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RESEARCH ARTICLE OPEN ACCESS

# Forms and Functions of Gestures in Preverbal 12- to 15-Months Old Infants

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**Keywords:** co-speech gestures | comparative methods | gesture development | language acquisition | ontogeny

## ABSTRACT

Speech and co-speech gestures always go hand in hand. Whether we find the precursors of these co-speech gestures in infants before they master their native language still remains an open question. Except for deictic gestures, there is little agreement on the existence of iconic, non-referential and conventional gestures before children start producing their first words. Here, we bridge this knowledge gap by leveraging an ethological method already established for describing speech independent gestures in nonhuman primates, to analyze the spontaneous gestures produced by infants when interacting with their caregivers. We manually annotated video recordings of infant-caregiver interactions (26 h) from the *CHILDES platform*, to describe the gesture forms, types and functions in six infants from 12 to 15 months of age. We describe 62 gesture forms in the preverbal repertoire. These were categorized into deictic, iconic, non-referential and conventional gesture types, similar to co-speech gesture types. We also find that the type-function relation of preverbal gestures map similarly to type-meaning relation of co-speech gestures. Taken together, our results illustrate linguistic properties of infant gestures in the absence of speech, suggesting them to be precursors of co-speech gestures.

## 1 | Introduction

Across cultures and age groups, we all gesture while speaking (Hewes 1974). These co-speech gestures play a crucial role in enhancing communication, either by complementing the spoken message or conveying information that is not expressed through speech alone (Goldin-Meadow 1999). They also facilitate speech comprehension (Kelly et al. 2015) and shape social interactions (Holler and Levinson 2019; Clark 1996). Co-speech gestures can be broadly categorized into four types (Kendon 2004; McNeill 1992; Cartmill and Goldin-Meadow 2016): deictic gestures, such as pointing, indicate the position of a referent in the

conversational space; iconic gestures, such as pretending to sip from a glass when uttering “do you want water”, transparently reflect certain aspects of the meaning that is being conveyed; conventional or emblematic gestures, such as a “thumb up” to mean “okay”, have conventionalized meanings<sup>1</sup> that are not iconically related to the form of the gesture. Finally, non-referential gestures (also known as beat gestures), are rhythmic movements that are aligned with the speech prosody. While deictic, iconic, and conventional gestures make semantic contributions to speech, non-referential gestures do not. Rather, the latter have pragmatic functions used to punctuate the structure of the discourse (Ekman and Friesen 1969; Bavelas et al. 1992). They

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act as markers of speech-acts, indicating the illocutionary act that a speaker is engaged in (Kendon 1995, 2004). Although extensive research has examined the meanings of co-speech gestures (for a review, see Wagner, Malisz, and Kopp 2014; Kendon 2004; McNeill 1992; Bavelas et al. 1992), their developmental trajectory in relation to language acquisition remains poorly explored. This is largely because understanding the meaning of these gestures depends not only on interpreting the gestures themselves but also on understanding the accompanying speech and the relationship between the two. A key open question is thus whether early precursors of these co-speech gestures emerge during the preverbal stage, before infants fully master their native language. The aims of this study are to identify the forms, types and functions of infant gestures, and thereafter, to test whether the different gesture types found in infants map on to similar semantic and pragmatic functions as those found in adult co-speech gestures.

Infants use intentional gestures to communicate before they start speaking; deictic gestures, especially pointing, develop in infants typically between 9 and 12 months of age (Bates, Benigni, and Bretherton 1979; Bates 1974). Infants point to request objects in their vicinity (imperative pointing) (Rohlfing, Grimminger, and Lüke 2017) and even to refer to absent objects encountered in the past (Bohn et al. 2018). Pointing assumes more complex functions, such as attracting others' attention toward an object or event (declarative pointing) (Liszkowski et al. 2004, 2007) or informing or interrogating others and learning new labels (interrogative pointing) (Lucca and Wilbourn 2019; Kovács et al. 2014; Begus and Southgate 2012; Tomasello, Carpenter, and Liszkowski 2007; Liszkowski et al. 2006). Besides pointing, infants produce other deictic gestures (e.g., giving, and showing) that successfully elicit responses in adult social partners thus suggesting clear imperative and declarative communicative functions (Orr and Kashy Rosenbaum 2023; Karasik, Tamis-LeMonda, and Adolph 2014; Beuker et al. 2013; Goldin-Meadow and Alibali 2013; Kirk et al. 2013; Tomasello, Carpenter, and Liszkowski 2007; Tamis-LeMonda, Bornstein, and Baumwell 2001; Carpenter et al. 1998).

In contrast to deictic gestures, there is no consensus on the onset of iconic gestures. Some studies suggest that iconic gestures are produced as early as 11- to 12-months (L. P. Acredolo and Goodwyn 1985; L. Acredolo and Goodwyn 1988), while others suggest that iconic gestures only emerge from between 22 and 27 months of age (Behne, Carpenter, and Tomasello 2014; Özçalışkan and Goldin-Meadow 2011). For example, L. P. Acredolo and Goodwyn (1985) found that 12-month-olds raise their arm to mean “big” while Özçalışkan and Goldin-Meadow (2011) reported a similar gesture (holding the hand above head to indicate “tall”), only emerging around 26 months. The resulting discrepancy may be due to methodological differences: while the first study (L. P. Acredolo and Goodwyn 1985) primarily reported on gesture production by 11-month-olds from individual case studies and interviews with caregivers, the second study (Özçalışkan and Goldin-Meadow 2011) analyzed direct video recordings of infants aged 14–34 months.

In this paper, we maintain a clear operational distinction between iconic and conventional gestures—we categorize gestures

as iconic when their forms resemble an action or an object (McNeill 1992); we categorize gestures as conventional only when there is an arbitrary relationship between their forms and meanings and have shared conventional meanings (Ekman and Friesen 1969; Kendon 2004; McNeill 1992; Cartmill and Goldin-Meadow 2016; Cartmill, Beilock, and Goldin-Meadow 2012). The definition of conventional gestures has been operationalized differently across studies using the terms “iconic” and “symbolic” interchangeably (Goodwyn, Acredolo, and Brown 2000; L. Acredolo and Goodwyn 1988). Caselli et al. (2012), on the other hand, describe a list of conventional gestures produced in conjunction with words at 18- to 24-months of age that includes both arbitrary conventional gestures, such as waving the hand for bye-bye, and iconic gestures that resemble actions, such as giving a slap or sleeping by leaning the head on a hand or pillow and closing the eyes. Such interchangeable use of the names may have arisen from the fact that some iconic gesture forms evolve into arbitrary conventional gestures over time (Werner and Kaplan 1963). This leads to a lack of clarity about the onset of conventional gestures in infants (Caselli et al. 2012; Bates and Dick 2002). Moreover, we do not consider nominal gestures (Mishra et al. 2021) which are similar to “adaptors” (Ekman and Friesen 1969) as these are not produced with any communicative intent, or at least the communicative intent is not always evident (see Cartmill and Goldin-Meadow 2016).

Finally, non-referential gestures, may emerge around 2–3 years of age, when language is already in place, and are mostly associated with pragmatic properties of communication (Vila-Gimenez and Prieto 2021; Levy and McNeill 2013; Nicoladis, Mayberry, and Genesee 1999; Bavelas et al. 1992). In 5- to 6-year-olds, these non-referential gestures carry distinct roles of information structuring (brief biphasic palm-turns to emphasize words in a narrative; Rohrer et al. 2022). Some non-referential gestures have been argued to appear earlier: from 9 months of age, infants produce rhythmic hand movements synchronized with their vocalizations (Iverson and Fagan 2004; Iverson and Thelen 1999). However, it is unclear at this stage what functions these movements serve in communication and whether they can be compared to adult gestures. Throughout the manuscript, we follow the broad category “non-referential gestures” (McNeill 1992; Prieto et al. 2018) for those which do not have a direct referent. We deliberately avoid calling them “beat gestures” as it is defined top-down in relation to speech (Prieto et al. 2018), and we do not want to presuppose that “beat gestures” occur in preverbal infants. Furthermore, even in adults, beats are now understood to be only a subset of a larger category of other non-referential co-speech gestures (Prieto et al. 2018).

In summary, with the exception of deictic gestures, there is a large variation in the reported onset of iconic, conventional and non-referential gestures. Although these categories of gestures are sometimes reported to appear preverbally (Green et al. 2023), it remains unclear whether these are precursors to the co-speech gesture types found in adults. This is because the type and the function of gestures are often determined by the accompanying speech or by the knowledge of cultural conventions (in the case of conventional gestures). Even apparently transparent gestures such as deictic gestures rely heavily on the shared linguistic and social context to be understood

(Clark 1996). For instance, when a child points at an apple without producing any word, it could either be interpreted as that she wants the apple (imperative function) or she wants to show that there is an apple (declarative functions); in their one-word phase, however, if a child points to an apple and says “give” (Butcher, Goldin-Meadow, and McNeill 2000), the imperative function of the pointing is clear. Such a top-down approach makes it difficult to identify the precursor of co-speech gestures in the absence of speech in early infancy.

