesture-speech relation distorts their functional trajectories. Because co-speech palm-ups are much more common than no-speech palm-ups, grouping these pragmatic gestures by form alone masks the strong association between no-speech palm-ups and epistemic uncertainty across early childhood and perhaps emblematic roots of palm-ups gestures in language development. Grouping by presence or absence of speech without a division by form fails to account for how commonly palm-up gestures function emblematically. An analysis lumping together co-speech beats and co-speech palm-ups under a broad label of "non-referential gestures" may not identify early relationships between these gestures and complex pragmatic meanings because it includes gestures primarily operating on a semantic rather than pragmatic level.

Pragmatic development is a long and complicated process, where different pragmatic skills are highly dependent on other linguistic, cognitive, and social skills that continue to develop well beyond early childhood. Dividing along the dimensions of gesture form and gesture-speech relation allows us to examine how pragmatic gestures can perform more specified roles in development than just "doing pragmatics." Epistemic expression (like no-speech palm-ups expressing ignorance) is not the same pragmatic skill as emphasizing selective information (like beats adding emphasis to assertions). Nor is it the same as selecting request-making strategies, soliciting attention, negating, or marking affect (functions frequently performed by co-speech palm-ups but rarely by no-speech palm ups or co-speech beats). Breaking down how different pragmatic gesture constructions serve different pragmatic functions helps us understand how children develop proficiency putting together many separate contextual puzzles into discourse.

This study carves up a gesture space in an oversimplified way. We considered just two possible dimensions in which pragmatic gestures can differ and just two possibilities within each dimension. We do not claim that these basic divisions give a complete model of pragmatic gesture's role in early language development. Instead, these results indicate that even such simplistic divisions provide compelling reasons to avoid over-generalizations of pragmatic gestures in developmental research. If we afford pragmatic gestures the same fine-grained attention we give to topic gestures – like differentiating between complete and reduced palm-ups or allowing for multiple categories of gesture-speech relation for co-speech gestures – we can more fully appreciate how children use gesture and speech together pragmatically in early communicative development.

Acredolo, L. P., & Goodwyn, S. W. (1985). Symbolic gesturing in language development. *Human Development*, *28*(1), 40–49.

Balcomb, F. K., & Gerken, L. (2008). Three-year-old children can access their own memory to guide responses on a visual matching task. *Developmental Science*, *11*(5), 750–760.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48.

Bates, E., Camaioni, L., & Volterra, V. (1975). The acquisition of performatives prior to speech. *Merrill-Palmer Quarterly of Behavior and Development*, *21*(3), 205–226.

Bavelas, J. B., Chovil, N., Lawrie, D. A., & Wade, A. (1992). Interactive gestures. *Discourse Processes*, *15*(4), 469–489.

Beattie, G., & Shovelton, H. (2002). An experimental investigation of the role of different types of iconic gesture in communication: A semantic feature approach. *Gesture*, *1*(2), 129–149.

Beaupoil-Hourdel, P., & Debras, C. (2017). Developing communicative postures: The emergence of shrugging in child communication. *Language, Interaction and Acquisition*, *8*(1), 89–116.

Beaupoil-Hourdel, P., Morgenstern, A., & Boutet, D. (2015). Beaupoil-Hourdel, P., Morgenstern, A., & Boutet, D. (2015). A child's multimodal negations from 1 to 4: The interplay between modalities. In *Negation and polarity: Experimental perspectives* (pp. 95-123). Springer, Cham.

Benazzo, S., & Morgenstern, A. (2014). A bilingual child's multimodal path into negation. *Gesture*, *14*(2), 171–202.

Borràs-Comes, J., Roseano, P., Vanrell Bosch, M., Chen, A., & Prieto, P. (2011). Perceiving uncertainty: facial gestures, intonation, and lexical choice. *Proceedings of GESPIN*.

