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Multimodal strategies in development. Predictive value of early simultaneous gesture-speech combinations

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Abstract

The present study investigates the predictive value of the early appearance of simultaneous pointing-speech combinations during early communicative development. An experimental task based on Liszkowski et al. (2008) was used to obtain a communicative productive sample from nineteen children, in two early longitudinal moments, namely at 1;0 and 1;3. The development of infant's types of communicative productions (speech-only, pointing-only, and pointing-speech combinations), in combination with gaze joint engagement patterns, were analyzed in relation to different social interaction conditions. Parental report language measures were obtained with the CDI questionnaire at 1;0, 1;3, and 1;6. The results show a significant effect of age and social condition on infants' communicative productions. Gesture-speech combinations seem to be well integrated at 1;3, and seem to work as a strong communicative resource to attract the adult's attention in social demanding communicative contexts. Gaze joint engagement was used in combination with simultaneous pointing-speech utterances to attract adults' attention during social demanding conditions. Finally, the use of simultaneous pointing-speech combinations at 1;0 in demanding conditions predicted greater expressive vocabulary acquisition at 1;3 and 1;6. These results indicate that the use of gesture-speech combinations may be considered a significant step towards the early integration of language components.

1. Introduction

Research on early gesture acquisition and its relationship to language emergence has shown evidence that the early appearance of iconic and pointing gestures predict early language development. For example, Colonnesi et al. (2010) found that child comprehensive pointing at 1;0 contributed to comprehension of other children's actions at 3;3. In the same study, authors found a strong correlation between pointing gestures and language development. Specifically, the appearance of pointing gestures with a declarative function predicted infant verbal language to a greater degree than the appearance of imperative pointing gestures. Similarly, some studies have unveiled the predictive value of pointing gestures in early vocabulary development. Bavin et al. (2008) found that children's gesture and object use at 0;8 and 1;0 predicted vocabulary development at 1;0 and 2;0. In Caselli et al. (2012), an infant's early actions and gestures correlated with comprehensive vocabulary in the 0;8 to 1;6 age range, indicating a transition to productive vocabulary. Similarly Özçaliskan & Goldin-Meadow (2005) and Rowe & Goldin-Meadow (2009) recorded infants at home during daily communicative activities. They found that communicative gesture, and specifically the use and function of pointing gestures, was able to predict both lexical and grammatical development. It seems thus that in early stages of language and cognition development, pointing gestures signal intentional communication, and this pointing ability predicts the emergence of verbal language.

Gesture-speech integration is an important feature of human communication. As McNeill (1992) noted, in human languages both systems are coordinated not only at the temporal and phonological level (that is, they are temporally coordinated and the most prominent part of the gesture is aligned with the most prominent part of speech) but also at the semantic and pragmatic levels (that is, they perform the same semantic functions and intentions). Despite its importance, little is known about the development of simultaneous gesture-speech combinations and its importance as a predictor of language development. Simultaneous gesture-speech integration happens during the babbling stage and the beginning of one-word acquisition, when children develop an ability to temporally synchronize gesture and speech to express conveyed information e.g., when a child points to a book while saying the word "book") (Butcher & Goldin-Meadow, 2000, Esteve-Gibert & Prieto, in press, 2013). Esteve-Gibert & Prieto (in press, 2013) showed that in the transition between the babbling stage and single-word period infants start combining deictic gestures and speech and, when combined, the two modalities are temporally coordinated. Moreover, they found that most of these early simultaneous gesture-speech combinations are pointing gestures (pointing and reaching gestures) with a declarative communicative purpose. Pizzuto et al. (2005) indicate that while gestural and vocal modalities are meaningfully and temporally integrated forms, infants use gesture modality more than speech to express referents. Prior to this achievement, infants' vocal productions are rhythmically coordinated with body and oral movements. For example, around 0;6-0;8 canonical babbling occurs with rhythmic hand movements (i.e., waving) (Ejiri et al. 2001; Iverson et al. 2004). Even functional development follows a path that parallels those of gesture and speech, so that at 0;8-0;10 child word comprehension develops, deictic gesture unfolds, gestural routines appear, and the first tool use emerges, all at the same time (Bates & Dick, 2002).

A series of studies have examined the predictive role of gesture and speech combinations on the development of two-word combinations. Focusing on the period before two-word combinations, Iverson & Goldin-Meadow (2005) found that children who first produced gesture - word combinations conveying two different meanings (the so-called supplementary combinations, i.e., pointing to a cookie and saying "give") were also the first to produce two-word combinations. Results confirming that the gesture - word combinations at 16 months correlated with overall vocal production at 18 months were obtained by Capirci et al. (1996). Correlations between the age of onset of supplementary gesture - word combinations and the onset of two-word combinations were also found by Goldin-Meadow (1998), Ozcalışkan & Goldin-Meadow (2005), and Iverson et al. (2008). Of particular relevance to the present study, Parladé & Iverson (2011) found an interesting negative correlation between the use of simultaneous gesture-speech combinations and the vocabulary burst period (which is characterized by a sharp increase in active vocabulary). In their study, children showed a diminishing use of facial, gesture, and speech combinations when going through a vocabulary burst stage, revealing the relationship between the use of pointing-speech combinations and the acquisition of early vocabulary. In this study, children exhibited worse gesture-speech coordination performance during the vocabulary burst period than during periods characterized by a gradual increase in vocabulary.

However, very few studies have addressed the predictive role of simultaneous gesture-speech integration on lexical development. We would expect that if the appearance of supplementary gesture-speech combinations plays an important role in the development of two-word combinations, the appearance of simultaneous gesture-speech combinations might be a similar indicator of early lexical development. Recent results reported by Murillo & Belinchón (2012) seem to support this hypothesis. They observed parent-infant dyad interactions (N = 11) in structured play context at three longitudinal moments, namely 9, 12, and 15 months. Their analysis of the children's spontaneous speech showed that the use of pointing gestures at 12 months, especially when accompanied with vocalizations and the social use of gaze, correlated with vocabulary development at 15 months of age. Nonetheless, the analysis of spontaneous interactions does not allow for the control of two important aspects of early communication patterns, namely, (a) the pragmatic motives that lie behind children's use of pointing gestures; and (b) the social interaction patterns used by caregivers.