In contexts where there is no linguistic information, such as in non-human primate communication, the functions of gestures can be nevertheless inferred from the situational and social contexts by observing the behavior of both the signaler and the receiver. In these studies, the function of a gesture in the prevailing context can be deduced based on whether the receiver’s reaction satisfies the signaler. The termination of further gesturing from the signaler is considered to have satisfied the signaler and is termed an apparently satisfactory outcome (ASO, Hobaiter and Byrne 2014). This method has revealed that primate gestures are produced flexibly and intentionally (Call and Tomasello 2020), two key properties of human language (Corballis 2002). However, deictic, iconic, or non-referential gestures do not naturally occur in primate communication and thus seem to be unique to humans (but see Wilke et al. 2022; Krause et al. 2018; Douglas and Moscovice 2015; Gupta and Sinha 2016; Pika and Mitani 2009; Gómez 2005; Leavens and Hopkins 1999). Therefore, it is still unknown whether the different types of co-speech gestures only emerge after mastering spoken language, or if they appear earlier in infancy.

In the present study, we adapt the ethological method originally developed for primates to analyze the spontaneous gestures produced by 12- to 15-month-old infants during interactions with their caregivers (Cartmill and Byrne 2010; Genty et al. 2009; Graham et al. 2018; Grund et al. 2024; Gupta and Sinha 2019; Molesti, Meguerditchian, and Bourjade 2020). Unlike previous research that primarily relied on top-down approaches to identify gestures—such as parental reports (e.g., L. Acredolo and Goodwyn 1988) or on gestures accompanied by speech (e.g., Özçalışkan and Goldin-Meadow 2011)—our approach offers a systematic and comprehensive documentation of gesture inventories and their functions, independent of speech-related or functional classifications. Recent studies have used this ethological method to compare gesture forms in apes and human infants (Kersken et al. 2019; Rodrigues, Maroco, and Frota 2021). However, these studies did not analyze infants’ preverbal gesture functions (but see Kersken et al. 2019, who analyzed gesture flexibility in terms of the number of social goals). Here, we aim to fill this gap. Specifically, we (1) describe longitudinally the *gesture forms* produced by infants, and compare them with the repertoire of gesture forms reported in previous studies (Rodrigues, Maroco, and Frota 2021; Kersken et al. 2019); (2) Define the *type* of these gestures (deictic, iconic, non-referential, conventional) and (3) define their *semantic and pragmatic functions*.

Our objective is to test whether the different types of gestures found in infants are mapped to similar semantic and pragmatic functions as those found in adult co-speech gestures. In adults, the functions of co-speech gestures are strictly tied to their

types, which are directly derived from speech: referential (deictic, iconic and conventional) gestures are semantic, while non-referential ones are pragmatic. However, this top-down approach cannot be applied to classify preverbal infant gestures for two reasons. First, infant gestures may lack spoken reference, making it impossible to use the meaning of accompanying speech to derive the type and function of the gesture. And second, except for deictic gestures, there is limited understanding of the other types and functions of gestures in the infant’s repertoire to use this in a top-down approach. Therefore, we assume that all preverbal gesture forms can be categorized into multiple gesture types, and simultaneously have semantic and pragmatic functions. This allows for a ground-up emergence of the relation between infant gesture forms, types and their functions, without any presuppositions. Once established, this relation can be compared to co-speech gesture type-function relationships found in adults. In particular, we predict that if the preverbal gestures contain the precursors of linguistic features of adult co-speech gestures, we will find that (i) referential gestures in the preverbal stage have a wider span of semantic functions than non-referential gestures, as referential co-speech gestures are found to bring semantic diversity to speech (Kendon 2004); (ii) non-referential gestures in infants have more declarative pragmatic functions than referential gestures, thus acting as precursors to narrative performance of beat gestures in children and adults (Vila-Gimenez and Prieto 2021; Levy and McNeill 2013; Nicoladis, Mayberry, and Genesee 1999).

## 2 | Method

### 2.1 | Data

Video recordings of spontaneous infant-caregiver interactions were taken from two open-source corpora from CHILDES -the PhonBank French-Paris and the PhonBank French-Lyon corpora (videos and transcriptions can be downloaded at <https://phon.talkbank.org/access/French/Paris.html>; <https://phon.talkbank.org/access/French/Lyon.html>). For our study, we used longitudinally collected recordings from 12- to 15-months of six infants—Antoine, Madeleine, and Theophile (French-Paris corpus); Anaïs, Marie, and Nathan (French-Lyon corpus). This resulted in 25.74 h of videos. We chose these corpora for two reasons: first, selecting a French corpus facilitated working with French-speaking students and second, several of our colleagues have already studied speech and non-verbal signal development in these two corpora, providing us with an opportunity for future comprehensive cross-study analyses.

#### 2.1.1 | French-Paris Corpus

This corpus contains video and audio recordings. These recordings have been investigated primarily from the perspective of language development, although deictic gestures were coded (Morgenstern and Parisse 2012). The infants were filmed at home about once a month for an hour in contexts of playing, taking a bath and having dinner. The three infants that we studied from this corpus had consistent video recordings from

12- to 15-months of age. Moreover, their linguistic competence (measured as the number of word types per hour of recording & number of words per hour of recording), became comparable by the age of 3-years, although with individual differences at a younger age (Morgenstern and Parisse 2012).

### 2.1.2 | French-Lyon Corpus

This corpus consists of video and audio recordings previously analyzed from the perspective of speech and grammar development (Demuth and Tremblay 2008). The children and their parents were recorded at home for approximately one hour every two weeks in similar contexts as those in the French Paris corpus. The three infants that we studied from this corpus had the best quality video recordings (Jourdain 2022). Their linguistic competence (measured as the number of utterances) was comparable between 2- to 3-years of age, although Anaïs had an exceptionally high rate of utterance production (Jourdain 2020, 2022).

### 2.1.3 | Ethical Statement

We used pre-existing open-source video corpora, and we abided by all the ethical requirements set by the data sharing platform.

## 2.2 | Coding Scheme

We used the ELAN video coding software (Version 6.7, Max Planck Institute for Psycholinguistics 2023) to code the form, type, and semantic-pragmatic functions of gestures occurring during spontaneous infants-caregiver interactions. A schematic representation of the consecutive steps followed for coding the videos is provided in Figure 1. The coding process can be described in four steps:

### Step 1. Identify Gestures

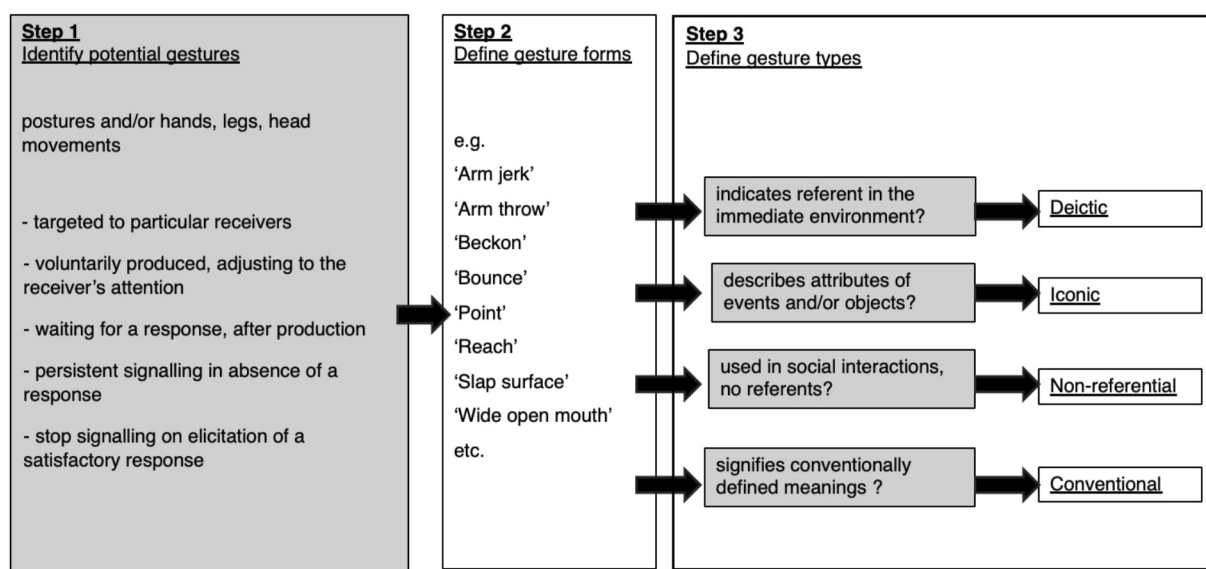
To identify gestures, we observed the infant's body postures and/or movements of the hands, legs and head that met the following criteria (for nonhuman primate gestures, Call and Tomasello 2020 and for human infants, Bates, Camaioni, and Volterra 1975): (i) the movements are targeted toward specific receivers, (ii) the movements are voluntarily produced by the infant, that is they are not based on imitative process (see exclusion criteria) and are voluntarily controlled depending on the attention state of the receiver (iii) the infant waits for the receiver's response after producing the movement, (iv) in the absence of a response from the receiver, the infant persistently produces the same or different movements until a response is elicited, (v) on elicitation of an ASO from the receiver, the infant stops producing any movement targeted to the receiver (Hobaiter and Byrne 2014). We coded infants' actions as potential gestures only if they met all of these criteria. These five criteria not only establish that the infants' gestures reflect a clear intent to communicate but also that the function of these gestures (see Step 4) is derived from their interactive communication with a caregiver.

