Toddler gestural accommodation in Portuguese nursery schools

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Abstract

This study investigated whether toddlers accommodate their gestures to partners of different ages. Video data from 53 toddlers (410-1080days, 27boys) were collected during free play time in 3 Portuguese nursery schools. Toddlers adjusted their vocabulary complexity and the temporal patterns of their gestures to the recipient's age, but did not change their prominence. Toddlers communicated with younger peers at a slower pace and using a simpler vocabulary, following child-directed communication patterns. However, when comparing adult-directed with peer-directed communication, toddlers used a more diverse set of gestures and shorter gestures. This study suggests that our ability to accommodate our communication emerges before language is fully developed, and that accommodation is flexibly expressed as a result of intersecting features of social partners.

Key-words: Child-directed communication, Gestural accommodation, Toddlers

Introduction

A central aspect of developing social competence is the ability to adjust one's behaviour to myriad nuances within the social environment, including to features of our social partners' identity and behaviour (Brownell & Carriger, 1990). Communicative behaviour is no exception: we accommodate speech and gestures to our partners' characteristics and relationships (Giles et al., 1987). Adults do so at a broad level by employing different signals: for example, we may greet a friend with a hug or a kiss, but with a stranger, we might shake hands; and, in some circumstances and cultures, people bow or kneel before a powerful person as a sign of respect. We can also modify more subtle features of our communication such as complexity (degree of elaboration), tempo (speed), and prominence (notability; Biersack et al., 2005; Snow, 1977). These adjustments can be almost imperceptible at times and may be processed at a subconscious level. For example, when we communicate with speakers who do not share our first-language (so called: 'foreigner-directed speech'), we tend to speak more slowly, and to articulate our words more clearly (Biersack et al., 2005; DePaulo & Coleman, 1986).

Another well-known example of linguistic accommodation in our daily life is the special register (communicative style) we use when talking to young children, often referred to as infant-directed speech, child-directed speech, babytalk, or motherese (Ferguson, 1964; Snow, 1977). Infant-directed speech is typically characterized by the use of a higher and more variable pitch, simpler vocabulary, more repetition, and a slower rate (Fernald et al., 1989; Snow, 1977). Argued to facilitate language acquisition and to promote social bonding, these adjustments have been reported across a wide variety of different cultures and languages (Fernald et al., 1989; Kitamura et al., 2001; Masataka, 1992). However, which features are present, as well as the nature and quantity of input given to children varies across cultures (e.g., Loukatou et al., 2022; Soderstrom, 2007). In some cultures, children are rarely directly addressed and yet they rapidly acquire language, suggesting that while infant-directed speech is important in many cultures, it is not essential for language development (Lieven, 1994; Ochs & Schieffelin, 1984). Infant-directed speech is not the primary (let alone exclusive) source of linguistic input for young children (Soderstrom, 2007) and investigating the influence of other environmental aspects that affect language development is crucial in furthering our understanding (Hoff, 2006; Oshima-Takane et al., 1996; Schick et al., 2022).

The use of a special linguistic register towards young children is found in both spoken and signed languages. When signing with young infants, adults tend to repeat utterances, use more exaggerated signs, and sign at a slower tempo, including the use of longer signs (Holzrichter & Meier, 2000; Masataka, 1992). Infant-directed language – both spoken and signed – is also accompanied by other non-linguistic adjustments, such as more exaggerated facial expressions (Kim & Johnson, 2013; Reilly & Bellugi, 1996) and modified patterns of body motion ("motionese") that involve using movements that are larger in scale but reduced in complexity (i.e., with small and simple action units, Brand et al., 2002). In addition, adults tend to modify their use of para-linguistic gestures in infant-directed communication ("gesturese"): when communicating with infants, as opposed to other adults, adults reduce their use of gesture overall (in particular using fewer beat gestures: non-meaningful movements, typically biphasic and produced with the hands or head accompanying the rhythm of the speech); but do increase the use of gestures indicating an external referent (deictic gestures; Bekken, 1989; Iverson et al., 1999; O'Neill et al., 2005).

But when and how does the ability to accommodate our communication emerge? Our cognitively sophisticated ability to accommodate our behaviour according to our social relationships was likely built on a set of ontogenetic precursor abilities already in place, such as the ability to distinguish different partners, to remember the result of previous interactions, and to use different signals to achieve the same goal. These abilities seem to emerge early in infancy, for example, toddlers (1-3 year-olds) can remember previous interactions with different partners (Hawley, 1999; Hinde, 1976) and adapt their behaviour according to the partner's social characteristics, including age, gender, interaction style, and expertise (Brownell & Carriger, 1990; Kachel et al., 2021). Toddlers' ability to use different signals to achieve the same goal is another indicator of communicative flexibility (Bates et al., 1975; Kersken et al., 2019). Early in ontogeny they seem broadly sensitive to both their partners' age and differences in their 'social competence' (here defined as: the ability to evaluate social situations and determine what is expected or required in a given context; APA Dictionary of Psychology, 2023). Fourteen-month-old children already demonstrate an impressive set of skills to seek, elicit, and employ information from individuals with differing levels of competence (Chow et al., 2008; Zmyj et al., 2010). As these interactions are shaped by different expectations of different partners who have different motivations, the way toddlers respond to peers and adults also differs, for example: giving them back different things in response to the same request (Franco et al., 2009; Kachel et al., 2021). Moreover, toddlers seem to be sensitive to relatively small differences in age, already ascribing different interpersonal qualities and competences to peers of different ages, and adjusting their behaviour accordingly (Brownell & Carriger, 1990; Franco et al., 2009). In sum, young children seem already able to adapt their communication in similar ways to the patterns described in adult use of infant-directed speech. Preschool children use shorter utterances, less complex structures, and more repetition when communicating with younger partners (Sachs & Devin, 1976; Shatz & Gelman, 1973), and take their listeners' linguistic capacity into account, making adjustments when communicating with younger peers (Shatz & Gelman, 1973). Dunn & Kendrick (1982) found similar patterns in even younger infants. When communicating with infant siblings, children as young as two-years old increased their use of attention getting utterances, made their speech shorter in duration, and used fewer exchanges and more repetition. Some infant-directed speech features used by adults have not, yet, been observed in children, for example: 4-year old children spoke more slowly and used shorter words, but did not modify their pitch (Weppelman et al., 2003).

As young children are still learning to master language, there may be limits on the way in which they can adjust their speech and sign. But, as shown in adults, adjustments may also be present in communicative behaviour outside of language. Given that children remain predominantly nonverbal until well into their third year (Eckerman et al., 2001) it is important to consider adjustment across non-linguistic communicative expression. One prominent form of communication in toddlers is gesture use, and its role in linguistic development prior to and accompanying speech is well described (Bates et al., 1975). As a result, early spontaneous gestures represent an ideal – and to date untested – system in which to explore the emergence of accommodation skills in early ontogeny.

The goal of the present study was to make a first attempt to investigate the emergence of accommodation and child-directed communication within the naturalistic gesturing of toddlers. We opted for the term 'child-directed communication' for two main reasons: the word 'communication' aims to capture the multichannel nature of the diverse modifications beyond spoken language use; and we use the word 'child' to include the communication directed towards toddlers (as opposed to only infants younger than 1-year old). We examined whether toddlers adjust their gesturing to their recipients' age, suggesting the use of a child-directed communicative register. To do so, we compared toddlers' adult-directed and peer-directed gestures during periods of free play. We then focused on gestures directed to peers and explored whether toddlers were sensitive to more fine-grained age differences in their communication towards younger and older peers. We explore three dimensions frequently studied in child-directed communication: vocabulary complexity, temporal patterns, and prominence. To measure vocabulary complexity, we focused on the diversity of gesture forms and on the use of gesture sequences. To explore variations in tempo we analysed changes in gesture duration and gesture rate (number of gestures per sequence divided by the sequence duration). Finally, to assess prominence, we looked at the likelihood of using repetition and incorporating objects in gesturing. We predict that toddlers will use simpler vocabulary, will gesture more slowly, and will use more prominent gestures when directing their gestures towards younger individuals (towards peers as compared to adults, and towards younger, as compared to older, peers).