It is well known that different types of social interaction between an infant and his or her caregivers (interaction routines between infants and adults, shared attention, vocal games, or informative pointing) have an effect in the infant's communicative patterns (Locke, 1997; Soltis, 2004; Liszkowski et al. 2008; Tomasello, Carpenter & Liszkowski, 2007). Vocabulary development in relation to sharing attention to an object was studied by Brooks & Meltzoff (2008). In this study a gaze-following task was used, meaning that the time spent looking at an object when attention was directed to that object by an adult was measured. Authors found that longer looking time at ages 0;10 and 0;11 correlated with better language development measures at 2;0. More interestingly, communicative integration of looking time and pointing were even better predictors of later vocabulary performance, so infants with long and short looking times in combination with pointing had better results than children who solely looked or pointed. Though sharing interaction with reference to an object is a basic milestone in the acquisition of intentional communication, Liszkowski et al. (2008) showed that infant's communicative behaviors are also affected by adults' attention patterns to the object of reference. They found that the adult's attention influenced a child's productions, as the child used more complex production abilities when the experimenter did not look at the object pointed to (attending experimental condition) as opposed to when he looked at neither the object nor the child (non-attending experimental condition). These repairing strategies to attract the adult's attention occurred significantly only during experimental conditions, especially in the attending experimental condition, not during communicative conditions (baseline condition), in which the experimenter shared attention with the infant by looking at his eyes and then at the object, thus actively encouraging the child to look.

The main goal of the present study will be to test the predictive role of the frequency of use of pointing-speech combinations on early lexical development by using a declarative pointing task based on Liszkowski et al. (2008). This procedure makes it possible to obtain pointing behavior with the same pragmatic functions (i.e., a declarative motive) in three different "social conditions" that provide three different patterns of interaction between the adult and the infant (i.e., baseline, attending condition, and non-attending condition). The experimental procedure motivates the child to initiate communication by means of a pointing gesture and deploy his or her repertoire of communicative strategies in order to direct the adult's attention to a stimulus which has appeared from behind the experimenter. Liszkowski et al.'s (2008) experimental task is especially suited to our purposes for three main reasons: (a) it controls for the infant's communicative motive to comment about an object appearing behind the adult; (b) it controls for adult social interaction patterns through visual interactions with the infant; and (c) it encourages the infant to produce simultaneous gesture-speech combinations during the experimental conditions, as reported in Liszkowski's et al. (2008) results.

Nineteen Spanish children participated in the declarative pointing task at two points of their language development, i.e., at ages 12 and 15 months. The analysis of the data will focus on assessing the infant’s communicative patterns produced during the pointing task (i.e., their ability to use pointing-speech combinations, together with eye patterns) and testing their effects on later lexical development at 12, 15, and 18 months. As mentioned above, our main hypothesis is that an infant’s ability to simultaneously integrate pointing gesture and speech with a conveyed meaning at early ages is correlated with earlier language acquisition.

Methods

1.1. Participants

Twenty-six typically-developing infants initially participated in the study. Two of them had to be excluded from analysis because of oral habits which interrupted pointing activity (dysfunctional digital suction and tooth emergence), and another one had to be excluded because she was afraid of the puppets used in the experiment. Four parents withdrew their child from the study after the second session. Thus, in the end a total of nineteen infants (N = 19; 12 boys and 7 girls) were recorded at two longitudinal moments, the first recording taking place at around 12 months (mean = 12;12; range = 11;23-12;27) and the second recording occurring three months later. Six of these infants were recruited from public nurseries in Albacete from monolingual Spanish families that had expressed interest in participating in the study. The other thirteen infants were recruited form APAL's language research database at Sant Joan de Déu Hospital in Barcelona. Although Barcelona is a Spanish-Catalan bilingual context, the results of a language questionnaire administered to the parents showed that adults in contact with the infant predominantly used Spanish during different communicative contexts (Mean percentage and SD of infant's contact with Spanish: Mean = 85.81%, SD = 11.30). When initially contacted, all families reported to the researcher that their infant already begun to point at objects, thus making them eligible for participation in this experiment.

1.2. *Experimental setting and materials*

The recordings took place in a 2.5 x 5 m distractor-free testing room in Albacete and a 2 x 3 m distractor-free testing room in Barcelona. The experimental setting was based on Liszkowski et al. (2008), as follows. An opaque white cloth screen hid from view the middle of the back of the room, and the infant sat on his or her caregiver's lap in the middle of the room facing the screen at a distance of 2 m, with the experimenter seated between child and screen (see Figure 1). A small table was placed between the experimenter and the caregiver with his or her child, who were seated in a higher chair to facilitate video recording. The caregiver wore a pair of earphones with music to distract him or her from the activity.

Through a large opening in the upper center of the screen a camera recorded the child's reactions, and a second camera was placed at the back of the room in such a way that it could record the use of stimuli and the experimenter's utterances. The screen also had three lateral openings through which the puppets were made visible to the child, one at a time. These openings (four of them 60 cm and two of them 100 cm from the floor) were symmetrically positioned at about 30° (2×) and 25°≙ to the left and right of the infant's midline. The puppets were manipulated by an assistant hidden behind the screen.[1] Two electronic stimuli (an electronically activated dancing pig and a light) were positioned on the floor in front of the screen at approximately 30° to the infant's left and right. A moveable bead toy and a pair of infant books were used between conditions to return the infant's attention to the experimenter, the large moveable beads toy being attached to the small table.

[1]A total of three assistants helped with the task, all of them specialists in education or rehabilitation and also trained in the procedure used in this study.

A total of ten stimuli were used. Eight consisted of hand puppets (cat, frog, cow, chicken, sun, snail, grandmother, and mouth), which could be made to appear in the holes in the screen, and the remaining two stimuli were the electronic items (the pig and light) permanently visible on the floor in front of the screen and could be activated electronically by the experimenter (see Figure 2). The target words which served as lexical stimuli were all chosen from López-Ornat et al. (2005), the Spanish version of MacArthur's inventory of communicative development vocabulary items for children aged 8 to 15 months.