### Step 2. Define Gesture Forms

The gestures identified in Step 1 were then visually described in terms of the body part used to execute them and their movement patterns. To ensure coding consistency, we checked whether the fundamental aspects of gesture forms were present, even if there were variations in execution among individuals and contexts. For instance, we coded all raised arm gestures above the shoulders as "arm/raise." A complete list of the gesture forms, along with the criteria used for their categorization is given in Table 1.

### Step 3. Define Gesture Types

Once the gesture forms were defined, we classified them into the following four types corresponding to the types of adults' co-speech gestures (McNeill 1992):



**FIGURE 1** | Schematic representation of the various steps to code forms, types, and meaning functions of gestures defined in 12- to 15-months old infants.

**TABLE 1** | Name and descriptions of gesture forms in the repertoire of 12- to 15-months-olds with corresponding gesture type classification.

	<b>Gesture form</b>	<b>Description</b>	<b>Gesture type</b>
1	Arm/hand fling	Moving arm/s or hand/s rapidly and repetitively in the direction of the receiver	NR
2	Arm jerk	Rapid, horizontal movement of one or both arm/s or hand/s, keeping it bent at the elbow	I, NR
3	Arm jerk with object	Like “Arm jerk”, while holding an object	D, NR
4	Arm raise	Raising arm/s above shoulder and holding it vertically in the air	D, I, NR
5	Arm swing	Swinging motion of one or both arm/s, sometimes bent at the elbow or falling straight by either side of the body	NR
6	Arm throw	Rapid vertical movements of one or both arm/s, raised above the shoulders	I, NR
7	Arm wave	Large repeated back and forth motion of the arm raised above the shoulder	D, NR
8	Arm wave with object	Like Arm wave, while holding an object	D
9	Beckon	Rapid closing and opening of the fist/s while holding out arm/s away from the body	D
10	Bite	Holding receiver’s body part between the teeth or lips of the signaler	NR
11	Bounce	Rapid vertical movements of the upper body, while sitting or standing	D, I, NR
12	Bow	Bringing head toward the ground, while bending at the waist	I
13	“Chin-chin”	Bringing drinking glass in contact with that of the receiver and making a raising movement as the glasses touch	CO
14	Clap	Bringing repeatedly both palms together in audible contact	NR
15	Eating	Pretending to mix imaginary food in a bowl (real or imaginary), pretending to scoop out imaginary food with a spoon (real or imaginary), pretending to bring the spoon (real or imaginary) to the signaler’s mouth, pretending to eat	I
16	Embrace	Wrapping one or both arm/s around the receiver and maintaining physical contact	NR
17	Facepalm	Bringing two hands over the face and keeping the face covered with palms; not repeated, like in the context of playing hide and seek or peekaboo	NR
18	Finger-flicking	Rapid movements of the fingers (of one or both hand/s) while touching the signaler’s mouth	NR
19	“Flying kiss”	Covering the signaler’s mouth with a hand followed extending the palm toward a receiver, pretending to send them a kiss	CO
20	“Good-bye”	Hand wave to mean goodbye; arm usually bent at the shoulder, or the arm held out straight ahead away from the body	CO
21	Grab and hold	Firmly closing one or both hand/s over part of the receiver’s body and maintain the hold for > 1 s	NR
22	Hand in mouth	Bringing one or both hands to the signaler’s own mouth and putting multiple or one finger inside the mouth, sometimes giving it a quick bite	I, NR
23	Hand jerk	Rapid vertical or horizontal movements of one or both arms and/or hand, keeping it bent at the elbow	NR
24	Hand to mouth	Bringing one or both hand/s toward or inside the receiver’s mouth	I, NR
25	Head bob	Rapid vertical movements of the head; either repeated movements, or produced just once to say “yes”	D, I, NR, CO
26	Head jerk	Sudden short movement/s of the head, sideways or slightly backwards	NR
27	Head shake	Shaking head from side to side; either repeated movements, or produced just once to say “no”	NR, CO
28	Head tilt	Tilting the head to one side and keeping it tilted, while looking at the receiver	NR
29	“Hello”	Opening and closing of the first to mean “hello”, while bending the arm at the elbow	CO
30	Hold head	Lifting both arms above the head, placing hands on the head and holding it	D, I, NR

(Continues)

TABLE 1 | (Continued)

	<b>Gesture form</b>	<b>Description</b>	<b>Gesture type</b>
31	Kiss like mouth movements	Making kiss-like action toward the receiver, without actually kissing	NR
32	Leg fling	Rapid movements of one or both leg/s away from the body, bending at the knees	NR
33	Mouth to body touch	Bringing mouth, with lips slightly apart, in contact to receiver's body and maintaining the touch for > 1 s	NR
34	Music conducting	Holding out two arms away from the body and waving them simultaneously in a horizontal motion, bending them slightly at the elbows	I
35	Offer hand	Reaching out one or both hand/s toward the receiver with index finger pointed out or open palm turned upwards or palm turned downwards	D, NR
36	Offer object	As "Offer hand", while holding an object, and a physical transfer of the object was effectuated at the end	D
37	Open mouth	Opening the mouth slightly, making rounded shape with the lips	I, NR
38	Open palm turned upwards	Extending out one or both arm/s toward the receiver, turning the palm/s upwards toward the receiver	D
39	Pat other	Bringing the palm of one or both hand/s in contact with the receiver's body, followed by repeated rapid movements, gently touching the receiver's body each time	NR
40	Pat self	Bringing one or both hands in contact with signaler's own body followed by repeated rapid movements to gently touch own body	D, NR
41	Peekaboo	Alternatingly covering and uncovering the face with one or both hand/s, while looking at the receiver during the face-uncovered phase	NR
42	Point	Extending whole arm of the signaler with open palm or with closed palm or index finger pointing out toward an object/another individual/self	D
43	Point and touch	As "Point", but elaborating it with touching the object/another individual/self with the extended arm or pointed finger	D
44	Puckered lips	Narrowing the lips, bringing them together, usually associated with crinkling of the nose	I
45	Push	Hand/s, placed over object/receiver, and a force exerted to move the object/receiver away from the signaler, yet not physically displacing the object/receiver	NR
46	Raspberry bubble	Making motorboat sound fluttering the lips together, making a cluster of spit-bubbles	D, I, NR
47	Reach	Extending one or both arm/s, upper body leaning forward, toward the receiver	D
48	Reach for object	Extending one or both arm/s, open palms turned downwards, upper body leaning forward, toward an object	D
49	Shake object	Holding an object in one or both hand/s, shaking the object, either with arms held up above the head, or extended out in front, or arms held close to the body of the signaler	D, NR
50	Show object	As "Offer object" but not letting the receiver take the object	D
51	Slap object	One or repeated forceful contact of one or both hand/s with the surface of an object	D, NR
52	Slap surface	One or repeated forceful contact of one or both hand/s with the surface of a furniture or the ground	D, NR
53	Stick out tongue	Sticking out tongue from the mouth and holding it out for > 1 s	NR
54	Stomp feet	Rapid, forceful vertical movements of one or both leg/s, lifting up and bringing in contact to the ground or the surface on which the signaler is standing	NR
55	Sway backwards and forwards	Movement of the torso backwards and forwards, while standing or sitting	NR
56	Sway side to side	Movement of the torso from side to side while standing or sitting	I, NR

(Continues)

TABLE 1 | (Continued)

	Gesture form	Description	Gesture type
57	Sweep surface	Rapid horizontal movements of one or both hand/s along the surface of a furniture or the ground	NR
58	Telephone	Making a hand-shape, as if holding a telephone, bringing it to an ear and pretending to speak to someone; same gesture can be produced using an object, as if holding a “telephone”, while it is not an actual telephone	I
59	Turn head	Rapid movement to turn the head away from the receiver; head could be turned on either right or left side, but not both	NR
60	Wide open mouth	Widely opening the mouth making a rounded shape with the lips, so much so that the cheeks are extended behind	D, I, NR
61	“Wow”	Opening the mouth widely, in a rounded shape and placing both hands one on each cheek	CO
62	Wrist rotate	Rotating both wrists repeatedly in circular motion, usually holding arms close to the body	D

Abbreviations: CO = conventional, D = deictic, I = iconic, NR = non-referential.