Boutet, D. (2018). The dual origin of gesture: Semiotic preconditions for the emergence of two kinds of symbolic gestures. *Language, Interaction and Acquisition. Langage, Interaction et Acquisition*, *8*(2), 288–310.

Butcher, C., & Goldin-Meadow, S. (2000). Gesture and the transition from one- to two-word speech: When hand and mouth come together. In D. McNeill (Ed.), *Language and gesture* (pp. 235–258). New York: Cambridge University Press.

Cartmill, E. A., Hunsicker, D., & Goldin-Meadow, S. (2014). Pointing and naming are not redundant: Children use gesture to modify nouns before they modify nouns in speech. *Developmental Psychology*, *50*(6), 1660–1666.

Caselli, M. C. (1983). Communication to language: Deaf children's and hearing children's development compared. *Sign Language Studies*, *1039*(1), 113–144.

Chu, M., Meyer, A., Foulkes, L., & Kita, S. (2014). Individual differences in frequency and saliency of speech-accompanying gestures: The role of cognitive abilities and empathy. *Journal of Experimental Psychology: General*, *143*(2), 694–709.

Cochet, H., & Vauclair, J. (2014). Deictic gestures and symbolic gestures produced by adults in an experimental context: Hand shapes and hand preferences. *Laterality: Asymmetries of Body, Brain and Cognition*, *19*(3), 278–301.

Colletta, J.-M., Guidetti, M., Capirci, O., Cristilli, C., Demir, O. E., Kunene-Nicolas, R. N., & Levine, S. (2015). Effects of age and language on co-speech gesture production: An investigation of french, american, and italian children's narratives. *Journal of Child Language*, *42*(01), 122–145.

Colletta, J.-M., Pellenq, C., & Guidetti, M. (2010). Age-related changes in co-speech gesture and narrative: Evidence from french children and adults. *Speech Communication*, *52*(6), 565–576.

Cooperrider, K., Abner, N., & Goldin-Meadow, S. (2018). The palm-up puzzle: Meanings and origins of a widespread form in gesture and sign. *Frontiers in Communication*, *3*, 23.

Debras, C. (2017). The shrug: Forms and meanings of a compound enactment. *Gesture*, *16*(1), 1–34.

Demir, Ö. E., Fisher, J. A., Goldin-Meadow, S., & Levine, S. C. (2014). Narrative processing in typically developing children and children with early unilateral brain injury: Seeing gesture matters. *Developmental Psychology*, *50*(3), 815–828.

Dijkstra, C., Krahmer, E., & Swerts, M. (2006). Manipulating uncertainty. The contribution of different audiovisual prosodic cues to the perception of confidence. *Proceedings of the Speech Prosody Conference*.

Dimitrova, D., Chu, M., Wang, L., Özyürek, A., & Hagoort, P. (2016). Beat that word: How listeners integrate beat gesture and focus in multimodal speech discourse. *Journal of Cognitive Neuroscience*, *28*(9), 1255–1269.

Ekman, P., & Friesen, W. V. (1969). The repertoire of nonverbal behavior: Categories, origins, usage, and coding. In A. Kendon, T. A. Sebeok, & J. Umiker-Sebeok (Eds.), *Nonverbal Communication, Interaction, and Gesture* (Vol. 41, pp. 57–106). De Gruyter Mouton.

Esteve-Gibert, N., & Prieto, P. (2014). Infants temporally coordinate gesture-speech combinations before they produce their first words. *Speech Communication*, *57*, 301–316.

Givens, D. B. (1977). Shoulder shrugging: A densely communicative expressive behavior. *Semiotica*, *19*(1–2), 13–28.

Graziano, M. (2014). The development of two pragmatic gestures of the so-called open hand supine family in Italian children. In M. Seyfeddinipur & M. Gullberg (Eds.), *From Gesture in Conversation to Visible Action as Utterance* (pp. 311–330). John Benjamins Publishing Company.