Methods

Participants

Formal collaborations were established with three nursery schools, comprising four groups of toddlers (Table 1), from the wider Lisbon area. The parents of these toddlers received information on the project and were asked for written permission for their child to participate in the study. Informed consent was obtained for all the toddlers from the four groups (n=63). To be included in the study, toddlers had to meet the following criteria: they had to be typically developing children aged between 367 days (12 months) and 1101 days (36 months) at the beginning of the observational period. In addition, they had to be present on at least two of the days in which observations took place. In the end, a total of 53 toddlers (27 boys; 26 girls) between the ages of 410 days and 1080 days were included in the current study (Table S1).

Table 1. Characteristics of the study groups (sample size, gender, and age range in days) and observation time (period of data collection). As some toddlers were not included in the study, the size of the whole group (N group) and the number of toddlers included in the study (N this study) are indicated.

Nursery school/ group	N group	N (this study)	Number of boys (this study)	Age range (days)	Period of data collection
A	12	11	6	410-912	06-14/12/2021
B	16	14	6	499-841	02-10/05/2022
C	18	12	6	846-1052	14-24/02/2022
D	17	16	9	472-1080	17-25/01/2022

Data collection

Data collection occurred between December 2021 and May 2022 (Table 1). In each nursery school the period of data collection (approximately two weeks) was preceded by a week of habituation in which the researcher collecting the data was present for the daily routines and collected ad libitum videos so that the toddlers could become accustomed to her presence and that of the camera. Interactions between the researcher and the toddlers were avoided wherever possible in order to minimise any interference with the toddlers' typical behaviour and the daily routines of the nursery school. The toddlers were free to move around the playground, which contained a range of toys located on the floor or in specific containers, as well as play-structures. In addition to the researcher, there were always one to three adults known to the toddlers in the play area (one teacher and two classroom assistants).

Video-footage was collected during playtime (mostly indoor) throughout the day using 5-min focal sampling (Altmann, 1974; Hawley & Little, 1999). We included 30 minutes of video per child (six 5-min focal periods), providing a total of 1590 minutes of observation.

Data coding and definitions

We coded each child's gesture use from the video data following a bottom-up approach that minimises a priori structural choices and inferences about gesture form and function (*GesturalOrigins*; Grund et al., 2023). The framework is implemented in the linguistic coding software ELAN 6.4 (*ELAN*, 2022) and the protocol and definitions are described in detail in Grund et al. (2023). Gestures were defined as discrete, mechanically ineffective physical movements of the body (including the whole body, limbs, or head) observed during periods of intentional communication (Hobaiter & Byrne, 2011). Intentional communication was defined as communication deliberately targeted to a particular recipient, with the aim of influencing their behaviour in a specific way. In order to be considered intentional, potential gestures needed to be accompanied by one or more of the following criteria: audience checking, response waiting, or goal persistence (Bates et al., 1975; Grund et al., 2023; Leavens et al., 2005; Tomasello et al., 1985; Table 2).

We employed the following features in analyses: the signaller and recipient ID, age, and gender; gesture actions (e.g., Embrace, Grab, etc.) and their morphological aspects including emphasis, object contact, and object use, their structural aspects including the number of gestures per sequence and persistence; and finally, their temporal aspects including durations for individual gesture tokens (Performed Action Unit duration) and of sequences of gesture tokens (Table 2 for full definitions). We first considered gestures at the level of Gesture Actions (Table 2). The 52 Gesture Actions we observed were then further refined to more specific Gesture Morphs through the inclusion of two modifiers – repetition (e.g., Stomp vs Stomping) and directedness (e.g., Present vs Present directed); resulting in a repertoire of 67 gesture forms (Table 3). A wide range of modifiers can be considered in the description of specific gesture forms, resulting in finer and finer grained splitting. The decision of which level of granularity to consider was driven by both the available data density (if every possible modifier is applied very few cases of each morph are available, limiting analyses) and by the relevance of specific modifiers. Here we selected rhythmic repetition and directedness as both have been shown to be salient in children's gesturing (Kersken et al., 2019; Liszkowski, 2010; Murillo et al., 2021).

Table 2. Definition of key terms and coded features. Terms employed follow the *GesturalOrigins* framework (Grund et al., 2023).

Term	Definition
Gesture action	Bodily movement that describes the current gesture instance. Each gesture form has an action movement at its core that distinguishes every gesture instance. These gesture actions are considered together with additional modifiers to produce more fine-grained gesture morphs. For example, the gesture form

	‘Present directed’ corresponds to the gesture morph that results from the gesture action ‘present’ with the modifier ‘directedness’.
Modifiers	Additional characteristics considered with the gesture actions that can be used as building blocks to further specify the observed behaviour, allowing for flexibility in constructing repertoires of gesture forms at different levels of granularity. In this study two modifiers were considered: rhythmic repetition and directedness.
Performed action unit (PAU)	The relevant and informative section of the gesture that includes the Minimum Action Unit (MAU) plus an optional hold or repetition phase. The PAU starts with the body part performing the gesture moving from its neutral state (or a previous gesture in a sequence) to perform the gestural movement and ends as soon as the signaller starts to return it into a neutral position (or, alternatively, starts a subsequent gesture in a sequence using the same body part). This means the PAU does not include the recovery phase that corresponds to the body part performing the gesture returning into its neutral position.
Minimum Action Unit (MAU)	The smallest possible section of the gesture movement in which the recipient can sufficiently distinguish the specific gesture action being produced. The MAU starts at the point when the signaller starts moving from neutral position (or a previous gesture in a sequence) and ends when the gesture action is fully in place.
Neutral position	When the body part involved in gesturing is at rest or used in non-communicative behaviour before and after its employment in gesturing.
Repetition gestures	In addition to the MAU, these gestures (e.g., Hitting, Stomping) include a rhythmic repetition phase in their gesture production. These gestures are distinguished from multiple single gestures (e.g., Hit, Stomp) by the rhythmic nature of the repeated movement.
Repetition count	Where gesture actions could be rhythmically repeated, we counted the number of repetitions.
Emphasis	Where two gestures of the same form are used with a communication, we indicate whether a gesture is produced with more or less energy invested into it (for example in terms of the size or speed of the movement) as compared to the previous examples.
Object contact	Indicates whether the signaller made contact with an object during the gesture.
Object use	Indicates whether an object was manipulated in order to produce the gesture.
Sequence	All gestures produced with less than 1-second between them. The 1 second is measured from the end of the MAU. Sequence duration is measured from the start of the first gesture to the end of the last gesture of that sequence, and thus includes both the gestures and any brief pauses in the sequence.
Audience checking	The signaller checks the recipient’s state of visual attention before the production of the signal
Gaze before	The signaller looks in the direction of the recipient before starting a sequence of gestures

Gaze during	The signaller looks in the direction of the recipient while producing a sequence of gestures
Response waiting	The signaller pauses and waits for the recipient to respond to signaller's request. Pauses indicating response waiting must last for at least 1-second from the end of the last MAU in a sequence.
Persistence	The signaller continues to signal after response waiting and persists (same gesture forms) or elaborates (novel gesture forms) with more gesturing when the recipient does not respond or responds in a way that does not appear to satisfy them.

Table 3. Gesture action definitions and the frequency with which they were directed towards Adult and Peer recipients, distinguishing between older and younger peers. Forty-five gestures were directed to peers that could not be identified and are not included in the older/younger totals.