- Deictic: when the gesture directly indicated a referent (object, person) present in the immediate environment
- Iconic: when the gesture form describes the attributes of an object and/or actions
- Non-referential: when the gesture form has no direct referent in the environment
- Conventional: when a gesture form bears resemblance to a socially conventionalized gesture with precise meanings and can be replaced by a single word (e.g., *Good-bye* or *Hello*)

#### Step 4. Define Gesture Functions

We assumed that all gesture forms could simultaneously have semantic and pragmatic functions. To determine the semantic function of a gesture, we asked “what did the signaler achieve by using a gesture form?” For example, if an infant persistently points to an object until the caregiver retrieves it, the infant achieved the goal of obtaining a desired object; the semantic function of this pointing here is coded as “acquire object.” For deducing the pragmatic function of a gesture, we asked “what did the gesture achieve in the context of communication?” For example, when the infant persistently points to an object until the caregiver retrieves it for him/her, the gesture fulfills the pragmatic function of placing a “request” to the caregiver. We achieved this using the “Apparently Satisfactory Outcome” (ASO), which is based on the response of the receivers (often the caregivers) that appears to satisfy the signaler (the infants). Satisfaction of the signaler was indicated by termination of further gesturing upon elicitation of a response (Hobaiter and Byrne 2014).

#### 2.2.1 | Exclusion Criteria

We did not analyze gesture forms, types and functions when the receiver of the gesture and the subsequent response were not clearly visible in the recordings. This excluded 784 instances out of the 1734 identified gestures across all of the corpora (45%). Although this exclusion criterion may result in an

underestimation of the full range of preverbal gestures, it ensures that the gestures we analyze are intentionally communicative and that their functions can be accurately identified.

Additionally, during interactions with adults, if infants were observed to repeat gestures made by adults (i.e., imitation), we did not code these as gestures as they lacked communicative intent. However, in cases where gestures initially learned through imitation were later used by infants with communicative intent—specifically to initiate interactions or solicit actions—we coded these as gestures.

For example: Antoine, at 15 months, observed his aunt using a was observed to learn the “Music conducting” gesture from his aunt while listening to music. His aunt later held his hands and trained him on the arm movements as a music conductor would do. In this case, we did not code “Music conducting” movement as a gesture. In another situation from the same recording, Antoine looked at his aunt and voluntarily made the same arm movements as the music replayed, and his aunt followed his suit. In this second case, we coded “Music conducting” as an iconic gesture produced by Antoine to “solicit action” of music conducting from his aunt.

#### 2.2.2 | Reliability

Coder1 (SG) coded all the videos for gesture forms, types and functions. Inter-rater reliability was assessed for 20% (5 h) of all the videos, which corresponded to 106 identified gesture tokens coded by Coder2 (EP). Agreement between Coder1 and Coder2 was 93% for gesture forms, 91% for gesture types, and 82% for gesture functions. Cohen’s Kappa statistics for these coding decisions were 0.91, 0.88, and 0.78, respectively, rendering our agreement score as “Substantial” to “Perfect” (Landis and Koch 1977). SG has extensive video coding experience for gestures and other social behaviors in macaques, apes, and human adults. EP is a naïve coder with beginners’ level experience with ELAN software and a theoretical knowledge about the goals and principles of the present study and was provided with the coding scheme in this



study as a reference for reliability assessment. The coding instructions used for the reliability coding have been provided in Supporting Information S3.

### 2.2.3 | Analysis

All statistical analyses were performed using the software R (version 4.3.1, 2023-06-16). Figures 2 and 3 were generated using David Sjoberg’s “ggsankey” package (Sjoberg 2021; R Core Team 2021).

## 3 | Results

Our analyses were conducted on the 950 gesture tokens (mean number of gestures produced per infant = 93.6, SEM = 32.2) which complied with the definition criteria of communicative intent and allowed us to code their semantic and pragmatic functions.

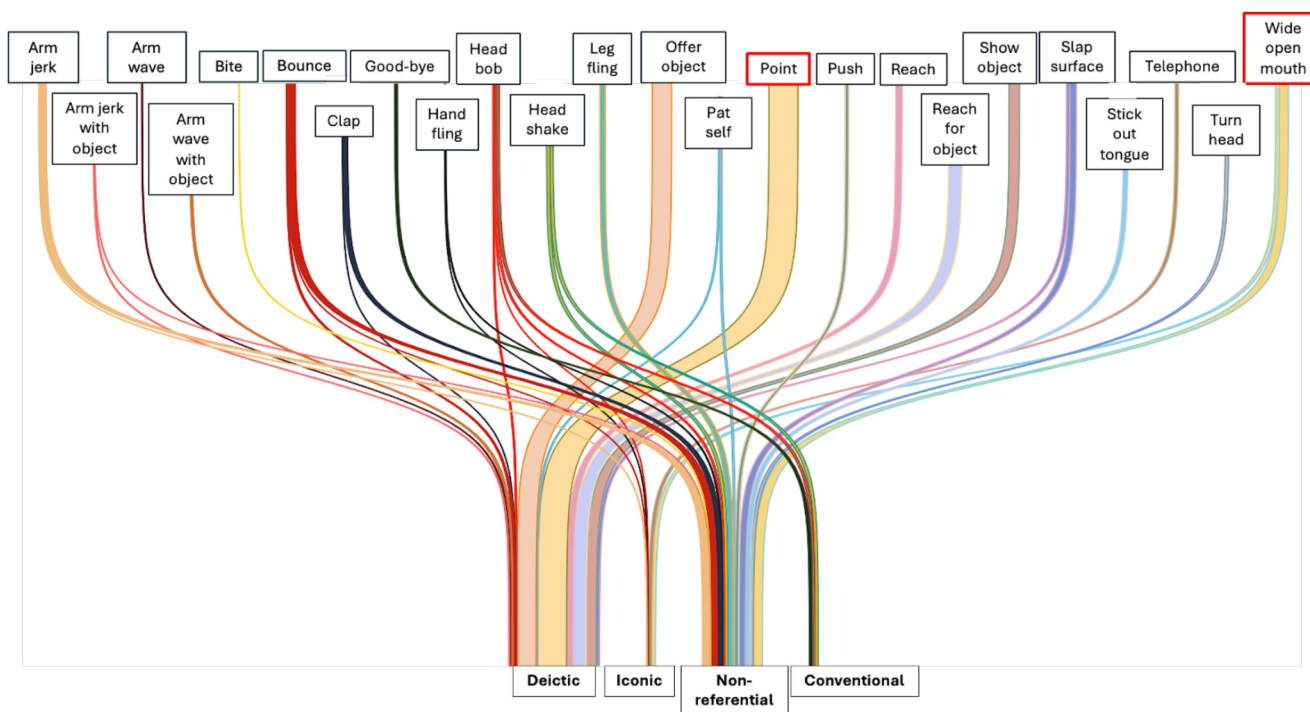
### 3.1 | Gesture Forms

Gesture forms are described based on their physical forms and movement patterns. We identified and described 62 unique gesture forms in the repertoire of 12- to 15-month-old infants (Table 1, Column 1, 2). Each infant produced an average of 13.12 gesture forms (SEM = 1.2; range: 8–28). We conducted a one-way ANOVA to compare the mean number of gesture forms across ages, and since there was no significant main effect of age ( $F(3, 20) = 0.29, p = 0.81$ ), we removed this factor as a predictor