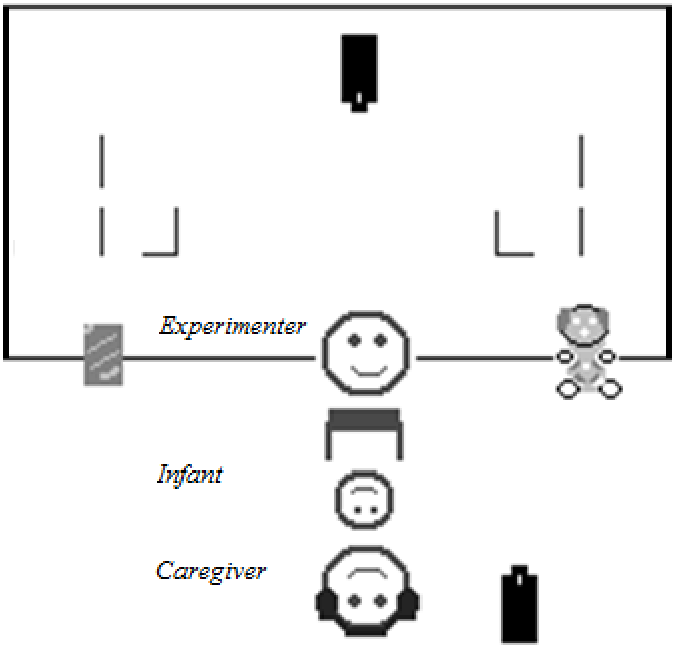

Figure 1. Experimental setting.

Figure 2. Experimental stimuli consisting of eight puppets, a light, and an electronically activated dancing pig.

1.3. Procedure

Liszkowski's et al (2008) procedure (which we will call *pointing task* as in Carpenter et al., 1998, and Matthews et al., 2012) was used to elicit infant communicative behavior (communicative gestures, vocalizations, and gaze engagement) through an enjoyable activity, in this case watching puppets. The experimenter facilitated the child's pointing gestures by reacting to his or her communicative behavior in three different ways, each reflecting a different social condition. In the most communicative condition (which will be called baseline condition) the experimenter established interaction with the child in a communicative way when the child initiated pointing. In the other two experimental conditions the experimenter's attention was directed at the child but not the stimulus (attending condition) or his attention was directed at neither the child nor the stimulus (non-attending condition). Results from previous research suggested that the latter two conditions would trigger greater communicative involvement on the part of the child, i.e., with repetitions and gesture-speech combinations.

For each experimental session, the procedure was as follows. First, caregivers were informed about the experimental procedure and permission to record was obtained. They also filled in a questionnaire to obtain information about their prior pregnancy and their infants' general health and hearing (i.e., whether the child suffered from ear infections), and their child's developmental stage, with questions regarding attention-sharing, playing habits, and pointing. Then instructions for the experiment task were given by the assistant. Warm-up time before the experiment consisted of extensive play between the experimenter and the infant in a different room in order for the infant to feel at ease with the experimenter. In the meantime, caregivers were brought to the testing room and instructed that they must not initiate any communicative behavior toward the infant during testing and or look at the screen at any time. Rather, they were encouraged to sit calm looking at their infant while listening to music through headphones. They were also asked to gently hold the infant in place on their laps to maintain constant the infant's position and minimize their potential stress during the experiment.

The pointing task began in the testing room with a short play period with the bead toy on the table to keep the infant interested in the experimenter as a social partner, though this toy was only used at the beginning of the trials involving communicative conditions, i.e., the baseline condition. When the experimenter judged that the infant was relaxed and attentive, he gradually withdrew from the interaction and signaled to the assistant behind the panel by means of snapping his fingers out of the child's sight that puppet stimuli could be activated. The assistant always waved puppets one at a time from side to side and front to back within different openings in the panel, silently, and looking through one of the holes to indicate when child pointed. For each stimulus, the experiment snapped his fingers as soon as the child initiated pointing. The child had 20 seconds within which to initiate the gesture. If the child pointed within this time the stimulus continued (i.e., the puppet continued to be visible) for 20 more seconds or until the infant was uninterested. But if child did not initiate a pointing gesture, the stimulus was withdrawn after the first 20 seconds. In all cases, the experimenter indicated by clucking his tongue when it was time for the puppet to be withdrawn.

The first trial was always in the baseline condition, i.e., when the stimulus was activated the experimenter looked at the infant and ignored the stimulus until the infant pointed to it, and then the experimenter reacted immediately and shared attention for the ensuing 20 seconds, that is, the experimenter repeatedly looked back and forth between the stimulus and the infant's face, talking excitedly about the stimulus and commenting on the fact that they were seeing it together. For example, the experimenter would say: "Oh..., look, it's a cat! Look!, It's saying hi to you!, Oh…, a cat!" Then, 20 seconds after the infant's first point the stimulus was withdrawn and the trial was over. Following the first trial, the experimenter shared a book activity until the child was relaxed and attentive, then gradually withdrew the activity, and indicated to the assistant by means of a finger snap to activate the next stimulus, which could correspond either to the available or the non-available condition. In both experimental conditions, when the child pointed, the experimenter responded to the child by saying "Hmm…? What…? What's there…? Hmm…?" Thus the experimenter's focus of attention changed depending on the condition. While during the attending condition trials the experimenter ignored the stimulus but looked at the infant, in the non-attending condition trials the experimenter ignored both the stimulus and the infant and looked only at the book.

Each session consisted of a sequence of a baseline condition and two experimental conditions repeated five times (3 conditions x 5 times = total of 15 trials). Trial sequences followed two orders counterbalanced in terms of experimental condition (Baseline–Attending–NonAttending or Baseline–NonAttending–Attending) and two orders counterbalanced in terms of the side of appearance of the first stimulus (starting from the right or from the left side). Five stimuli had to appear twice to complete a total of 15 trials in every session, and the order of stimulus appearance was randomly chosen by the assistant. The experimental sessions lasted an average of 18 minutes.