Gesture action	Definition	Adult	Peer	Peer	
				Older	Younger
Beckon	A scooping movement from one or more of the signaller's joints (e.g., fingers, wrist, elbow)	1	5	3	0
Bite	Signaller's mouth/teeth close on the recipient's body	0	5	3	1
Bite: Kiss	Gentle contact with the signaller's mouth that doesn't hold the recipient’s body (see 'Bite')	0	2	0	2
Bounce	Rhythmic vertical up-down movement of the signaller’s body.	16	13	6	6
Bow	Signaller bends forward from the waist.	4	1	1	0
Clap	Signaller moves both palms towards each other which are brought together with audible contact (may be repeated).	6	5	3	2
Crouch	Signaller lowers body by bending knees	1	5	3	1
Embrace	Signaller wraps one or both arms around recipient	4	6	2	4
Fling	Rapid movement of hand or arm away from the signaller's body, typically towards recipient	0	19	8	11
Grab	The signaller's hand is firmly closed over part of the recipient's body	2	19	6	11
Grab Hold	Same as 'Grab' but hand of signaller stays closed around recipient's body for at least 2 seconds	0	4	3	0
Hit(ting) Object/Ground [1]	Signaller makes a short hard contact with the ground/object	3 (3)	5 (6)	2 (2)	3 (2)
Hit(ting) Object/Ground with Object [1]	An object is brought into short hard contact with another object or ground	2 (1)	4 (3)	0 (1)	4 (2)
Hit(ting) Other with Object [1]	Same as 'Hit other', but the hand holds an object which is brought into contact with the recipient’s body	5(0)	9(6)	4(3)	5(3)
Hit(ting) Object/Ground Soft [1]	Same as 'Hit object/ground' but contact is gentle (as in tap, pat etc.)	2 (13)	6 (7)	0(5)	6(2)

Hit(ting) Other [1]	Same as 'Hit object/ground', but signaller makes deliberate contact with recipient as part of action	1(1)	16 (6)	11 (4)	5(2)
Hit(ting) Other Soft[1]	See 'Hit object/ground soft' but contact is deliberately made with recipient's body	4(11)	12(14)	8(7)	4(7)
Hit(ting) Self [1]	Same as 'Hit object/ground', but signaller makes deliberate contact with own body as part of action	3(0)	5(1)	4(0)	0(1)
Hit(ting) Self Soft[1]	Same as 'Hit object/ground soft' but contact is deliberately made with signaller's body	19(5)	4(1)	3(0)	1(1)
Hit(ting) Bystander[1]	Same as 'Hit other' but contact is made with third party (not the recipient)	2(0)	0(0)	0(0)	0(0)
Hit(ting) Bystander Soft [1]	Same as ‘Hit other soft' but contact is made with third party (not the recipient)	1(0)	0(0)	0(0)	0(0)
Jump	Both feet leave the ground simultaneously, accompanied by horizontal displacement	5	6	1	5
Locomote Gallop	An exaggerated running movement where the leg movements are typically stiff (straightened)	2	1	1	0
Lunge	Signaller's body is rapidly thrust towards recipient. No contact is made	0	3	3	0
Object Head	Signaller places detached object on their head and leaves it in place.	1	1	0	1
Object Mouth Unattached	Signaller holds an object in mouth. Hands should not normally be involved	0	1	0	1
Object Move Attached	Same as 'Object move unattached' but object remains attached to the environment	3	2	0	2
Object Move Unattached	Object is displaced, contact is maintained through movement. Object is free to move and not attached to environment	4	29	22	6
Object Shake	Repeated back and forth movement of an object (typically one still attached in the environment)	7	20	12	8
Out	Signaller's arm is extended out from the shoulder to the side of the body, elbow and hand are held in line	9	12	6	6
Over Stance	Signaller pauses while standing with at least one arm that has been moved into position and held over the recipient's body. In full form signaller's body forms a bridge over the recipient	0	3	1	2
Pot Human-Specific	Conventionalized gestures corresponding to the gestures whose form and function are culturally shared. No variation seen in the form and never occurring detached from its meaning	41	62	37	22
Present (directed) [2]	Signaller moves body or body part to deliberately expose an area to the recipient's attention	22(23)	10(8)	6(1)	4(6)
Pull (directed) [2]	Same as 'Push' but the contact between the signaller's hand and the recipient's body part happens usually in a grab position	1(1)	40(6)	15(1)	24(5)
Push (directed) [2]	Signaller contacts recipient's body (typically hand) and force is exerted into the recipient's body as if to displace recipient	6(0)	87(17)	46(9)	40(8)

Raise	Signaller raises body part (typically hand or arm) in a generally vertical movement	35	36	18	15
Reach	Signaller's body part (typically hand or arm) extended towards the recipient with no contact	241	243	142	83
Rocking Sit	Signaller moves body back and forth, or side to side, while sitting	0	1	0	1
Rub	Signaller push/rubs body part up and down against body of recipient (typically with hands)	0	3	3	0
Rub Self	Signaller push/rubs body part against part of their own body (typically with hands)	4	3	0	3
Shake	Signaller moves part of their body quickly and repeatedly back and forth (typically hand/arm or head)	58	69	44	24
Shake Other	Signaller holds body part of other individual and moves it quickly and repeatedly back and forth	0	1	1	0
Spin Pirouette	Signaller stands and turns around their bodies vertical axis while also displacing along the ground	1	0	0	0
Stance Bipedal	Signaller stands stiff in front of the recipient and holds position	0	1	0	1
Stomp(ing) Object[1]	The signaller's foot (or sometimes hand) is lifted vertically and brought into short hard contact with the ground (or object)	9(4)	8(7)	5(3)	3(2)
Stroke	Active gentle movements of the signaller's palm or fingers (rarely other) on the recipient's body	2	0	0	0
Swing (directed) [2]	Smooth continuous motion of signaller's body part (normally arm of leg) back and forth	4(2)	0(0)	0(0)	0(0)
Throw Object	Object is moved and released so that there is displacement of the object through the air after moment of release	0	5	2	3
Throw Threat	Object is lifted into position to throw it but is held in that position (typically raised above shoulder) without release	0	3	2	1
Touch	Light contact (typically of the signaller's fingers, knuckles, hand, or foot, rarely other) on the body of the recipient, contact under 2 seconds	25	27	14	12
Touch Long Other	Same as 'Touch' but contact is held for under 2 seconds	8	3	1	2
Touch Object	Same as 'Touch' but contact is made with a specific object/ground in a location between the signaller and recipient	44	16	11	3

[1] Distinct gesture forms considered based on regular rhythmic repetition, with the respective frequencies indicated in parenthesis.
[2] Distinct gesture forms considered based on the consistency of the recipient's behavioural reaction and the movement/location suggested by the signaller gesture action, with the respective frequencies indicated in parenthesis.

Data analysis

We examined how the gestural communication of toddlers was affected by the recipient's age. We focused on six different gestural features and fitted one model for each feature (Table 4). To explore vocabulary complexity, we calculated (1) the diversity of gestures and (2) the use of sequences. The diversity of gestures corresponded to the number of distinct gesture forms used by each child. To explore temporal patterns, we analysed (3) the gesture duration and (4) the gestural rate. The gesture duration corresponded to the relevant section of the gesture (PAU; see Table 2). The gesture rate was calculated as the number of gestures per sequence divided by the total sequence duration. To explore prominence of the gestural communication we analysed (5) the presence of repetition and (6) the use of objects. Within repetition we included examples of repetition by the signaller that occurred at both the gestural level (i.e., repetition of the gesture action within an instance of gesturing, e.g., Hitting, or Stomping), at the sequence level (the addition of further gestures of the same form) and at the bout level (persistence or elaboration, i.e. the addition of further gestures separated by more than 1 second; see Table 2). In considering the use of objects, we included gestures in which an object was used to produce them either as an object manipulation gesture (e.g., Object shake), or one that contacted an object or surface (e.g., Hit object; see Table 2).

We ran each model on two sets of data: (a) a first dataset including all gesture tokens produced by the focal, in order to compare the communication directed towards adults with that directed towards peers (n=1595); and (b) a second dataset including only the communications occurring between peers, in order to explore how the same gestural features varied with recipient age at a more nuanced level (n=878). Our analyses explored three different levels of gestural accommodation (Individual, Sequence, and Gesture), resulting in six different datasets (Table 4). Of the 923 gestures directed towards peers, 45 gestures were discarded from the subset of analyses focusing on peer communication due to a lack of relevant information about the recipient. One of the toddlers was never observed to communicate with other peers and for that reason was not included in the second set of analysis (b).

Table 4. Analysis structure. Models (Mod) for each gestural feature with respective datasets and sample sizes (N) for Adult-Peer and Peer-Peer comparisons.