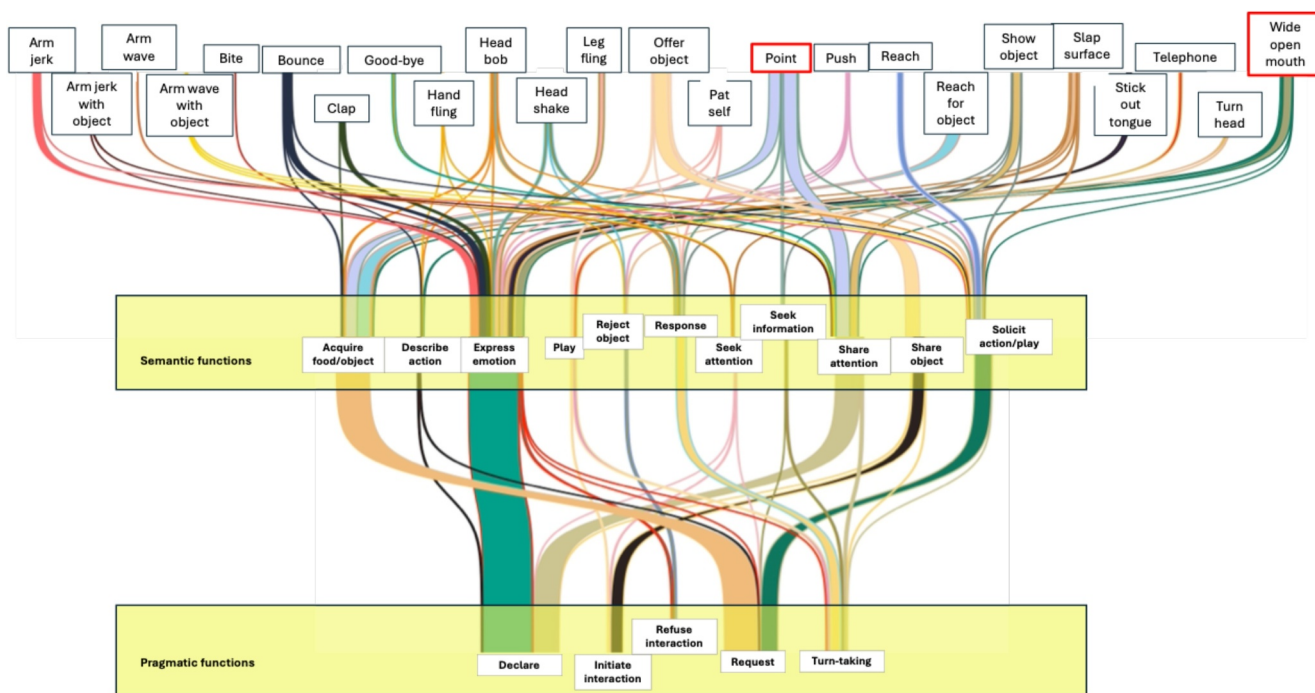
in all subsequent descriptions and analyses. The number of gesture forms for each individual, from 12 to 15 months of age, is provided in Table S1.

Eight gesture forms were used by all the six infants, nine forms were shared by five infants, and seven forms by four infants. Thus, 24 (39%) gesture forms were shared among half of the study group. These shared gestures taken together were produced most frequently among all instances of gesturing observed across individuals of all ages (83% of all the gesture tokens; Table S2, Column 3). Pointing alone made up 23% of all the gesture tokens performed, which is not surprising given that pointing gestures are the earliest to emerge in infants, serving a wide range of functions (Bates 1974).

Eighteen gesture forms solely occurred in the repertoire of a single infant (4.08% of all the gesture tokens; Table S2, Column 3), and 14 gestures were found in the repertoire of two infants (8.38% of all the gesture tokens; Table S2, Column 3). These gestures may not be idiosyncratic, as several of them were found in previous reports of infant gestures from different corpora (Table S2, Column 4 and 5). Note that we found only 36% overlap between our gesture forms repertoire with the one described by Kersken et al. (2019) for 1- to 2-year-olds; and only 25% overlap with the one described by Rodrigues, Maroco, and Frota. (2021) for 7- to 12-month-olds. This is a rather low overlap, given that 90% of gesture forms overlap between apes and human infants (Kersken et al. 2019), and meanings of some of these forms are also shared between apes and adult humans (Henderson et al. 2024). We come back to this in the general discussion.



**FIGURE 2** | Classification of the 24 gesture forms shared among half of the study group (83% of all the gesture tokens) into the four possible gesture types. The number of flows connecting a gesture form node on the left to the gesture type node on the right corresponds to the number of types each form was assigned to. Gesture forms “Point” and “Wide open mouth” are highlighted as examples that have been illustrated in the text.



**FIGURE 3** | Classification of the 24 gesture forms shared among half of the study group (83% of all the gesture tokens) into the eleven semantic functions identified, and their corresponding five pragmatic functions. The number of flows connecting a gesture form node on the left to the semantic and pragmatic function nodes in the middle and on the right correspond to the number of functions each form was assigned to. Gesture forms “Point” is highlighted as an example that has been illustrated in the text.

### 3.2 | Gesture Types

On average a gesture form could be classified into more than one (1.44) gesture type (SEM = 0.1) (range: 1–4) (Table 1, Column 3). 70.1% of the gesture forms (44 out of 62) were classified as non-referential, 38.71% (24/62) as deictic, 27.42% (17/62) as iconic and 12.9% (8/62) as conventional. Figure 2 shows a schematic representation of the classification for the subset of 24 gestures forms that were shared among half of the study group, into the four possible gesture types (83% of all the gesture tokens; Table S2, Column 3). For example, the gesture “Point” is always classified as deictic, since it is used for referring to an object or person in the immediate environment (see Figure 2, highlighted in red). The gesture “Wide open mouth” can be categorized as iconic, when it is used to describe the action of eating and categorized as non-referential when it is used to express surprise during social interaction (see Figure 2, highlighted in red). There were only a few gesture forms that were classified as conventional gestures, and most of them were produced by a single individual, except for *Good-bye*, which was found in four out of the six infants (Table S2, Column 1 and 2).

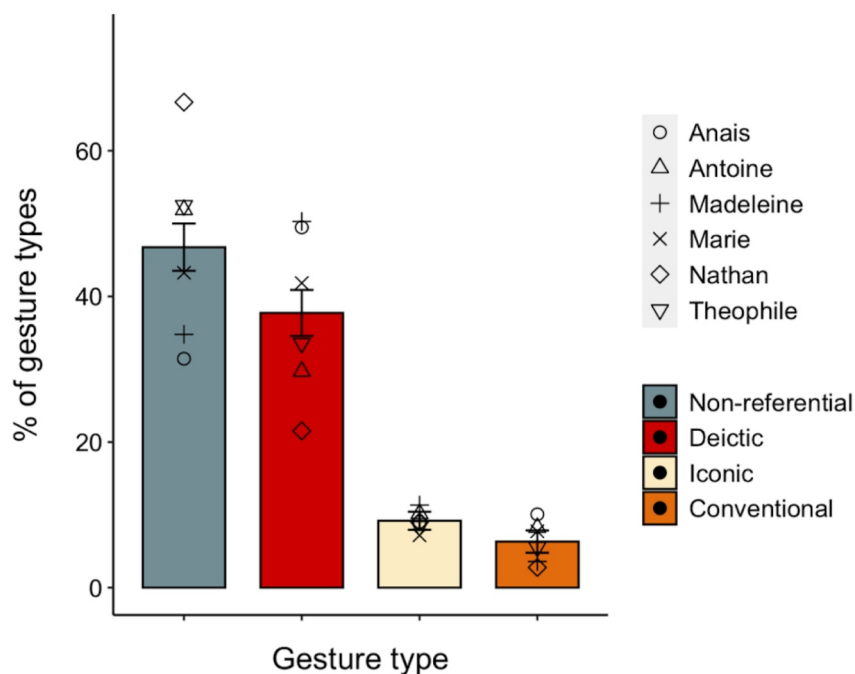
We modeled the percentage of gesture type (Perc) using a mixed model specified as:  $\text{Perc} \sim \text{GestureType} + \text{Age} + (1 | \text{infant})$ . A near-zero variance of the random intercept ( $\sigma^2 = 2.497\text{e-}19$ ,  $\text{SD} = 4.997\text{e-}10$ ) suggested negligible variability across infants. There was no main effect of Age ( $\beta = 1.293\text{e-}10$ ,  $t = 0$ ,  $p = 1$ ) and a main effect of gesture type ( $\chi^2(3) = 111.73$ ,  $p < 0.001$ ): there were more non-referential gestures (46.7%; SEM = 3.24) than deictic (37.7%; SEM = 3.16) ( $\beta = -9.01$ , SEM = 3.54,  $t = -2.54$ ,  $p = 0.01$ ), iconic (9.19%; SEM = 1.24) ( $\beta = -37.56$ , SEM = 3.54,  $t = -10.58$ ,  $p < 0.001$ ) and conventional gestures

(6.33%; SEM = 1.54) ( $\beta = -40.42$ , SEM = 3.548,  $t = -11.392$ ,  $p < 0.001$ ) (Figure 4). There were more deictic gestures than iconic ( $\beta = -28.54$ , SEM = 3.54,  $t = -8.13$ ,  $p < 0.001$ ) and conventional gestures ( $\beta = -31.40$ , SEM = 3.50,  $t = -8.95$ ,  $p < 0.001$ ). A detailed account of the age-wise variation of proportions of gesture types in infants from 12 to 15 months can be found in Table S3.