2.3.2. MacArthur-Bates Communicative Developmental Inventories

Parents completed the Spanish version of the MacArthur-Bates Communicative Development Inventories or CDI (López-Ornat et al. 2005), a widely used measure of early communicative development. Research on early gesture acquisition has strongly validated parents' reports of their infant's language development as measured with the CDI (Feldman et al., 2000; Bavin et al., 2008; Pérez-Pereira et al., 2011). The standardized Words form for children from 8-16 months was used at the 12 and 15 month observations. The Words and Sentences form of the 16-30 months CDI form was employed at 18 months.

The assistant explained the CDI to each caregiver and at 12 and 15 months most of the parents filled it out it after the experimental testing. If a second caregiver came to a subsequent session with a child we asked him or her to fill out the CDI while the pointing task was being carried out in a different room. At 18 months parents' either returned the completed CDI to the researcher in a pre-stamped self-addressed envelope, or answered the questions by telephone. Parents were contacted by telephone or email to check vocabulary and grammatical compounds.

2.4. Coding and reliability

Coding was performed with ELAN software (Lausberg & Sloetjes, 2009), for video annotations. Acoustic analysis was done with Praat (Boersma & Weenink, 2009) and then imported back into ELAN. Coding of infant audiovisual behavior measures was based on various authors (McNeill, 1992; Carpenter et al. 1998; Butcher & Goldin-Meadow, 2000; Liszkowski, et al., 2008; Cartmill et al., 2012). Figure 3 shows the three levels included in the analysis, namely communicative modality, pointing performance and infant's gaze engagement. Measures were assessed separately for baseline and experimental conditions.

Figure 3. Snapshot of the ELAN coding scheme. The ELAN template included the following tiers: (1) trial condition, (2) communicative modality, (3) infant's gaze engagement, and (4) pointing performance.

All of the infant's communicative productions that were directly related to the stimulus in each trial were coded. Communicative modality was coded in the second ELAN tier (see Figure 3) and included three options, namely, pointing-only (i.e., pointing to the stimulus), speech-only (i.e., vocalizations referring to the stimulus like 'aaaa' or 'gaba'), and gesture-speech combinations (i.e., simultaneously pointing and saying 'nana'). Below we explain the criteria used for this classification.

Gesture-speech combinations. According to McNeill (1992) and Butcher & Goldin-Meadow (2000), simultaneous gesture-speech combinations share all pragmatic function, semantic content, and phonological temporal cues. In our task, pointing gestures were frequently combined with vocalizations, and both modalities were employed to refer the same object. Pointing-speech combinations were coded when the vocalization overlapped at least with some portion of the stroke of the gesture.[2]

Speech-only: Meaningful speech not produced with a pointing gesture was coded when the infant uttered speech sounds consistently used to communicate about the target stimulus presented in the trial (Butcher & Goldin-Meadow, 2000). The infant's communicative vocalizations were coded when they were directed at the experimenter or clearly intended as a comment about the stimulus (e.g., even if the infant was not looking to it in that moment but he has previously looked to it). Speech sounds were excluded if the infant had just looked toward any other point of the room (i.e., at the place where a previous stimulus had appeared, at any of the visible stimuli, or at the book). Infants' shouts, laughs, groans, or vegetative sounds were excluded. In order to consider two sounds different vocalizations they had to be separated by a respiratory cycle and/or they were separated by the duration of 1 second a pause of at least one second in duration.

Gesture-only: Only instances of pointing that signaled at the target stimulus were coded, while other communicative gestures (e.g.., waving the hand to say "hello") were not taken into account. Following Brooks & Meltzoff (2008), Liszkowski et al. (2008), and Cartmill et al. (2012), the hand configuration of the pointing gesture was coded in tier as either (a) pointing with extended finger or (b) pointing with the hand with the palm downwards. Also pointing performance was coded according to how far the arm was

[2]Following McNeill, (1992), the stroke phase of the gesture is the interval of maximum effort in the gesture.

extended (either fully or partly bent). This aspect of the pointing configuration was coded in the forth ELAN tier (see Figure 3).

2.4.2. Infants' gaze engagement

Infant's gaze engagement was coded in the third tier (see Figure 3). We were interested in assessing the infant's ability to engage with the adult through gaze during a communicative utterance. Following Carpenter et al. (1998), joint engagement was coded as a visual attention coordination pattern between the stimulus and the adult (whether experimenter or parent). The infant's gaze was coded according to the pattern of joint engagement (Carpenter et al., 1998) as follows:

A. Gaze joint engagement: This code was assigned when infants looked from the object to the adult's face and back to the same object. If the infant had previously seen the stimulus, joint engagement was also coded when the infant looked from the adult then to the object and back to the adult's face.
B. No joint engagement: Gazes with simpler coordination patterns of engagement (e.g., looking at the adult), and fixed gazes at the object or the adult, were coded as *no gaze engagement.* We were primarily interested in those infants' gaze engagement performed during communicative productions.

The onset of the gaze pattern to object and/or adult coincided with the onset of communicative production (e.g., the onset of the speech in speech-only productions, or the onset of the preparation phase of the gesture in gesture-only and gesture-speech combinations). Gaze patterns did not last longer than 3 seconds after the end of the communicative production, or until a new communicative production started.

3. *Results*

The main goal of this study was to analyze the development of simultaneous gesture-speech combinations in relation to social factors, as well as the predictive value of different linguistic cues. The results section is divided in three specific subsections, which correspond to three different issues: (1) the effects of age and social condition on gesture-speech combinations, (2) the effects of gaze joint engagement abilities on pointing-speech combinations, and (3) the predictive value of early gesture-speech combinations.