Guidetti, M. (2005). Yes or no? How young French children combine gestures and speech to agree and refuse. *Journal of Child Language*, *32*(4), 911–924.

Harris, P. L., Bartz, D. T., & Rowe, M. L. (2017). Young children communicate their ignorance and ask questions. *Proceedings of the National Academy of Sciences*, *114*(30), 7884–7891.

Harris, P. L., Yang, B., & Cui, Y. (2017). 'I don't know': Children's early talk about knowledge. *Mind & Language*, *32*(3), 283–307.

Hemphill, L., & Siperstein, G. N. (1990). Conversational competence and peer response to mildly retarded children. *Journal of Educational Psychology*, *82*(1), 128–134.

Hickmann, M., & Bassano, D. (2016). Modality and mood in first language acquisition. In *The Oxford Handbook of Modality and Mood*.

Hickmann, M., Champaud, C., & Bassano, D. (1993). Pragmatics and metapragmatics in the development of epistemic modality: Evidence from French children's reports of think-statements. *First Language*, *13*(39), 359–388.

Hollos, M. (1975). *Comprehension and use of social rules in pronoun selection by Hungarian children. Working papers in sociolinguistics, no. 24*.

Holtgraves, T. (2000). Preference Organization and Reply Comprehension. *Discourse Processes*, *30*(2), 87–106.

Hostetter, A. B. (2011). When do gestures communicate? A meta-analysis. *Psychological Bulletin*, *137*(2), 297–315.

Hübscher, I., Borràs-Comes, J., & Prieto, P. (2017). Prosodic mitigation characterizes Catalan formal speech: The frequency code reassessed. *Journal of Phonetics*, *65*, 145–159.

Hübscher, I., Esteve-Gibert, N., Igualada, A., & Prieto, P. (2017). Intonation and gesture as bootstrapping devices in speaker uncertainty. *First Language*, *37*(1), 24–41.

Hübscher, I., Garufi, M., & Prieto, P. (2019). The development of polite stance in preschoolers: How prosody, gesture, and body cues pave the way. *Journal of Child Language*, *46*(05), 825–862.

Hübscher, I., & Prieto, P. (2019). Gestural and prosodic development act as sister systems and jointly pave the way for children's sociopragmatic development. *Frontiers in Psychology*, *10*.

Hübscher, I., Vincze, L., & Prieto, P. (2019). Children's signaling of their uncertain knowledge state: Prosody, face, and body cues come first. *Language Learning and Development*, *15*(4), 366–389.

Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., & Hedges, L. V. (2010). Sources of variability in children's language growth. *Cognitive Psychology*, *61*(4), 343–365.

Iverson, J. M., Capirci, O., Volterra, V., & Goldin-Meadow, S. (2008). Learning to talk in a gesture-rich world: Early communication in Italian vs. American children. *First Language*, *28*(2), 164–181.

Iverson, J. M., & Goldin-Meadow, S. (2005). Gesture paves the way for language development. *Psychological Science*, *16*(5), 367–371.

Jehoul, A., Brône, G., & Feyaerts, K. (2017). The shrug as marker of obviousness. *Linguistics Vanguard*, *3*(s1).

Johnson, H. G., Ekman, P., & Friesen, W. V. (1975). *Communicative body movements: American emblems*. 335–354.

Jokinen, K., & Allwood, J. (2010). Hesitation in intercultural communication: Some observations and analyses on interpreting shoulder shrugging. In T. Ishida (Ed.), *Culture and Computing* (Vol. 6259, pp. 55–70). Springer Berlin Heidelberg.

Kassambara, A. (2021). *Rstatix: Pipe-friendly framework for basic statistical tests*. Retrieved from https://CRAN.R-project.org/package=rstatix

Kendon, A. (2004). *Gesture: Visible action as utterance*. Cambridge University Press.

Kendon, A., & Versante, L. (2003). Pointing by hand in "Neapolitan." In *Pointing: Where Language, Culture, and Cognition Meet* (pp. 109–137).