Dimension	Level of analysis	Gestural feature *Response variable*	Adult-Peer (a)			Peer-Peer (b)		
			Mod	*Dataset*	*N*	*Mod*	*Dataset*	*N*
Vocabulary complexity	Individual	(1) Diversity of gestures	1a	ind.data.a	106	1b	ind.data.b	104
	Sequence	(2) Use of sequences	2a	seq.data.a	923	2b	seq.data.b	538
Tempo	Sequence	(3) Gesture rate	3a	seq.data.a	923	3b	seq.data.b	538
	Gesture	(4) Gesture duration	4a	gest.data.a	1595	4b	gest.data.b	878
Prominence	Gesture	(5) Repetition	5a	gest.data.a	1595	5b	gest.data.b	878
	Gesture	(6) Use of objects	6a	gest.data.a	1595	6b	gest.data.b	878

Model specifications

We fitted models to test the impact of the recipient age on the different gestural features mentioned above (1-6). All models were Generalized Linear Mixed Models (GLMM; Baayen, 2008) and, depending on the nature of the response variable, with one of the following error structures and link functions: Poisson (model 1a), Zero inflated negative binomial (model 1b), Binomial (models 2, 5, and 6), Gamma (models 3), and Gaussian error structure (models 4); and log link (models 1a, 3), logit/log (model 1b), logit (models 2, 5, and 6), or identity (models 4) link function.

In the first set of analysis (a) two levels were considered for recipient age: adult and peer. For the subset of data used in the second set of analyses (b) we employed the difference between the recipient's age and the signaller's age in days as a measure, allowing us to account for both the valency and the magnitude of age difference. An exception was made when analysing the diversity of gestures (1b) where relative proportions were required. For this analysis we considered again two levels for recipient age, but this time with younger-peer and older-peer as categories.

In all models, we controlled for the interaction between signaller age and signaller gender. To control for confounding effects, we also included group as further fixed effect into the model. As random effects (intercepts) we included the identity of the signaller (Signaller's ID). We included recipient age within Signaller's ID to keep type I error rate at the nominal level of 5% (Barr et al., 2013; Schielzeth & Forstmeier, 2009). An exception was made for Models 5 and 3b as including the random slope prevented the models from converging. For the other fixed effects (gender, age, and group), we did not include random slopes as they were constant within signaller's ID. To test the overall significance of our key predictor (recipient age; Forstmeier & Schielzeth, 2011) we compared the full models with reduced models lacking the key predictor using a likelihood ratio test (Dobson & Barnett, 2018).

Model implementation

We fitted models in R (version 4.0.2, R Core Team, 2020) using the functions glmer and lmer of the R-package lm4 (Bates et al., 2014). The zero-inflated model (1b) was fitted using the function glmmTMB (Brooks et al., 2017). Prior to fitting the model, we z-transformed signaller age and the difference between recipient and signaller's age to a mean of zero and a standard deviation of one to provide more easily interpretable estimates (Schielzeth, 2010). We also log transformed the duration of gestures to provide an approximately symmetrical distribution and mitigate against the effects of any influential cases. To control for collinearity, we determined Variance Inflation Factors (VIF, Quinn & Keough, 2002) from the equivalent standard linear models including only the fixed main effects and lacking the interaction, using the function vif of the R-package car (Fox & Weisberg, 2011). This check showed that collinearity was not an issue in any of the models (maximum VIF 1.87).

Ethical note

This study was observational, and participation was voluntary. All parents gave their written informed consent for their children to take part in the study. The parents could decide at any time to pause or stop their child's participation in the study and request that their child's video data be deleted. We anonymized all data to ensure that toddlers could not be identified during data analysis and in the presentation of the results. The study was approved by the ethical committee of ISPA – Instituto Universitário.

Results

Adult-directed gestures vs peer-directed gestures

Of the 1595 gesture tokens produced by the signallers (n=53), 672 gesture tokens were directed toward adults and 923 towards peers. Toddlers used 65 gesture forms: 49 when communicating towards adults, and 59 when communicating towards peers. Toddlers employed 6 gesture forms towards adults that were not seen in their communication with peers, and 15 gesture forms towards peers that were not seen in their communication with adults (Table 3). Examining the cumulative frequency of gesture forms directed towards adults and peers, suggests that our sample repertoire had reached asymptote within our observed contexts (adult-directed communication: 622; peer-directed communication: 829; Figure S1, Figure S2).

The age of the recipient influenced some features of the toddlers' gesturing, in particular the complexity of their vocabulary and their temporal patterns (Table S2-S4). Vocabulary complexity, as measured by the diversity of gesture forms used, increased in communication directed towards peers (full-null model comparison: χ^2 =28.064, df=31, p<0.001). Toddlers used a more diverse set of gesture forms towards peers as compared to the set of gesture forms they used towards adults (estimate= 0.634±0.117, z=5.43, p>0.001,

Figure 1; Figure S3). The full-null model comparison revealed no significant impact of recipient age on the use of sequences (χ^2=0.473, df=1, p=0.49).

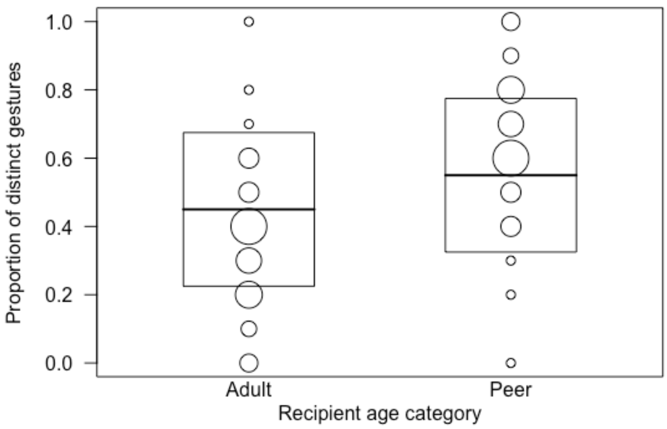

Figure 1. Proportion of different gesture forms directed towards adult and peer recipients. In total, 49 different forms of gesture actions were used towards adults and 59 towards peers. Larger bubbles represent more toddlers with a given proportion. Boxes indicate 25th, 50th, and 75th percentiles. The proportions were calculated for each toddler by dividing the number of distinct gesture forms directed towards adults or peers by the total number of the distinct gesture forms produced by each toddler.

In terms of temporal patterns, there was no clear effect of recipient age on gesture rate (full-null model comparison: χ^2=1.880, df=1, p=0.170), but recipient age did affect gesture duration (full-null model comparison: χ^2=16.709, df=1, p<0.001) with toddlers directing longer gestures towards adults (estimate= -0.118±0.043, t-value=-2.711, df=25.641, p=0.012, Figure 2).

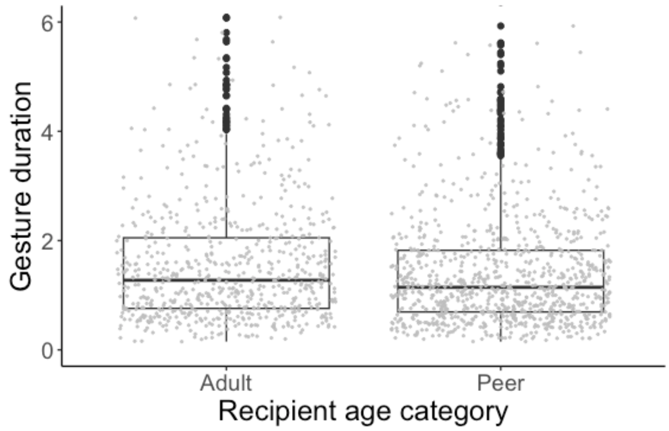

Figure 2. Difference in the gesture duration between gestures directed towards adults and peers. Boxplots show the gesture (PAU) durations of 1595 gestures: 672 directed towards adults and 923 towards peers. Raw data are represented by the grey dots.