### 3.3 | Functions of Gestures

We identified the following 11 semantic functions of the gestures produced by infants from 12- to 15-months: “acquire object/food”, “describe action”, “express emotion”, “play”, “reject object”, “response to other”, “seek attention”, “seek information”, “share attention”, “share object”, “solicit action/play”. These gestures fulfill 5 unique pragmatic functions as derived from their effects on the receivers during the interaction: “request”, “declare”, “initiate interaction”, “refuse interaction”, and “turn-taking” (Table 2).

A gesture form can be assigned to more than one semantic or pragmatic function depending on its contextual use. Figure 3 below shows a schematic representation of the classification for the subset of 24 gesture forms that are shared among half of the study group into their corresponding semantic and pragmatic functions (83% of all the gesture tokens; Table S2, Column 3). For instance, “Point” (highlighted in red, Figure 3) is a gesture form that can have the semantic meaning “acquire object”, pragmatically functioning as a “request” to the receiver; “Point” could also be used to “share attention” on an object of interest,



**FIGURE 4** | Mean percentage of non-referential, deictic, iconic, and conventional gestures in the infant gesture repertoire ( $n = 6$ ). The error bars represent standard errors of the mean. Each shape corresponds to one infant.

thus, pragmatically function to “declare”. We observed an interesting elaboration of pointing- “Point and touch” gesture- (2% of all the gesture tokens, shared among two infants, hence not visible in Figure 3; see Table S2, Column 3) which solely have the semantic function of seeking information about novel objects of interest.

### 3.3.1 | Semantic Functions

Overall, we found that deictic gestures were used for 9 out of the 11 semantic functions, and iconic gestures were used for 5 out of 11. The predominant five semantic functions of referential gestures (deictic, iconic) were “acquire food/object” (23.61%, SEM = 5.58), “play” (11.18%, SEM = 6.2), “share attention” (25.83%, SEM = 1.92), “share object” (13.26%, SEM = 0.75) and “solicit action/play” (25.46%, SEM = 7.16). Additionally, in our study, infants produced all iconic gestures without uttering any words. All iconic gestures were used for the semantic function “describe actions” (e.g., “Raspberry bubbling” to request to blow on hot food, Supporting Information S2, Video S2), except one gesture (“Sway side to side”) which was used to describe movement attributes of a toy.

Non-referential gestures (e.g., “Head shake” to express disinterest in food, Supporting Information S2, Video S2), although used for 10 out of the 11 identified semantic functions, were mostly used to “express emotion” (87.32%, SEM = 1.7) (Figure 5a).

The semantic functions of conventional gestures (e.g., “Good-Bye” and “Flying kiss” to end an interaction, Supporting Information S2, Video S3) were more restricted: they were solely used to fulfill two functions: “response to others” (53.16%, SEM = 7.79) and “share attention” (40.42%, SEM = 10.94)

(Figure 5a). Since these conventional gestures already have precise semantic meanings, we excluded these from our analyses of the diversity index of semantic functions.

We evaluated the diversity of semantic functions by quantifying their richness (i.e., how many different semantic functions) and evenness (i.e., how many gesture forms belong to each semantic functional category) for referential (deictic, iconic) and non-referential gestures, using the Shannon-Weiner diversity index (Shannon 1949), and compared them with the Hutcheson  $t$ -test (Hutcheson 1970). The Shannon-Weiner diversity index is a measure used in ecological studies to calculate species diversity in a community as a function of the proportion of each species relative to the total number of species present in the community. Here, we draw analogies by replacing an ecological “community” by infant “gesture type” (referential & non-referential), while replacing the “total number of species in a community” by “semantic functions” of infant gestures. The diversity index for semantic functions of infant referential gestures (deictic and iconic) (Shannon diversity index = 1.84) is significantly higher ( $t(311) = 12.1, p < 0.001$ ) than that of non-referential gestures (Shannon diversity index = 0.61). This result confirms that infants’ referential gestures cover a wider range of semantic functions than do non-referential gestures.

### 3.3.2 | Pragmatic Functions

As can be seen in Figure 5b, deictic and iconic gestures predominantly achieve a “request” (mean\_deictic = 51.46%, SEM = 2.72; mean\_iconic = 57.87%, SEM = 5.47) and a declaration (“declare”) (mean\_deictic = 27.6%, SEM = 2.43; mean\_ - iconic = 27.17%, SEM = 4.6). These gestures also facilitate “turn-taking” (mean\_deictic = 9.38%, SEM = 1.9; mean\_ - iconic = 29.86%, SEM = 7.64). It appears that the “describe

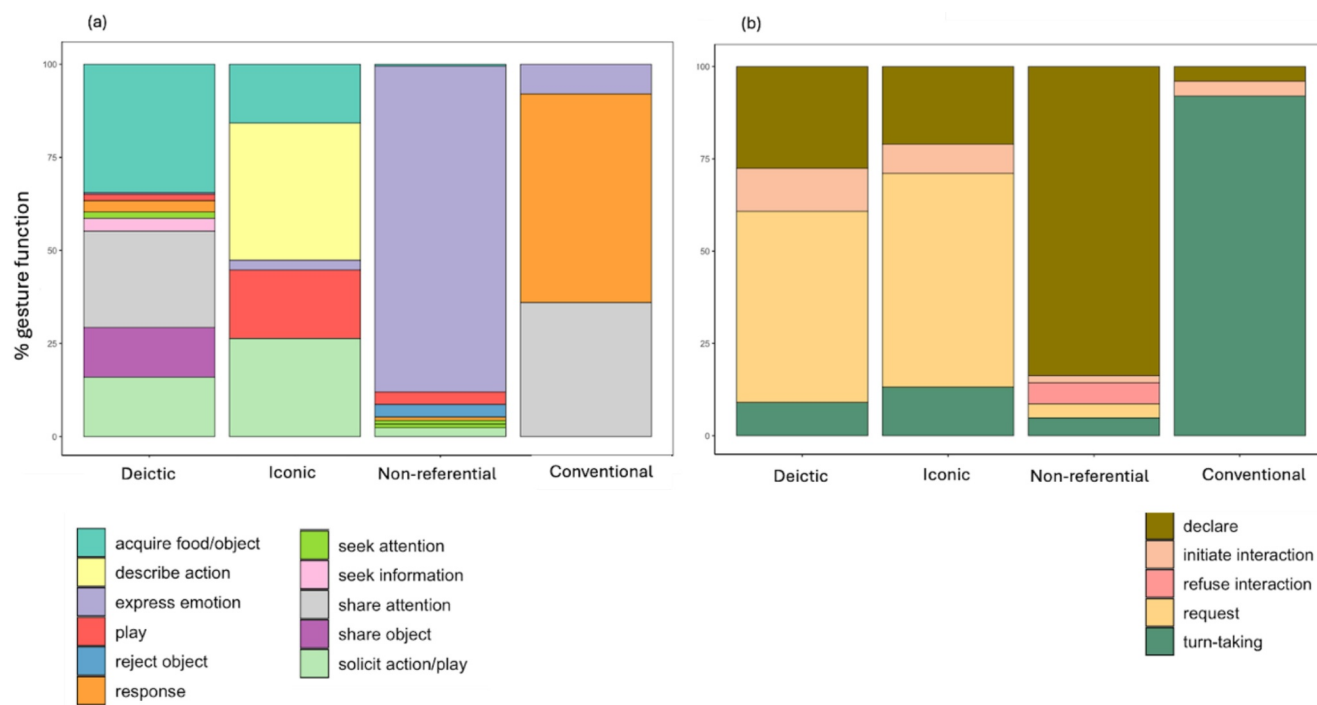
**TABLE 2** | Descriptions of semantic and pragmatic functions of gesture forms found in the repertoire of 12- to 15-months old infants.