Kim, S., Paulus, M., Sodian, B., & Proust, J. (2016). Young children's sensitivity to their own ignorance in informing others. *PLOS ONE*, *11*(3), e0152595.

Krifka, M. (2015). Bias in commitment space semantics: Declarative questions, negated questions, and question tags. *Semantics and Linguistic Theory*, *25*, 328–345.

Mathew, M., Yuen, I., & Demuth, K. (2018). Talking to the beat: Six-year-olds' use of stroke-defined non-referential gestures. *First Language*, *38*(2), 111–128.

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought*. University of Chicago Press.

Morris, D. (2015). *Bodytalk: A World Guide to Gestures*. Random House. (Original work published 1994)

Müller, C. (2004). Forms and uses of the palm up open hand: A case of a gesture family? *The Semantics and Pragmatics of Everyday Gestures*, *9*, 233–256.

Nicoladis, E., Mayberry, R. I., & Genesee, F. (1999). Gesture and early bilingual development. *Developmental Psychology*, *35*(2), 514–526.

Ninio, A., Snow, C. E., Pan, B. A., & Rollins, P. R. (1994). Classifying communicative acts in children's interactions. *Journal of Communication Disorders*, *27*(2), 157–187.

Özçalişkan, Ş., & Goldin-Meadow, S. (2005). Do parents lead their children by the hand? *Journal of Child Language*, *32*(3), 481–505.

Parrill, F., Lavanty, B., Bennett, A., Klco, A., & Demir-Lira, O. E. (2018). The relationship between character viewpoint gesture and narrative structure in children. *Language and Cognition*, *10*(3), 408–434.

R Core Team. (2022). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org.

Rowe, M. L. (2008). Child-directed speech: Relation to socioeconomic status, knowledge of child development and child vocabulary skill. *Journal of Child Language*, *35*(1), 185–205.

Rowe, M. L., & Goldin-Meadow, S. (2009). Early gesture selectively predicts later language learning. *Developmental Science*, *12*(1), 182–187.

Shattuck-Hufnagel, S., Ren, A., Mathew, M., Yuen, I., & Demuth, K. (2016). Non-referential gestures in adult and child speech: Are they prosodic? *Proc. Speech Prosody 2016*, 836–839.

Venables, W. N., & Ripley, B. D. (2002b). *Modern applied statistics with s* (Fourth). New York: Springer. Retrieved from https://www.stats.ox.ac.uk/pub/MASS4/

Vilà-Giménez, I., Demir-Lira, Ö. E., & Prieto, P. (2020, September 9). The role of referential iconic and non-referential beat gestures in children's narrative production: Iconics signal oncoming changes in speech. *Proceedings of the 7th Gesture and Speech in Interaction (GESPIN), KTH Speech, Music & Hearing and Språkbanken Tal*. Gesture and Speech in Interaction (GESPIN), KTH Speech, Music & Hearing and Språkbanken Tal, Stockholm, Sweden.

Vilà-Giménez, I., Dowling, N., Demir-Lira, Ö. E., Prieto, P., & Goldin-Meadow, S. (2021). The predictive value of non-referential beat gestures: Early use in parent–child interactions predicts narrative abilities at 5 years of age. *Child Development*, cdev.13583.

Vilà-Giménez, I., Igualada, A., & Prieto, P. (2019). Observing storytellers who use rhythmic beat gestures improves children's narrative discourse performance. *Developmental Psychology*, *55*(2), 250–262.

Vilà-Giménez, I., & Prieto, P. (2020). Encouraging kids to beat: Children's beat gesture production boosts their narrative performance. *Developmental Science*, *23*(6).

Vilà-Giménez, I., & Prieto, P. (2021). The value of non-referential gestures: A systematic review of their cognitive and linguistic effects in children's language development. *Children*, *8*(2), 148.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Yutani, H. (2019). Welcome to the tidyverse. *Journal of Open Source Software*, *4*(43), 1686.