Finally, the prominence of the toddler's gestures did not vary with the recipient's age. Toddlers were similarly likely to use repetition in their gesturing (full-null model comparison: χ^2=0.655, df=1, p=0.418) and to use objects in their gestures (full-null model comparison: χ^2=1.349, df=1, p=0.246) when communicating towards adults and peers.

Peer-directed gestures: younger vs older recipients

Within the subset of communication directed towards peers, toddlers (n=52) directed 379 gesture tokens from 51 gesture forms towards younger peer partners and 499 gesture tokens from 48 gesture forms towards older peer partners.

Toddlers were able to adjust their vocabulary complexity and temporal patterns to their partner's age (Table S5-S7). Recipient age did impact the diversity of gestures used (full-null model comparison: χ^2=6.130, df= 1, p=0.013). Across signallers a larger number of gesture forms were used to communicate to younger peers, with n=3 gesture forms used to younger peers that were not recorded used towards older peers. However, individual repertoires of gesture forms that toddlers produced towards younger peers was typically smaller than those used towards older peers (estimate= -0.378±0.146, z=-2.582, p=0.01;

Figure 3; Figure S4). In contrast, we found no effect of recipient age on the likelihood of using gesture sequences (full-null model comparison: χ^2=0.861, df= 1, p=0.353).

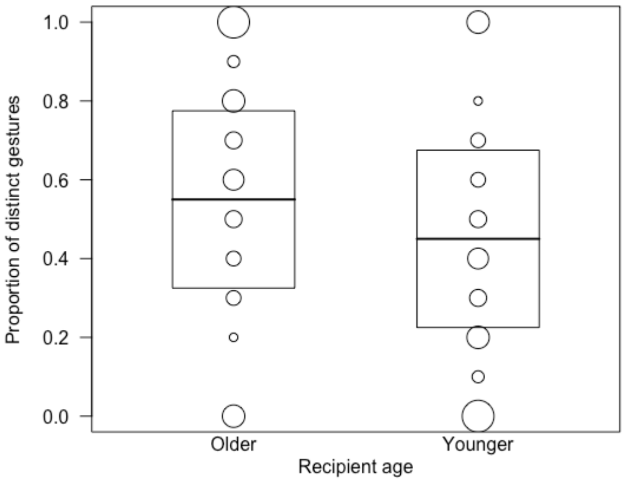

Figure 3. Proportion of different gesture forms directed towards younger and older peer recipients. Larger bubbles represent more toddlers with a given proportion. Boxes indicate 25th, 50th, and 75th percentiles. The proportions were calculated for each toddler, by dividing the number of distinct gesture forms directed towards younger or older peers by the number of the total distinct gesture forms produced by each toddler.

In terms of temporal patterns, peer recipient age did impact gesture rate (full-null model comparison: χ^2=4.876, df= 1, p=0.027): toddlers gestured more slowly towards younger peers (estimate= 0.066±0.03, z=2.217, p=0.027; Figure 4). However, partner age had no impact on the performed action unit (PAU) duration (full-null model comparison: χ^2=0.309, df= 1, p=0.578).

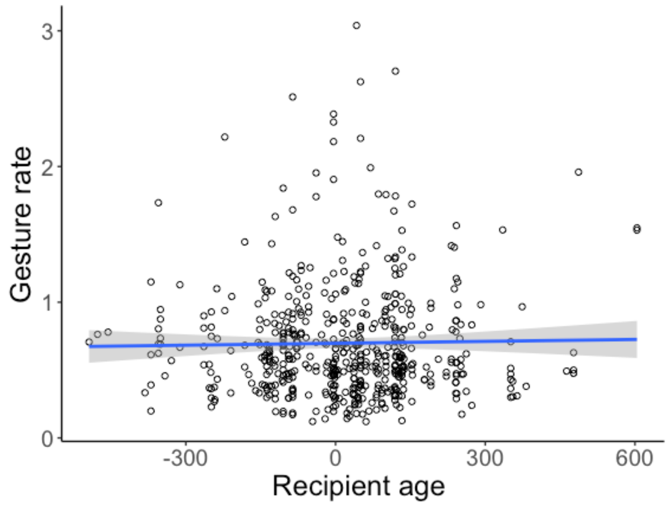

Figure 4. Effect of recipient age on the gesture rate. Gesture rate represents the number of gestures per sequence divided by the sequence duration. Each point in the plot represents a sequence.

Again, the prominence in gesturing did not vary with recipient age when comparing the communications directed towards younger and older peers. We found no variation in the use of repetition in gesturing (full-null model comparison: χ^2=0.065, df=1, p=0.799), nor in the inclusion of objects in gestural communication (full-null model comparison: χ^2=0.017, df= 1, p=0.895).

Discussion

We describe the emergence of our ability to accommodate communication to partners of different ages. We focused on the gestures produced by toddlers during free play and investigated the influence of recipient age on three dimensions usually explored in child-directed communication: vocabulary complexity, tempo, and prominence. We first compared whether toddlers address peers and adults in different ways. We then explored the same features in peer-directed communication to assess whether toddlers were sensitive to more subtle age differences, differently adjusting their communication to younger and older individuals within their peer group. Toddlers were able to adjust the vocabulary complexity and the temporal patterns of their gestures to their recipient's age but did not appear to change the prominence of their communication. When communicating with younger peers, some of the patterns of child-directed communication described in language use already appear present in toddlers' non-linguistic gestures: they communicated with younger peers at a slower pace and using a simpler vocabulary. However, when comparing adult-directed with peer-directed communication, we found an opposite pattern: toddlers used a more diverse set of gestures and shorter gestures when communicating with their peers as compared to adults.

Based on the ability of very young children to discriminate levels of social competence in their recipients, we predicted we would find patterns of accommodation towards their peers, as compared to adults, resembling those already described in child-directed communication, as they should recognise that younger partners are less proficient communicators. Interestingly, our finding of an opposite trend in the adult-peer comparison suggests that toddlers can accommodate their communication within different registers when communicating with peers and adults, but that there may be factors other than age or associated communicative competence driving this accommodation. For example, toddlers may recognise that adults, as compared to peers, have different motivations, expectations, or goals in mind (Kachel et al., 2021). The fact that the cumulative number of gesture forms directed towards adults also reached asymptote, makes it unlikely that the reduced diversity of gestures were a by-product of the fewer number of gestures produced towards adults. However, if toddlers engage with adults for different goals, or for a more restricted set of goals, they might use a specific subset of gesture actions to do so – apparently 'limiting' their vocabulary. Determining the meaning of gestures and goals is challenging in pre-linguistic children, and to investigate this further would require data across a more diverse range of contexts (Kersken et al., 2019) and substantially larger datasets than were available in this study. Moreover, at present, we are only able to determine goals for successful imperative requests in gestural communication (Bates, 1979; Cartmill & Byrne, 2010; Hobaiter & Byrne, 2017) further limiting our ability to explore across the full range of toddlers' gesturing. Similarly, we can not rule out that our unexpected pattern of longer-gestures towards adults, as compared to peers, was the result of variation in gesture forms – rather than extension of the gesture units themselves. Gesture forms are very different from each other, with some gesture forms necessarily longer than others to produce: for example, some involve the whole body as opposed to just a limb, some have an optional holding/repetition phase, some are characterized by a particular speed (e.g., a Fling cannot be slow). As our measure of gesture duration is dependent on gesture forms, we would ideally either control for gesture form, or investigate the use of specific gesture forms across recipients of different ages.

An additional factor that may have shaped our findings, in particular the ones regarding temporal patterns, is the interaction between age and social relationship. Social relationships shape the way we communicate: for example, differences in greetings based on social familiarity and hierarchy (Gallois et al., 2005; Giles et al., 1987), or our ability to communicate more efficiently with friends compared to strangers, based on shared common ground (Savitsky et al., 2011; Van Der Wege et al., 2021). The influence of common ground on some language properties is already well documented, affecting the use of syntax, vocabulary, accent, and intonation (e.g.: Clark, 1996; Hwang et al., 2015). In a nursery school context, the toddlers we observed may have shared more similar language competences and experiences with the other toddlers, interacting with them more often as compared to the adult teachers. This increased common ground may have contributed to their use of shorter gestures with peers. It would be interesting to compare toddlers' gesturing towards adult recipients of different social relationships and familiarities – for example, teachers and caretakers as compared to parents.