<b>Semantic function (“what did the signaler achieve by using a gesture?”)</b>	<b>Description</b>
Acquire object/food	Intention of the signaler is to obtain an object/food of desire and is measured by ASO of receiving the desired object/food
Describe action	Intention of the signaler is to represent an action or attributes of an object using gestures
Express emotion	Intention of the signaler is to express states of happiness, sadness, anger or disinterest, etc. toward an ongoing situation
Play	Intention of the signaler is to begin or continue a game
Reject object	Intention of the signaler is to directly reject any object offered to them; different from expression of disinterest, as this function directly refers to a physical object
Response to other	Intention of the signaler is to gesturally respond to the receiver's question or request
Seek attention	Intention of the signaler is to attract the receiver's attention either to begin an interaction or continue an ongoing one
Seek information	Intention of the signaler is to inquire about something in the environment
Share attention	Intention of the signaler is to attract receiver's attention on an external object
Share object	Intention of the signaler is to share an object with the receiver
Solicit action/play	Intention of the signaler is to elicit a particular action in the receiver
<b>Pragmatic function (“what did the gesture achieve in the context of communication ?”)</b>	<b>Description</b>
Request	The gesture was performed to make a request to the receiver; usually connected to the semantic functions “acquire object/food”, “describe action”, “seek information”, “solicit, action/play”
Declare	The gesture was performed to declare an emotion state or a fact; usually connected to semantic functions “express emotion”, “seek attention”, “share attention”, “share object”
Initiate interaction	The gesture was performed to start a new interaction or revive an interaction that had been paused; usually connected to semantic functions “play”, “seek attention”, “share object”
Refuse interaction	The gesture was performed to terminate an interaction; usually connected to semantic functions “express emotion”, “reject object”
Turn-taking	The gesture was performed to facilitate taking turns alternating with the receiver, during an ongoing interaction; usually connected to all the semantic functions described above

action” semantic function of the iconic gestures, also facilitate turn-taking, as if in conversation-like structures.

Non-referential gestures were predominantly used for the pragmatic function “declare” (83.82%, SEM = 0.9; Figure 5b). The percentage of declarative functions of non-referential gestures was significantly higher than that of the other pragmatic functions combined (independent sample *t*-test:  $t(31) = 6.38$ ,  $p < 0.001$ ). A one-way ANOVA revealed that non-referential gestures were significantly more likely to have a declarative function than referential gestures ( $F(3,8) = 118.9$ ,  $p < 0.001$ ).

Post-hoc Tukey tests showed that the percentage of declarative function for non-referential gestures (83.81%, SEM = 0.9) was higher than the percentage of declarative function for deictic (7.53%, SEM = 2.43;  $p < 0.001$ ), iconic (27.17%, SEM = 4.6;  $p < 0.001$ ) and conventional gestures (12.5%;  $p < 0.001$ ). This result confirms our expectations of infant non-referential gestures to have more declarative functions than the referential gestures, thus building upon their role in narrative performances and discourse structuring in children (Vila-Gimenez and Prieto 2021; Levy and McNeill 2013; Nicoladis, Mayberry, and Genesee. 1999).



**FIGURE 5** | Percentage of (a) semantic functions of (b) pragmatic functions of deictic, iconic, non-referential and conventional gesture types in 12- to 15-month-old infants.

Conventional gestures, on the other hand, were almost exclusively used to “turn-taking” in social interactions (93.75%, SEM = 6.25; Figure 5b), illustrating pragmatic roles of these preverbal gestures in coordinating social exchanges, like “Good-bye” followed by “Flying kiss” with the receiver to say good-bye (Supporting Information S2, Video S3).

A detailed account of the age-wise variation in semantic and pragmatic functions of infant gestures can be found in Tables S4 and S5. Example videos of gesture forms and their subsequent classification into gesture types and functions are provided in Supporting Information S2, Videos S1, S2, and S3.

## 4 | Discussion

The objective of this paper was to examine precursors of adult co-speech gestures in infants (12- to 15-months) prior to mastering spoken language. Previous research has focused primarily on pointing gestures and their significance in language acquisition. Here, we used a descriptive observational method, predominantly applied to primates, to identify the form, type and function of gestures used by preverbal infants. Our results show that infants employed a repertoire of 62 gesture forms, which can be classified into the four gesture types that characterize adult co-speech gestures (deictic, iconic, non-referential and conventional) (Kendon 2004; McNeill 1992; Ekman and Friesen 1969). In addition, we find that, in infants, referential gestures (deictic and iconic) cover a wider range of semantic functions than non-referential gestures, while non-referential gestures have more declarative functions than referential gestures. This is indicative of an early emergence of linguistic features similar to co-speech gestures, but in the absence of speech.

### 4.1 | Gesture Forms and Gesture Types

We find a strikingly low overlap (25% and 36%) between the repertoire of gestures forms identified in the present study and those found in previous studies (Rodrigues, Maroco, and Frota 2021; Kersken et al. 2019). The overlap of repertoires described by Kerksen and colleagues with those by Rodrigues and colleagues is however very high (81%). Recently, a considerable overlap of semantic functions between chimpanzee and human gestures has been reported (Henderson et al. 2024), suggesting an evolutionary continuity of form-meaning relations. The discrepancy between our report and other infant gesture inventories may be due to the fact that these studies used a pre-defined repertoire of ape gestures (Hobaiter and Byrne 2011) as a reference for conducting a phylogenetic comparison of gesture forms. Regardless, it is important to note that all of these studies, including our own, relied on small sample sizes ( $n = 6$  for 25 h of recordings in the present study;  $n = 13$  for 15 h of recordings in Kersken et al. 2019;  $n = 10$  for 50 h of recordings in Rodrigues, Maroco, and Frota 2021). We also acknowledge the fact that the 62 gestures that we identified here, since we analyzed only the gestures for which a clear response from the receivers was visible. This only comprised about half of the total gesture tokens coded in the dataset. Therefore, it is important to consider that no single study can definitively define the exhaustive repertoire of gestures found in infancy, however, a collective effort can give rise to a clearer picture of the infant gestural repertoire, in terms of the diversity of gesture forms, communicative functions and variations as a response to socio-cultural environments.

In contrast to previous studies focusing on gesture forms, we further classified them into gesture types and found that infant gestures, without speech, also classify as deictic, iconic, non-

referential and conventional gestures, similar to adults' co-speech gestures.

Deictic gestures in infants included pointing, reaching, showing object, offering object and reaching for object. These gestures have been extensively documented in earlier work and can emerge, as early as in 9 months old (Rohlfing, Grimminger, and Lücke 2017; Liszkowski et al. 2004, 2007; Bates, Benigni, and Bretherton 1979; Bates 1974). Additionally, we observed that infants sometimes elaborate their pointing gesture followed by “touch”- this “point and touch” gesture serves the semantic function of seeking information about novel objects. Pointing is already known to be used for learning new labels, paving the way for asking questions later in life (Lucca and Wilbourn 2019; Kovács et al. 2014; Begus and Southgate 2012; Tomasello, Carpenter, and Liszkowski 2007; Liszkowski et al. 2006). The “point and touch” gesture further indicates the infants' intention to gather information about specific objects of interest. The caregiver's responses (providing the labels for the objects) is not a random outcome of the interaction, but rather a response to the infants' intention. Future studies should determine whether this specialized form of deictic gesturing (“point and touch”), rather than pointing in general (Lucca and Wilbourn 2018, 2019; Begus, Gliga, and Southgate 2014), serves as a precursor to children's ability to ask questions (Chouinard, Harris, and Maratsos 2007).

We observed iconic gestures, without accompanying speech in 12- to 15-month-olds confirming findings from previous studies (L. P. Acredolo and Goodwyn 1985; L. Acredolo and Goodwyn 1988; Green et al. 2023). However, other corpus studies report the use of iconic gestures much later around 22–26-months (Green et al. 2023; Behne, Carpenter, and Tomasello 2014; Özçalışkan and Goldin-Meadow 2011). In adults, the functions of iconic co-speech gestures are tightly linked to speech (McNeill 1992)- their “meaning” is defined by the spoken label. Surely, this top-down approach makes it difficult to identify iconicity in preverbal gestures in the absence of words. As a result, the identification of iconic gestures often only occurs after the production of the first words. In contrast, our bottom-up, speech-independent method enabled us to identify iconic gestures by matching them with preceding and/or following actions, referential contexts and reactions from the receivers. This method could reveal the existence of iconic gestures before proficient word-use.

The majority of the gestural repertoire of 12- to 15-month-old infants consists of non-referential gestures. These gestures are produced intentionally and directed to a target receiver, similarly to other gesture types. However, unlike deictic, iconic or conventional gestures, they do not have an external referent. Interestingly, 22 of the 42 non-referential gestures are rhythmic in nature (e.g., *Arm jerk*, *Arm throw*, *Bounce*, *Leg fling*, *Swaying side to side*, among others), perhaps indicating a continuum with the rhythmic arm movements synchronized with babbling reported from younger infants (Iverson and Fagan 2004; Iverson and Thelen 1999; Thelen 1979). This could also be the potential “proto-versions of beat gestures” (Pouw and Fuchs 2022) in

adults, which are included in a larger category of non-referential co-speech gestures (Prieto et al. 2018).