Wilkens, D. (2003). Why pointing with the index finger is not a universal (in sociocultural and semiotic terms). In S. Kita (Ed.), *Pointing: Where Language, Culture, and Cognition Meet* (pp. 171–215). Psychology Press.

Yap, D. F., Brookshire, G., & Casasanto, D. (2018). Beat gestures encode spatial semantics. *40th Annual Conference of the Cognitive Science Society*, 6.

Supplemental Materials

Table 1

Participant demographics

Subject	Sex	Race/ethnicity	MLU group	Household income	Maternal education
42*	M	White, Non-Hispanic	Low	$15,000-$34,999	Some College or Trade School
48	M	White, Non-Hispanic	Low	>$100,000	Advanced Degree
77	F	Black	Low	<$15,000	Some High School
78	M	White, Non-Hispanic	Low	$35,000-$49,999	Advanced Degree
84	M	White, Non-Hispanic	Low	>$100,000	Some College or Trade School
105	F	White, Non-Hispanic	Low	$50,000-$74,999	Bachelor's Degree
24	F	Black	Middle	>$100,000	Advanced Degree
33	M	Black	Middle	$50,000-$74,999	Some College or Trade School
37	F	White, Non-Hispanic	Middle	$75,000-$99,999	Bachelor's Degree
62	M	White, Non-Hispanic	Middle	>$100,000	High School or GED
74	F	White, Non-Hispanic	Middle	>$100,000	Bachelor's Degree
88	M	White, Hispanic	Middle	$75,000-$99,999	Advanced Degree
29	F	Mixed/other race	High	>$100,000	Advanced Degree
43	M	White, Non-Hispanic	High	$50,000-$74,999	Bachelor's Degree
44	F	Black	High	$35,000-$49,999	Some College or Trade School
50	M	White, Non-Hispanic	High	$50,000-$74,999	Bachelor's Degree
92	M	White, Non-Hispanic	High	>$100,000	Bachelor's Degree
103	F	Mixed/other race	High	$75,000-$99,999	Bachelor's Degree

Note. Subject 42 completed 11 visits. All other subjects completed all 12 visits.

Table 2

ANOVA, gesture construction onset

Group 1	Group 2	n1	n2	Statistic	df	*p*	*p*-adj	Adj. sig.
Co-speech BEAT	Co-speech PALM-UP	18	18	3.817	17	0.001	0.004	**
Co-speech BEAT	No-speech PALM-UP	18	18	2.899	17	0.010	0.030	*
Co-speech PALM-UP	No-speech PALM-UP	18	18	0.170	17	0.867	1.000	*ns*

Table 3

GLMM Model 1 (without age), poisson; gesture frequencies predicted by gesture construction and communicative acts

	Estimate	Std. error	z value	Pr(>|Z|)
(Intercept)	-0.870	0.290	-3.001	0.003
gtypeCo-speech palm-up	0.974	0.146	6.655	0.000
gtypeNo-speech palm-up	-0.047	0.169	-0.277	0.781
gtypeCo-speech beat:n_acts_c	0.965	0.108	8.942	0.000
gtypeCo-speech palm-up:n_acts_c	0.686	0.078	8.821	0.000
gtypeNo-speech palm-up:n_acts_c	-0.173	0.123	-1.403	0.161
n_gestures ~ gtype + gtype:n_acts_c + (1|subject)				

Table 4

GLMM Model 2 (with age), poisson; gesture frequencies predicted by gesture construction, communicative acts, and child age