Another dimension of our social relationships that shapes our daily interactions is dominance and hierarchy (Gallois & Others, 1992; Giles et al., 1987). For example, in some cultures, the way we address more dominant individuals, such as the matriarch of a family, or a university professor is more formal and, as a result, more energetically 'expensive' in the sense that we choose to use more complex and longer structures. In our observations the adults were familiar with our toddlers, but also individuals in positions of social authority (teachers and classroom assistants). If similar sensitivity to social hierarchy is already present in early ontogeny, toddlers may have perceived the adults as more distant and more dominant individuals, and consequently employed longer gestures. In these types of socially stratified relationships children may also want to 'display' newly acquired communication skills to create a positive impression in someone that can acknowledge their skills (as one might put more effort into preparing a meal for a friend who is a chef).

Finally, nursery schools provide a very specific social setting in which there are diverse sources of interest, such as objects and social partners (usually a greater variety as compared to the ones that they would have at home), but also more competition for those same objects and partners. Particularly, where there is a small ratio of adults/toddlers - toddlers experience greater competition for the attention of the adults as compared to peers. In our study there was usually a maximum of 3 adults, excluding the researcher, per room (the teacher and up to 2 classroom assistants) in groups that varied from 12 to 18 toddlers. As a result, to get an adult's attention, toddlers might have to hold a gesture for longer while waiting for the adult to pay attention to them. Audience effects are well established in communication (Alibali & Don, 2001; Cartmill & Byrne, 2007; Galati & Brennan, 2010); and although we focused on dyadic interactions, the presence of other individuals in their environment – such as the large number of peers contrasting with the fewer adults who needed to divide their attention among them – could also have influenced the children to compete for adult's attention.

To better understand the influence of friendship, familiarity, dominance, and competition on toddlers' gestural accommodation, future studies could incorporate a range of different settings, cultures, and social relationships across a wider range of recipient ages. For example, further research could investigate how gestural accommodation varies between close family relationships and more formal relationships with non-family members (such as teachers). Similarly, exploring gesture between different states of attention and within different social audiences would help disentangle the diverse possible effects in this complex phenomenon.

It is somehow a little surprising that we did not find any change in the 'prominence' of the gestures used by the toddlers. One function of child-directed communication is to get the attention of the recipient, and we selected two features that we anticipated would capture some of the potential variation related to prominence: repetition and the use of objects. Repetition is one of the most well documented features of child-directed communication (Cameron-Faulkner et al., 2003; Masataka, 1992; Papoušek et al., 1987); however, there are several possible explanations for the apparent lack of an effect in this study. We may have missed describing the ways in which prominence was varied, such as with additional acoustic signals, or in other variations in the use of space, movement, and energy in gesture production. For example, more expansive gestures are usually wider and exploring more the peripheral space, which involves more energic demanding movements, but they could attract/maintain the recipient's attention more easily. Increased energic demand could also be reflected in more forcefully produced gestures that make louder or harder contact with other objects or individuals. While we did consider emphasis across gestures in our coding, we were only able to do so where two instances of the same gesture action were produced in the same communication. The signaller might use other strategies outside of the specific gesture production to capture and hold the recipient's attention, such as moving into the recipient's line of sight, or by producing attention getting signals in other modalities – such as a vocal or facial signal. Some of these possible patterns in gestural prominence of child-directed communication may only emerge if we consider the full multimodal nature of the communication.

Alternatively, accommodation through adjusted prominence might not be present at this stage of development. Repetition at this stage may only be used in persistence towards a goal that was initially declined, or to repair a miscommunication. Although younger recipients may be more likely to misunderstand or to take more time to understand the goal, any effect might remain undetected by our methods and in this specific social context. For example, play contexts in nursery schools represents a non-urgent context in which children, regardless of their age, are free to move around their environment. This freedom of movement could influence gestural production and the use of accommodation as the signaller is able to easily move to the front of the recipient to capture their attention, move to a new partner to interact with instead, or they could find something else to do and give up on the interaction entirely. Additionally, using objects in gesturing makes the gestures themselves more salient. For instance, hitting an object with another object, or extending an arm (Reach) while holding an object, are both more noticeable than their non-object counterpart actions. However, toddlers did not vary their object use based on interaction partner (adults or either type of peers, younger or older). These findings suggest that toddlers may not use objects as attention getters (i.e., to capture the attention of the recipient and subsequently communicate about other things), but instead, that the communication itself is likely to be about the objects.

A closer look at peer-directed gestural communication suggests that our ability to accommodate our communication to younger individuals is already present during toddlerhood, and that toddlers use of this register partially follows the patterns described in infant-directed speech. In this study, we found that when communicating with younger partners, toddlers opted for using simpler vocabulary (reflected on the use of a more restricted set of gesture actions) and at a slower pace (lower gesture rate). The use of fewer gesture actions may, again, be related to a more limited range of interactions and goals, which we suggest may have occurred in gestures directed to adults. However, here this bias would be in line with the predictions of the Interactional Artifact Theory, which suggests that gesture modification may be a by-product of the semantic simplicity of interactions with infants (O'Neill et al., 2005; Pine, 1994).

Our analyses of the temporal patterns in toddlers' peer-directed gestures showed that the pace of their communication was also adjusted when communicating with younger individuals. We used the total duration of the sequence, and accounted for pauses between gestures in calculating gesturing rate. Thus, a slower rate may reflect longer gestural units or longer pauses between them or both. The fact that we did not find an effect of peer age on the duration of the gesture (Performed Action Unit), strongly supports the suggestion that it was the length of the pauses that were adjusted – aligning with the findings that longer pauses are an established feature of child-directed communication (e.g.; Fernald et al., 1989). In the future, exploring this feature by directly measuring pause lengths, and by looking more generally at the whole communication, including pauses between distinct sequences that may reflect persistence or exchanges, could provide a better understanding of how distinct structural elements are adjusted.

Some of the measures chosen for this study did not reveal any effect of the recipient's age on the gestures directed to them, suggesting that these features are not (yet) adjusted by toddlers in their gesturing. However, child-directed communication registers are not universal, and not all features are present across all cultures and contexts. Conversely, other features in child-directed communication may already be in place but were not explored in this study, such as the use of space, the number of exchanges, or the use of deictic gestures. Specificities in the Portuguese language, culture, or in the school environmental context of free play may also promote and shape the use of certain features in gestural accommodation. We chose free play due to the richness of opportunities this context provides, particularly as it is often free of more formal scaffolding and instructions. However, these freedoms also provide a challenging context for analysis, perhaps masking patterns that would be present in other communicative contexts.

Here, we provide a first case-study that showed how and where child-directed communication registers could emerge in the gesturing of toddlers in Portuguese nursery schools during free play. Further study across a more diverse set of contexts, communities, relationships, and features of interest is needed to assess how these findings might generalise more broadly. Nevertheless, we establish that toddlers can accommodate their gestural communication, and that they do so both by varying these patterns in unexpected ways when gesturing with adults, and by adopting similar patterns to adults in child-directed communication registers in their gesturing with younger peers.

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Supporting information

Toddler gestural accommodation in Portuguese nursery schools

Supplementary tables

Table S1. Characteristics of the focal toddlers namely their ID (code name), gender, age at the start of data collection, and the group to which they belonged.