3.1. Effects of age and social condition on gesture-speech combinations

A total of 754 communicative behaviors were coded, including speech-only productions (N = 385), pointing-only productions (N = 142), and gesture-speech combinations (N = 227). First, in order to assess the effects of the different experimental factors on the number of communicative productions uttered by the infants, we conducted a Generalized Linear Mix Model (GLMM) with COMMUNICATIVE MODALITIES (three levels: speech-only, gesture-only, and gesture-speech combinations) as the dependent variable (Poisson distribution, log link); AGE (two levels: 12 and 15 months), TASK CONDITIONS (three levels: baseline, attending, and non-attending conditions), and COMMUNICATIVE MODALITIES (three levels: speech-only, gesture-only, and gesture-speech combinations) and all their possible interactions as fixed factors; and SUBJECT, TRIAL, and TASK as random factors. Bonferroni paired post-hoc tests were carried out for the significant main effects and interactions. The results of the analysis showed a main effect of age (F (1, 1647) = 6.609, p < .05), with an increase in communicative productions at 15 months (F (1, 1647) = 6.110, p < .05).

As can be observed in Figure 4, infants show a significant increase in the number of gesture-speech combinations at 1;3, (F (1, 1647) = 21.092, p < .001), yet speech-only and gesture-only do not change significantly between sessions. , speech (F (1, 1647) = .017, p = .897), and pointing (F (1, 1647) = .571, p = .450). This shows that integrated gesture-speech coordination is fully developed in this later period of speech development. Figure 4 shows the mean number of communicative productions (expressed as the number of occurrences per trial) of gesture-only, speech-only, and gesture-speech combinations occurring at the two longitudinal moments (ages 1;0 and 1;3), for the 19 infants under analysis.

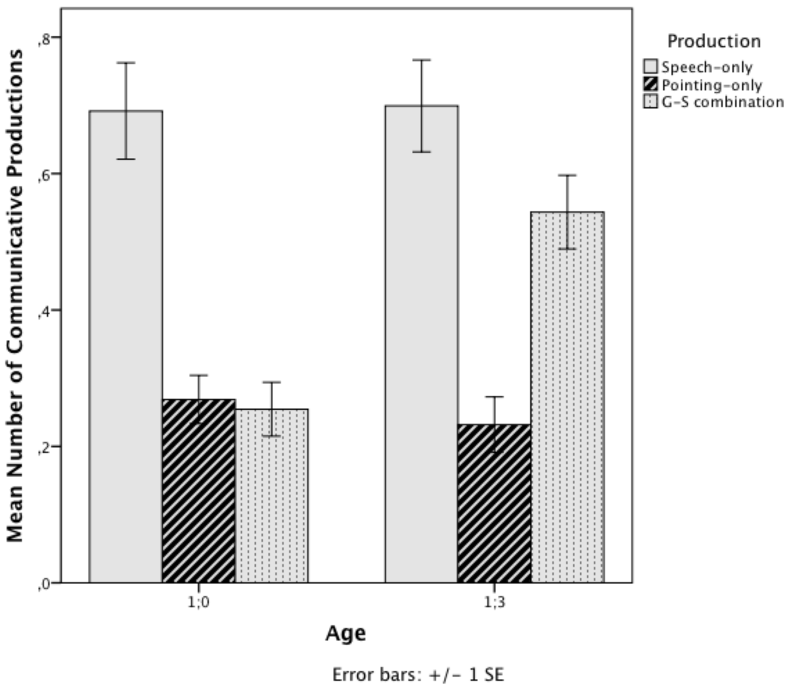

Figure 4. Mean number of occurrences per trial of communicative productions (speech-only, pointing-only, and pointing-speech combinations) at ages 1;0 and 1;5, for 19 infants.

There was also a main effect for TASK CONDITIONS (F (4, 1647) = 7.317, $p < .001$), indicating that communicative productions behave differently depending on the social condition. In Figure 5 we can observe an increase in gesture-speech combinations in the experimental condition with respect to the baseline condition, similarly to Liszkowski et al. (2008). Post-hoc results showed main significant effects in *simultaneous gesture-speech combinations* with a greater number of productions in the attending experimental condition than in the baseline condition or the non-attending experimental condition, (F (2, 1647) = 4.703, $p < .01$). By contrast, *vocalization productions* did not show significant differences between task conditions (F (2, 1647) = 2.159, $p = .116$). On the other hand, *pointing productions* showed a significant decrease in utterances between baseline condition and non-attending condition. This means that simultaneous gestures-speech combinations increased in number of repetitions during demanding social conditions. Figure 5 shows the distribution (expressed as the mean number of occurrences per trial) of speech-only, pointing-only, and gesture-speech combinations separated by social conditions produced by the 19 children.