	Estimate	Std. error	z value	Pr(>|Z|)
(Intercept)	-4.123	0.614	-6.720	0.000
gtypeCo-speech palm-up	2.170	0.450	4.818	0.000
gtypeNo-speech palm-up	2.149	0.534	4.023	0.000
gtypeCo-speech beat:months	0.068	0.012	5.882	0.000
gtypeCo-speech palm-up:months	0.042	0.010	4.279	0.000
gtypeNo-speech palm-up:months	0.016	0.013	1.250	0.211
gtypeCo-speech beat:n_acts_c	0.958	0.115	8.358	0.000

gtypeCo-speech palm-up:n_acts_c	0.680	0.078	8.765	0.000
gtypeNo-speech palm-up:n_acts_c	-0.007	0.131	-0.054	0.957
n_gestures ~ gtype + gtype:months + gtype:n_acts_c + (months|subject)				

Table 5

ANOVA model comparison, with and without age predictor

	npar	AIC	BIC	logLik	deviance	Chisq	Df	Pr(>Chisq)
Model 1 (-age)	9	1523.317	1563.540	-752.6583	1505.317			
Model 2 (+age)	12	1495.685	1549.316	-735.8426	1471.685	33.63147	3	<.0001

Table 6

Post-hoc Chi-square residuals, construction and pragmatic function

Dimension	Epistemic agreement	Epistemic uncertainty	Expressive speech act	Negation	Requesting speech act	Unbiased assertion
Co-speech beat	-0.435	-7.562***	-2.872	0.663	1.039	7.881***
Co-speech palm-up	0.640	-0.136	0.459	1.423	1.158	-1.806
No-speech palm-up	-0.343	9.809***	3.011*	-2.835	-2.941	-7.499***
** p<0.05, **p<0.01, ***p<0.001*						

Table 7

Multinomial logistic regression, form/function over time

	Term	Estimate	Std.error	Statistic	P.value
Epistemic uncertainty	Co-speech beat	3.407	3.189	1.068	0.285
	Co-speech palm-up	3.621	1.025	3.533	0.000
	No-speech palm-up	7.510	3.773	1.990	0.047
	months_0	-0.077	0.094	-0.814	0.416
	Co-speech palm-up:months_0	0.024	0.100	0.238	0.812
	No-speech palm-up:months_0	-0.052	0.136	-0.385	0.700
Expressive speech act	Co-speech beat	5.667	3.303	1.716	0.086
	Co-speech palm-up	2.061	1.114	1.850	0.064
	No-speech palm-up	5.735	3.801	1.509	0.131
	months_0	-0.192	0.105	-1.828	0.068
	Co-speech palm-up:months_0	0.150	0.111	1.354	0.176
	No-speech palm-up:months_0	0.073	0.145	0.503	0.615
Negation	Co-speech beat	3.118	3.118	1.000	0.317
	Co-speech palm-up	1.531	1.129	1.355	0.175
	No-speech palm-up	-1.829	0.826	-2.213	0.027
	months_0	-0.057	0.091	-0.621	0.535
	Co-speech palm-up:months_0	0.038	0.098	0.388	0.698
	No-speech palm-up:months_0	-0.284	7.136	-0.040	0.968
Requesting speech act	Co-speech beat	-0.318	3.228	-0.099	0.922
	Co-speech palm-up	1.079	1.150	0.939	0.348
	No-speech palm-up	-1.812	2.471	-0.734	0.463
	months_0	0.049	0.092	0.529	0.597
	Co-speech palm-up:months_0	-0.051	0.099	-0.518	0.604
	No-speech palm-up:months_0	-0.504	12.870	-0.039	0.969
Unbiased assertion	Co-speech beat	4.161	2.872	1.449	0.147
	Co-speech palm-up	1.475	1.051	1.404	0.160
	No-speech palm-up	5.183	3.879	1.336	0.181
	months_0	-0.028	0.083	-0.331	0.741
	Co-speech palm-up:months_0	0.055	0.089	0.612	0.540
	No-speech palm-up:months_0	-0.179	0.146	-1.230	0.219

pragmatics6 ~ gtype + months_0 + months_0:gtype + 0; multinomial logistic regression conducted using the nnet *R-package*

Figure 6

Comparison of predictive models for gestures frequency. The model fit of GLMM predicting gesture frequency by gesture construction and communicative act count is improved by including child age as a predictor. Children increase use of co-speech gestures, particularly beat gestures, above and beyond expected increases from increasing amount of talk. A model including age predicts no increase in frequency for no-speech palm-ups despite increases in amount of talk.