ID	Gender	Age (days)	School	ID	Gender	Age (days)	School
Columba	F	928	D	Lyra	F	692	B
Cepheus	F	947	D	Aquila	F	577	B
Antlia	M	593	D	Microscopium	F	599	B
Chamaeleon	F	725	D	Corvus	M	659	B
Circinus	M	842	D	Leo Minor	F	841	B
Dorado	F	599	D	Equuleus	F	540	B
Auriga	F	1080	D	Libra	M	532	B
Capricornus	M	953	D	Carina	F	577	B
Eridanus	M	599	D	Canis Minor	F	571	B
Cygnus	M	975	D	Aries	M	600	B
Ophiuchus	M	472	D	Monocerus	F	673	B
Lepus	F	842	D	Lacerta	M	499	B
Coma Berenices	M	554	D	Horologium	M	699	B
Fornax	M	716	D	Corona Australis	M	579	B
Hercules	F	1076	D	Aquarius	F	982	C
Lupus	M	481	D	Crater	M	861	C
Octans	M	440	A	Cetus	F	846	C
Apus	M	774	A	Draco	F	983	C
Corona Borealis	F	600	A	Canis Major	M	947	C
Delphinus	F	663	A	Crux	F	1052	C
Centaurus	F	628	A	Norma	F	905	C
Mensa	F	410	A	Lynx	F	966	C
Gemini	F	827	A	Hydrus	M	959	C
Leo	M	912	A	Bootes	M	1052	C
Camelopardalis	M	873	A	Cassiopeia	M	1001	C
Musca	M	566	A	Canes Venatici	M	1019	C
Grus	M	720	A				

Table S2. Factors influencing the following toddlers' gestural communication features: (1a) Diversity of gestures, (2a) Use of sequences, (5a) Repetitions and (6a) Use of objects.

Term	Estimate	Std. Error	lower CI*	upper CI*	z	P-value
(1a) Diversity of gestures						
Intercept	1.24	0.221	0.82	1.633		[1]
Signaller gender (male)	-0.092	0.137	-0.355	0.183		[1]
Signaller age	0.504	0.12	0.291	0.745		[1]
Recipient age (peer)	**0.634**	**0.117**	**0.419**	**0.877**	**5.43**	**<0.001**
School (B)	0.326	0.235	-0.07	0.767	1.388	0.165
School (C)	0.077	0.251	-0.403	0.546	0.306	0.76
School (D)	0.115	0.211	-0.266	0.516	0.544	0.587
Signaller gender (male) x Signaller age	-0.154	0.144	-0.423	0.103	-1.071	0.284
(2a) Use of sequences						
Intercept	-0.372	0.232	-0.855	0.086		[1]
Signaller gender (male)	0.075	0.181	-0.262	0.427		[1]
Signaller age	0.261	0.14	-0.007	0.533		[1]
Recipient age (peer)	0.106	0.154	-0.218	0.4	0.686	0.493
School (B)	0.005	0.282	-0.564	0.578	0.017	0.986
School (C)	-0.135	0.278	-0.676	0.395	-0.487	0.626
School (D)	-0.39	0.271	-0.915	0.099	-1.438	0.151
Signaller gender (male) x Signaller age	-0.062	0.183	-0.436	0.301	-0.336	0.737
(5a) Repetitions						
Intercept	-0.584	0.189	-0.949	-0.219		[1]
Signaller gender (male)	-0.123	0.145	-0.405	0.168		[1]
Signaller age	0.276	0.112	0.061	0.495		[1]
Recipient age (peer)	-0.095	0.117	-0.32	0.142	-0.811	0.417
School (B)	0.158	0.229	-0.273	0.6	0.69	0.49
School (C)	-0.02	0.223	-0.449	0.413	-0.09	0.928
School (D)	-0.344	0.222	-0.747	0.08	-1.553	0.12
Signaller gender (male) x Signaller age	-0.38	0.144	-0.666	-0.101	-2.635	0.008
(6a) Use of objets						
Intercept	-0.533	0.317	-1.176	0.095		[1]
Signaller gender (male)	-0.005	0.264	-0.57	0.495		[1]
Signaller age	-0.18	0.195	-0.551	0.21		[1]
Recipient age (peer)	-0.309	0.256	-0.781	0.157	-1.206	0.228
School (B)	-1.138	0.398	-1.956	-0.402	-2.859	0.004
School (C)	-0.597	0.415	-1.4	0.191	-1.439	0.15
School (D)	0.045	0.392	-0.67	0.745	0.115	0.908
Signaller gender (male) x Signaller age	0.218	0.278	-0.292	0.68	0.785	0.433

[1] Not shown as lacking a meaningful interpretation

Table S3. Factors influencing (3a) the gesture rate of toddlers' gestural communication.

Term	Estimate	Std. Error	lower CI	upper CI	t	P-value
Intercept	-0.353	0.1	-0.684	0.002		[1]
Signaller gender (male)	-0.097	0.077	-0.349	0.156		[1]
Signaller age	0.119	0.064	-0.081	0.33		[1]
Recipient age (peer)	0.078	0.059	-0.142	0.309	1.324	0.185
School (B)	-0.087	0.113	-0.496	0.296	-0.769	0.442
School (C)	-0.04	0.131	-0.43	0.367	-0.303	0.762
School (D)	-0.134	0.11	-0.532	0.262	-1.212	0.226
Signaller gender (male) x Signaller age	-0.091	0.078	-0.361	0.167	-1.164	0.244

Table S4. Factors influencing (4a) the gesture duration of toddlers' gestural communication.

Term	Estimate	Std. Error	lower CI	upper CI	df	t value	P-value
Intercept	0.194	0.083	0.024	0.361			[1]
Signaller gender(male)	0.074	0.065	-0.056	0.204			[1]
Signaller age	-0.149	0.049	-0.248	-0.05			[1]
Recipient age (peer)	**-0.118**	**0.043**	**-0.202**	**-0.034**	**25.641**	**-2.711**	**0.012**
School (B)	-0.053	0.097	-0.261	0.158	46.533	-0.544	0.589
School (C)	-0.012	0.103	-0.221	0.205	28.244	-0.115	0.909
School (D)	0.11	0.095	-0.081	0.31	38.41	1.161	0.253
Signaller gender (male) x Signaller age	0.098	0.062	-0.023	0.231	42.126	1.585	0.121

Table S5. Factors influencing the following features of toddlers' gestural peer-directed communication: (1b) Diversity of gestures, (2b) Use of sequences, (5b) Repetitions and (6b) Use of objects.

Term	Estimate	Std. Error	lower CI*	upper CI*	z	P-value
(1b) Diversity of gestures						
count part - Intercept	1.650	0.233	1.193	2.108		[1]
count part - Signaller gender (male)	-0.168	0.172	-0.506	0.17		[1]
count part - Signaller age	0.661	0.161	0.345	0.976		[1]
count part - Peer recipient age category	**-0.378**	**0.146**	**-0.665**	**-0.091**	**-2.582**	**0.010**
count part - School (B)	0.571	0.269	0.043	1.098	2.12	0.034
count part - School (C)	-0.198	0.303	-0.793	0.396	-0.654	0.513
count part - School (D)	-0.047	0.276	-0.588	0.495	-0.169	0.866
count part - Signaller gender (male) x Signaller age	-0.097	0.172	-0.435	0.24	-0.564	0.572
zero part - Intercept	-1.825	0.367	-2.543	-1.106	-4.975	0.000

(2b) Use of sequences						
Intercept	-0.114	0.341	-0.814	0.521		[1]
Signaller gender (male)	-0.067	0.232	-0.497	0.389		[1]
Signaller age	0.164	0.225	-0.303	0.628		[1]
Age difference recipient-signaller	-0.117	0.125	-0.379	0.137	-0.938	0.348
School (B)	-0.115	0.415	-0.954	0.756	-0.277	0.782
School (C)	-0.085	0.415	-0.923	0.75	-0.204	0.839
School (D)	-0.68	0.388	-1.462	0.089	-1.752	0.08
Signaller gender (male)x Signaller age	-0.149	0.237	-0.61	0.288	-0.629	0.529
(5b) Use of repetitions						
Intercept	-0.635	0.105	-0.831	-0.423		[1]
Signaller gender (male)	-0.265	0.165	-0.591	0.053		[1]
Signaller age	0.115	0.109	-0.083	0.34		[1]
Age difference recipient-signaller	-0.02	0.078	-0.183	0.12	-0.254	0.8
Signaller gender (male)x Signaller age	-0.345	0.161	-0.66	-0.033	-2.138	0.033
(6b) Use of objects						
Intercept	-0.772	0.521	-1.732	0.223		[1]
Signaller gender (male)	-0.097	0.375	-0.833	0.672		[1]
Signaller age	0.114	0.338	-0.542	0.731		[1]
Age difference recipient-signaller	0.024	0.179	-0.36	0.393	0.135	0.893
School (B)	-1.029	0.62	-2.123	0.142	-1.661	0.097
School (C)	-0.218	0.671	-1.395	1.024	-0.325	0.745
School (D)	-0.56	0.597	-1.677	0.573	-0.937	0.349
Signaller gender (male)x Signaller age	-0.455	0.36	-1.216	0.27	-1.265	0.206

Table S6. Factors influencing (3b) the gesture rate of toddlers' peer-directed gestural communication.