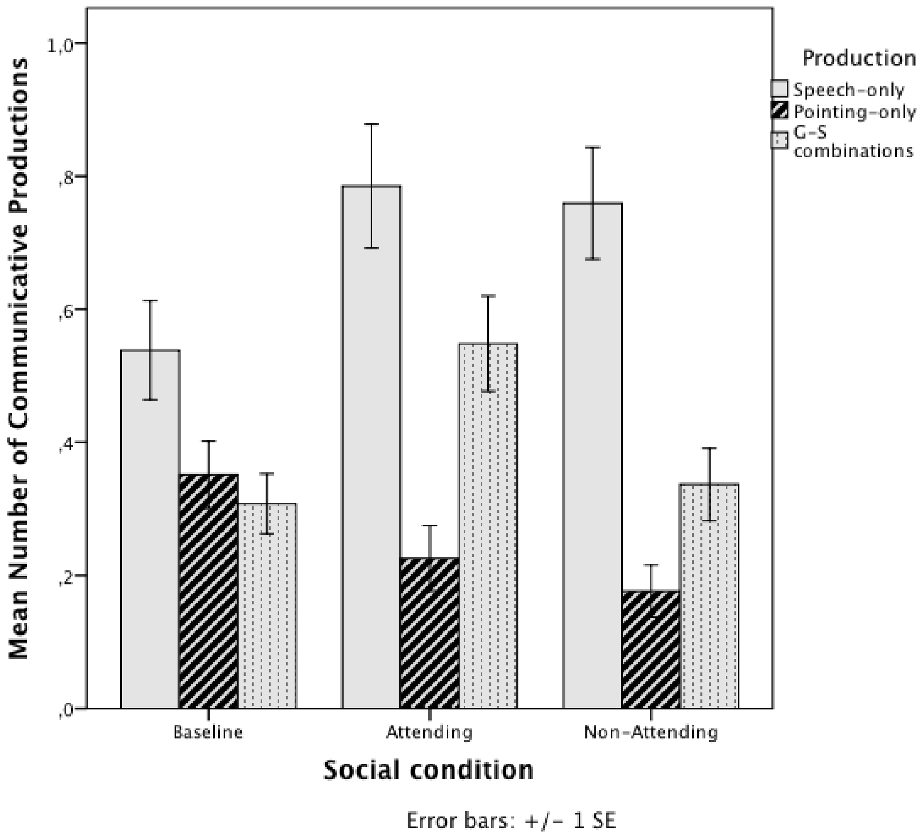

Figure 5. Mean number of occurrences per trial of communicative productions (speech-only, pointing-only, and pointing-speech combinations) as a function of social condition (baseline, attending, and non-attending conditions), for 19 infants.

Despite this triple interaction of communicative modality, task condition and age did not reveal significant differences, (F (4, 1647) = 0.457, p = .767). In Figure 6 we see a clear increase in simultaneous gesture-speech combinations when comparing the attending experimental conditions to the baseline condition. In fact, post-hoc analysis results revealed that children at 15 months show an increase in the use of gesture-speech combinations in both experimental conditions, attending (F (1, 1647) = 7.125, p < .010) and non-attending (F (1, 1647) = 16.005, p < .001). There are no other significant effects of development (1;0 and 1;3) on the communicative modalities and task interactions. That is, when the child has to make an effort to attract the adult's attention, like in trials within the attending condition (adult looked at infant but not at object) and the non-attending condition (adult looks at neither infant nor object), we observe an increase in the more complex production abilities (meaning gesture-speech combinations), which are significantly different at 1;3. Therefore, the new ability of gesture-speech combinations seems to be activated in order to attract the adult's attention in more adverse conditions and achieve the communicative goal around 1;0, but by age 1;3 it is clearly established.

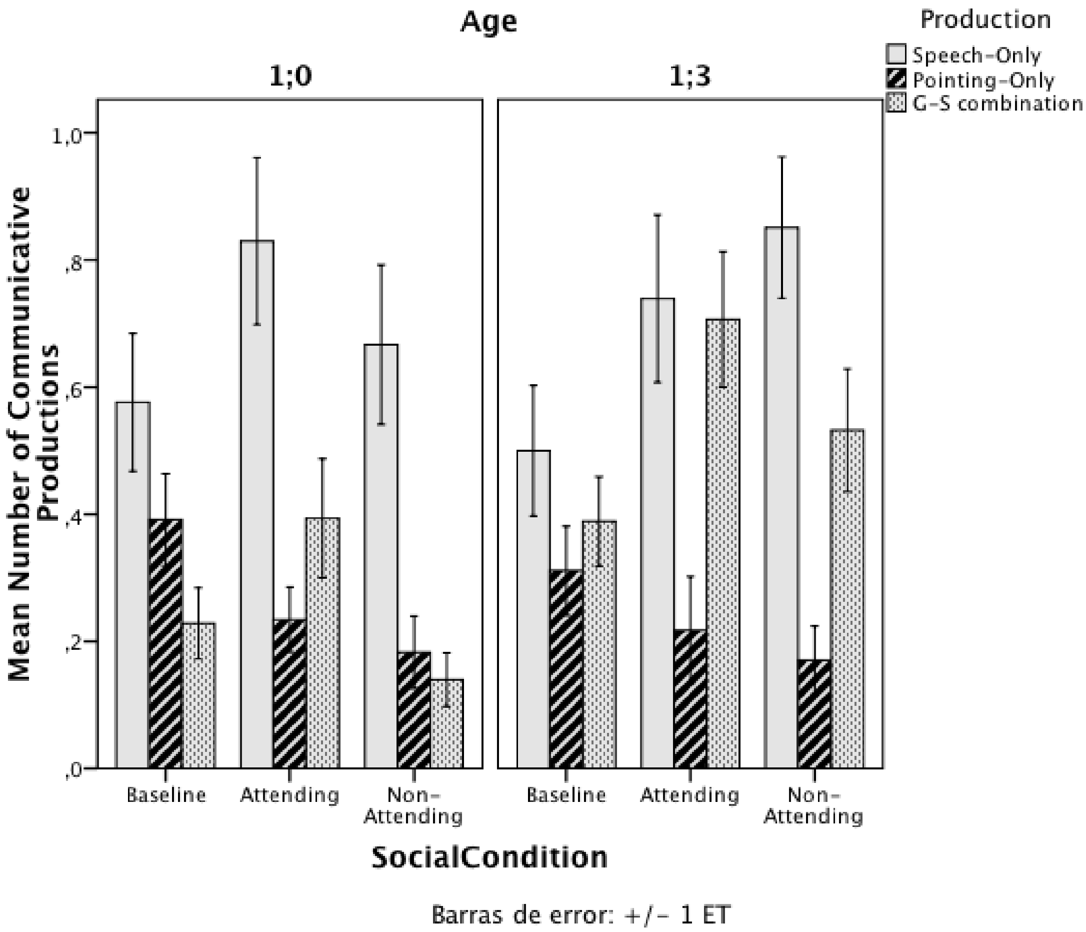

Figure 6. Mean number of occurrences per trial of communicative productions (speech-only, pointing-only, and pointing-speech combinations) as a function of social condition (baseline, attending, and non-attending conditions), and age (1;0 and 1;3), for 19 infants.