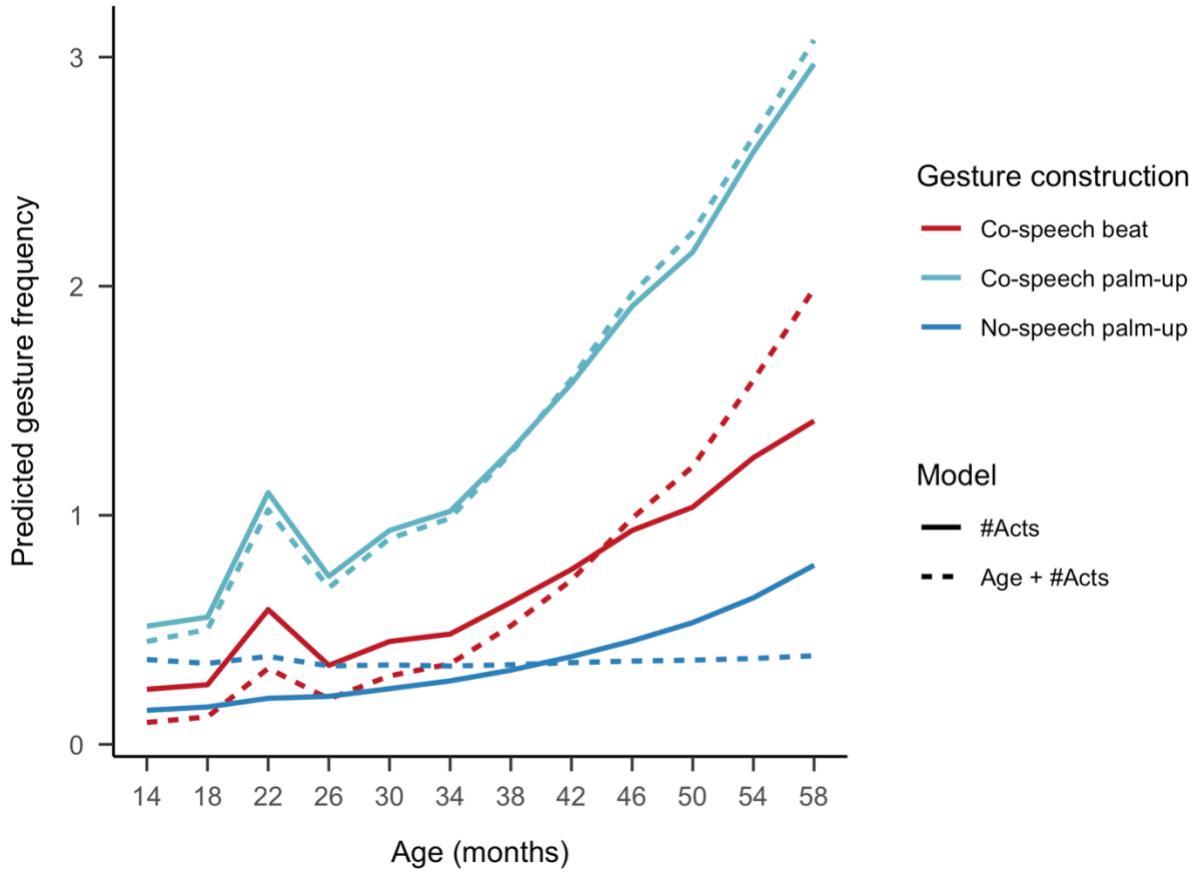


Figure 7

Chi-square residuals of form-function associations