Term	Estimate	Std. Error	lower CI*	upper CI*	t value	Pr(>|z|)
Intercept	-0.261	0.117	-0.728	0.252		[1]
Signaller gender (male)	-0.069	0.085	-0.375	0.248		[1]
Signaller age	0.137	0.078	-0.17	0.43		[1]
Age difference recipient-signaller	**0.066**	**0.03**	**-0.085**	**0.21**	**2.217**	**0.027**
School (B)	-0.023	0.137	-0.568	0.519	-0.17	0.865
School (XXGa S4)	-0.175	0.149	-0.754	0.413	-1.174	0.24
School (D)	-0.102	0.131	-0.647	0.412	-0.783	0.433
Signaller gender (male)x Signaller age	-0.02	0.085	-0.334	0.281	-0.231	0.818

Table S7. Factors influencing (4b) the gesture duration of toddlers' gestural communication.

Term	Estimate	Std. Error	lower CI*	upper CI*	df	t value	Pr(>|z|)
Intercept	0.038	0.106	-0.178	0.255			[1]
Signaller gender (male)	0.062	0.073	-0.084	0.222			[1]
Signaller age	-0.095	0.068	-0.23	0.039			[1]
Age difference recipient-signaller	-0.02	0.035	-0.09	0.045	66.821	-0.573	0.569
School (B)	-0.05	0.126	-0.3	0.193	39.902	-0.393	0.697
School (C)	0.084	0.129	-0.152	0.336	28.851	0.651	0.52
School (D)	0.107	0.119	-0.125	0.35	34.962	0.893	0.378
Signaller gender (male)x Signaller age	0.026	0.072	-0.119	0.168	29.349	0.364	0.718

Supplementary figures

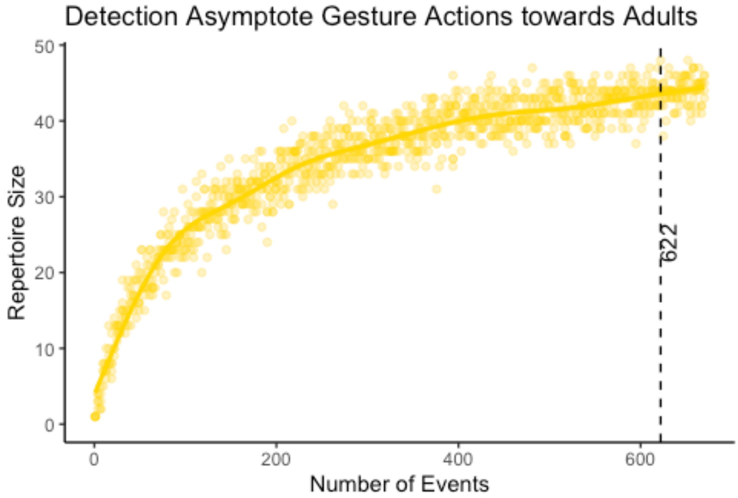

Figure S1. Cumulative record of gesture actions in toddler's adult-directed communication obtained through a function that takes random subsamples of the data and check how many of the gesture actions are identified in each subsample.

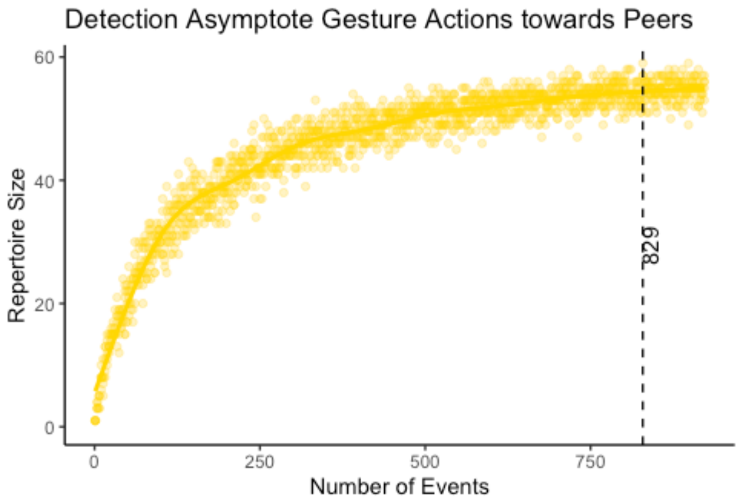

Figure S2. Cumulative record of gesture actions in toddler's peer-directed communication obtained through a function that takes random subsamples of the data and check how many of the gesture actions are identified in each subsample.

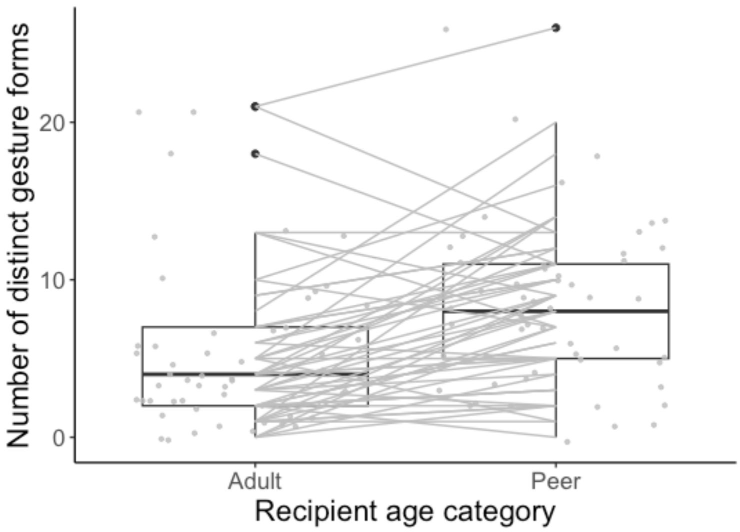

Figure S3. Boxplots show the number of distinct gesture forms produced by the 53 toddlers. Each toddler is represented by a grey dot next to each box and the lines connect the number of distinct gesture forms produced by the same toddler towards adults and peers.

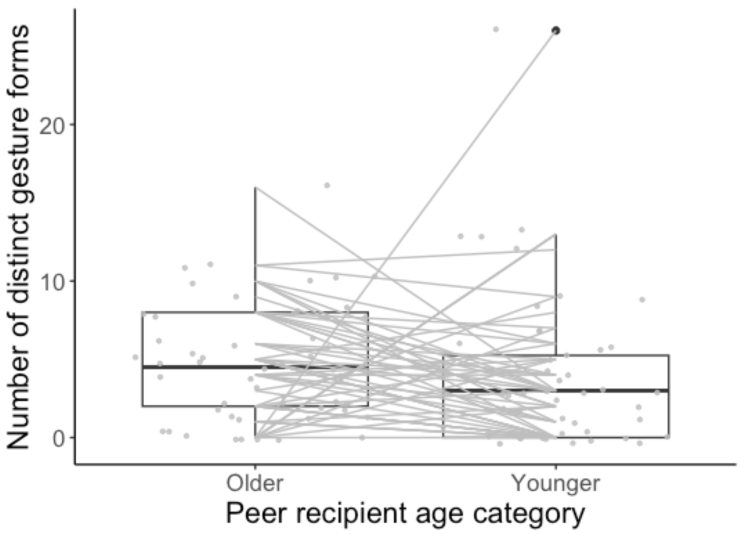

Figure S4. Boxplots show the number of distinct gesture forms produced by the 52 toddlers in peer-directed communication. Each toddler is represented by the grey dots and the lines connect the number of distinct gesture forms produced by the same toddler towards younger and older peers.