3.2. Effects of gaze joint engagement on gesture-speech combinations

In order to assess the development of gaze joint engagement patterns, we conducted a second GLMM analysis with the NUMBER OF GAZE PRODUCTIONS (two levels: gaze joint engagement, no joint engagement) as the dependent variable (Poisson distribution, log link); AGE (two levels: 12 and 15 months), TASK CONDITIONS, (three levels: baseline, attending, and non-attending conditions), COMMUNICATIVE MODALITIES (three levels: speech-only, gesture-only, gesture-speech combinations), and GAZE (two levels: gaze joint engagement and no joint engagement) and all their possible interactions as fixed factors; and SUBJECT, TRIAL, and TASK as random factors. Bonferroni paired post-hoc tests were performed for the significant main effects and interactions. The analysis revealed no main effects of task condition (F (2, 851) = 1.387, p = .250), nor main effects of age on number of gaze productions, (F (1, 857) = 1.298, p = .255). That is, gaze distributions (meaning gaze joint engagement and simpler gaze patterns) behave similarly between baseline and experimental task conditions, and gaze distributions are similar at 1;0 and 1;3. These results may be due to the fact that the ability to coordinate attention with the gaze has usually been reported to occur at earlier developmental stages (Carpenter et al., 1998)

Despite this, we also analyzed gaze engagement abilities in combination with speech, pointing, and pointing-speech combinations. The results of a GLMM analysis showed a significant effect of gaze pattern on communicative modalities (F (2, 851) = 6.457, p < .010). As shown in Figure 7, a post-hoc analysis reveal a significant increase in simpler gaze patterns (no joint engagement) occurring in coordination with speech-only productions (F (2, 851) = 11.382, p < .001), while gesture-speech combinations showed a tendency to combine with complex gaze patterns (gaze joint engagement). Figure 7 shows the distribution of joint engagement in relation to speech, pointing, and simultaneous combinations.

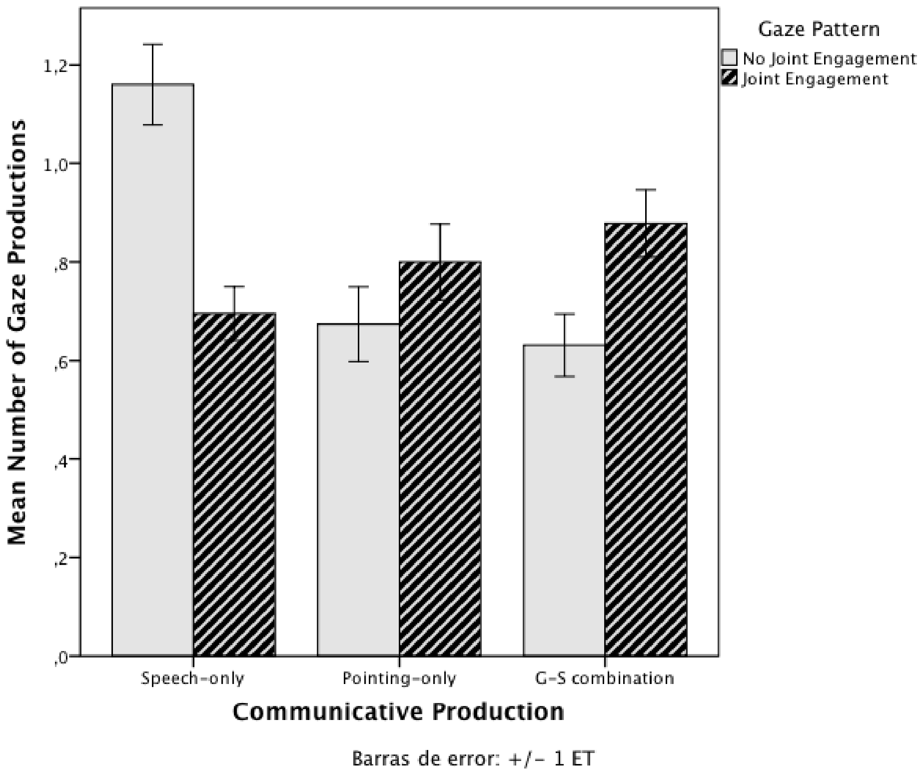

Figure 7. Mean number of occurrences per trial of communicative productions (speech-only, pointing-only, and pointing-speech combinations) occurring in combination with gaze engagement patterns (gaze joint engagement and no engagement patterns) for 19 infants.

The results displayed in Figure 8 show significantly different gaze pattern behaviors in a triple interaction with communicative modalities and task conditions (F (4, 851) = 2.563, p < .05). In other words, in trials with experimental conditions speech productions usually coordinated more with simpler gaze patterns (no engagement pattern) than with joint engagement gaze patterns. Post-hoc analysis revealed a significant use of speech-only productions in combination with simpler engagement patterns, for attending (F (1, 851) = 6.592, p = .010) and non-attending conditions (F (1, 851) = 21.691, p < .001). As we see in Figure 8, pointing-speech combinations produced in trials with the attending condition were combined with gaze joint engagement patterns more often than with simpler gaze patterns (no engagement pattern) (F (4,851) = 2.563, p < .05). No other post-hoc main effects were found among these three variables' interactions. Figure 8 shows the distribution of gaze patterns (gaze joint engagement and no engagement patterns) in combination with communicative modalities (speech-only, pointing-only, and gesture-speech combinations) separated by social conditions. It shows that the infants' use of gaze to attract adult attention by means of gaze alternations between object and adult was most frequently combined with simultaneous gesture-speech combinations in attending condition. In contrast, vocalizations were combined with simple gaze patterns, which suggest that the role of speech utterances in attracting adult attention is less clear-cut.