Conventional gestures represented the smallest proportion of gesture types (7 out of 62; e.g., “Chin-Chin”, “Flying kiss”, “Good-bye”, “Head shake”, “Head bob”, “Hello” and “Wow”) and were limited to certain individuals (Table S2). Individual variation could be attributed to levels of exposure to these gestures, or even varying degrees of time spent with adults (L. Acredolo and Goodwyn 1988).

## 4.2 | Gesture Functions

We examined the relationship between the different types of infant gestures and their functions, thus, addressing a previously neglected area of research. To do so we adopted the Apparently Satisfactory Outcome (ASO) method from primate studies (Hobaiter and Byrne 2014) to indirectly derive gesture functions as a consequence of particular contexts, relying only on the receiver's responses. Our results indicate that infants use deictic and iconic gestures for a large array of semantic functions. These gestures enable them to acquire their desired object, share attention with others on objects of desire, and describe actions to solicit actions from others. Their pragmatic functions are, therefore, mostly imperative (to request) and declarative. Co-speech referential gestures are also known to add semantic diversity to speech (Kendon 2004), suggesting an ontogenetic continuity here.

We found that iconic gestures in preverbal infants predominantly describe actions, rather than attributes of objects. Similar observations had been made by Özçalışkan and Goldin-Meadow (2011) and L. Acredolo and Goodwyn (1988) in older 2-year-old children. This early emergence of iconic action representation suggests a capacity to associate forms with meanings, even in the absence of speech. From an embodied cognition perspective, it is suggested that infants develop representations of bodily actions as their motor skills mature; this then leads to iconic representation of actions through gestures, which may serve as the first step toward symbolic communication and language acquisition (Fuchs, Etzelmüller, and Tewes 2016; Werner and Kaplan 1963), found ubiquitously across languages (Perniss, Thompson, and Vigliocco 2010).

Our results show that infant non-referential gestures largely serve declarative purposes. The main semantic function of infant non-referential gestures was to express happiness, discomfort, dislike, or anger toward others or about an event. Gesturing stopped when an appropriate reaction was elicited from the audience, either by continuing the interaction (in case of positive emotion), or termination of the interactions (in case of negative emotions). These declarative gestures in infants are thus interactional, as reported for adult non-referential co-speech gestures (beat gestures) (Bavelas et al. 1992; Kendon 2004).

Conventional gestures such as “yes”, “no”, hand wave for “goodbye” have already been reported in 12 to 34-month-olds (Fusaro and Vallotton 2011; Özçalışkan and Goldin-Meadow 2011). We

found that the main pragmatic function of these gestures was turn-taking, suggesting that conventional gestures may enable conversation-like structures between the infant and their caregivers before proficient spoken language develops.

### 4.3 | Gesture Flexibility

Infant gesture forms are not inflexibly tied to their corresponding gesture types, nor their functions; they are rather used depending on the context, exhibiting a form-to-function dissociation. In the infant repertoire described here, we found that a single gesture, such as pointing at an object, can carry two distinct semantic functions—“give me the object” or “look at the object”. These serve two different pragmatic functions: the first is a “request”, and the second is a “declaration.” We also observe that multiple distinct gestures can have a similar function. For example, to express emotions we describe a wide range of non-referential gestures in these infants (e.g., gestures *Hand fling*, *Leg fling*, *Head shake* were all used to express the emotion of not being content with the situation). This genre of form-to-function dissociation is a key cognitive marker of involuntary, intentional communication, also described for gesture production in non-human primates (Call and Tomasello 2020).

It is worth noting that co-speech gestures in adults follow a more rigid classification: referential gestures are primarily semantic and non-referential gestures are predominantly pragmatic in nature. However, this strict distinction between referential and non-referential gesture functions may result from the top-down influence of speech. It might be valuable to consider a bottom-up, ethological approach to classify adult gestures, similar to the method we used in this study. This could lead to a more nuanced understanding of co-speech gestures and broaden their expanding their meaning-scape, as has been recently proposed (Rohrer, Delais-Roussarie, and Prieto 2020; Prieto et al. 2018). Our open-ended approach, which assumes that all co-speech gestures can have both semantic and pragmatic functions depending on the context, could lead to a multidimensional, multimodal classification of speech-gesture integration in humans, as envisioned by Rohrer et al. (2022).

### 4.4 | Challenges, Limitations and Future Directions

One important challenge of the current ASO method is that gesture functions are deduced indirectly from the infant's behavior in response to the receiver's reaction to their gesture. In essence this indirect, contextual interpretation is similar to approaches used in past studies that inferred function by looking at the context in which gestures occur (Patel-Grosz 2023; Tomasello and Call 2019; Tomasello et al. 1994, 1997; Goldin-Meadow, Alibali, and Church 1993; Goldin-Meadow 1999), but with a key distinction. Inferring a gesture's function cannot be done solely by observing what happens before and after the gesture. Rather, our method identifies the infant's intended communicative goal more precisely by determining which specific response from the recipient satisfies the infant, as indicated by the cessation of gesturing. To illustrate,

consider an example: when an infant points to a doll and the adult brings the doll to her, satisfying the infant, we infer that the infant's communicative goal was to request the doll. In another scenario, if the adult responds by saying, “Yes, that's your doll”, and this satisfies the infant, we infer that her goal was to declaratively point at the doll, sharing her interest and attention with the adult. Without these responses and the infant's subsequent reactions, it would be impossible to determine the semantic functions (requesting the object vs. sharing attention) or the pragmatic functions (a request vs. a declaration) of the original pointing gesture. Thus, the gesture alone, even in a familiar context, can have an ambiguous meaning without considering the interaction that follows. The ASO method, by focusing on the infant's response to the recipient's reaction, provides a deeper understanding of the infant's communicative intent, going beyond merely analyzing the surrounding context.

Perhaps then, one of the most important methodological limitations of the ASO approach is an almost exclusive focus on gestures that require the receiver to do something in response. This criterion led us to discard 45% of all gesture instances. Thus, while the current approach reveals a complex and rich repertoire of gestures that could not be reported with previous methods, the inventory of gestures reported here is likely to be an underestimation of the actual gesture repertoire of infants.

The corpora of infant-caregiver interactions that we used here were originally created with the aim to examine factors driving spoken language development (MacWhinney 2000; Demuth and Tremblay 2008; but also see Morgenstern and Parisse 2012). Thus, often in these videos, we could not see the child, perhaps leading to an oversight of the gestures produced in these moments. This, in turn, could have resulted in an underestimation of some gesture forms and their functions in the infant repertoire. One possibility is that the individual variation that we observe in our data is a result of such a sampling bias rather than being by actual variations in gesture production at an individual level. Due to this unresolvable distinction between a potential developmental process and sampling bias, we refrained from performing any longitudinal analyses on the current data. Future studies on infant gesture development should ideally be conducted on video corpora recorded with gesture production as the main goal (e.g., Iverson and Goldin-Meadow 2005; Özçalışkan and Goldin-Meadow 2011). Our primary goal was to study the early precursors of co-speech gestures, but in this study, we focus on non-speech gestures alone. To bridge this gap, future research should explore how these non-speech gestures relate to infant vocalizations, eventually leading to the integration of gestures and speech. While we have not examined this integration in the current paper, we plan to investigate it in future studies by documenting the longitudinal development of gesture-vocalization combinations and their functional roles in early communication.

### 4.5 | Conclusions

In sum, our results demonstrate that preverbal infants possess a wide range of gesture forms that align with the four co-speech

gesture types typically observed in adults. Our findings mark an important first step in understanding the development of co-speech gestures independently of spoken language. This progress was made possible by using an ethological approach (Hobaiter and Byrne 2014), which allows for the identification of gestures and their functions based solely on behavioral signals. This approach, which does not rely on speech, offers new insights into the early development of gestural communication in infancy.

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### Author Contributions

**Shreejata Gupta:** conceptualization, data curation, formal analysis, funding acquisition, project administration, writing—original draft, writing—review & editing. **Eulalie Pequay:** methodology. **Clément François:** project administration, resources, supervision, validation, writing—original draft, writing—review & editing. **Isabelle Dautriche:** project administration, resources, supervision, validation, writing—original draft, writing—review & editing.

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### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

### Endnotes

<sup>1</sup> Conventional gestures are traditionally considered as “co-speech” gestures although they can sometimes replace words (“pro-speech” gestures; Schlenker 2020; Ekman and Friesen 1969).

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### Supporting Information

Additional supporting information can be found online in the Supporting Information section.