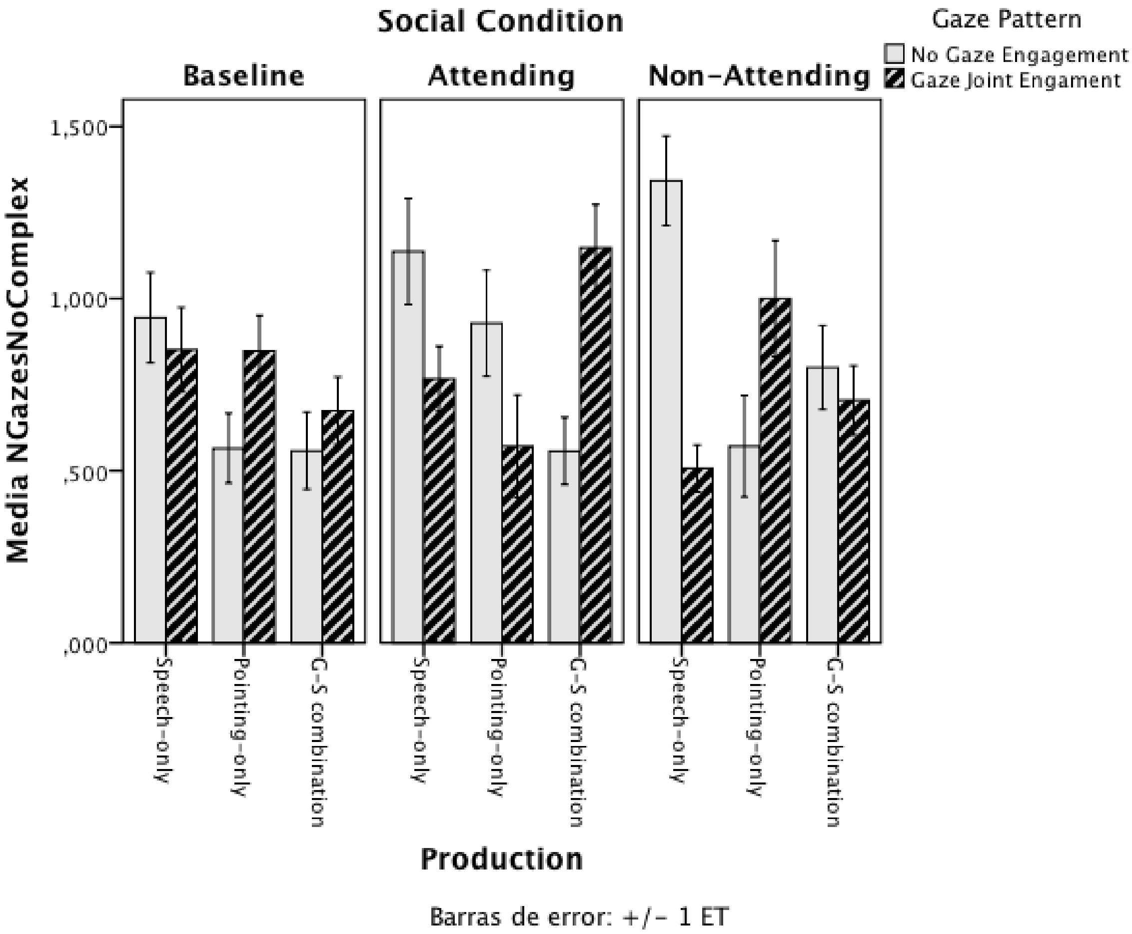

Figure 8. Mean number of occurrences per trial of communicative productions (speech-only, pointing-only, and pointing-speech combinations) occurring in combination with gaze engagement patterns (gaze joint engagement and no engagement patterns), as function of social condition, for 19 infants.

3.3. Predictive value of simultaneous gesture-speech combinations on for the development of expressive language.

3.3.1. CDI vocabulary scores

In this section we provide the results of the Spanish version of the MacArthur-Bates CDI results for all children at 1;0, 1;3, and 1;6. CDI scores of expressive and comprehensive vocabulary sections were assessed at 1;0 and 1;3, and expressive vocabulary and grammatical (morphosyntactic section) CDI components were assessed at 1;6. Table 1 shows the minimum, maximum, average, and standard deviation (SD) of the CDI scores on vocabulary and grammar sections at the age indicated.

	Mean	SD	Min	Max
Comprehensive vocabulary at 1;0.	72,95	46,894	19	215
Expressive vocabulary at 1;0.	9,58	9,203	0	36
Comprehensive vocabulary at 1;3.	143,11	71,271	35	284
Expressive vocabulary at 1;0.	19,58	16,648	0	80
Comprehensive vocabulary at 1;6.	65,42	82,823	3	367
Grammar endings at 1;6.	1,63	2,409	0	8
Morphosyntax at 1;6.	11,21	15,072	0	67

Table 1. CDI scores including minimum, maximum, average, and standard deviation (SD) measures of vocabulary and grammar sections at 1;0, 1;3, and 1;5, respectively.

CDI scores reported at the same age were positively correlated with one another, i.e., expressive and comprehensive vocabulary positively correlated at 1;0 (r = .622, p

$<.010$) and at 1;3 (r = .492, p <.050). Also, scores measured at 1;6 were positively correlated with one another: for example, expressive vocabulary was positively correlated with morphosyntactic measures (r = .953, p <.001), as were grammar endings (r = .806, p <.001). Thus, all measures at the same age were positively correlated with one another.

Moreover, correlations between measures at different ages revealed that expressive vocabulary correlated positively with all other CDI measures (at $p < .05$). The highest correlations were found between expressive vocabulary measures at 1;0 and 1;3 (r = .817, p <.001), expressive vocabulary at 1;0 and 1;6 (r = .661, p <.005), and expressive vocabulary at 1;3 and 1;6 (r = .935, p <.001). These results reveal a clear positive correlation among parental CDI reports at the same age and across different ages, leading us to choose expressive vocabulary as the representative CDI compound of expressive language development in our database.

3.3.2. Gesture-speech combinations in relation to expressive vocabulary

In order to assess the predictive value of the early appearance of pointing-speech combinations in relation to expressive vocabulary development, a series of simple regression analyses were conducted. First, we checked the potential effects of social condition (baseline, attending, and non-attending conditions) as a confounding factor, since the results in Section 3.1 already showed a main effect of social condition on the infant's communicative behavior.

Pearson's correlations were calculated for the variables which reflected infant productions depending on social condition and age, and in relation to expressive vocabulary development at 1;3 and 1;6. We tested the assumption of normality of the variables using the Kolmogorov-Smirnov test. The normal distribution could be assumed for all the tested variables except for gesture-speech combinations produced at 1;0 and pointing produced at 1;3, both in the attending condition. We obtained the same results using a Kendall Tau analysis. Only productions uttered in attending experimental conditions were positively correlated with later language development. Pointing-speech combinations expressed at 1;0 in the attending condition were positively correlated with expressive vocabulary measures at 1;3 (r = .487 p <.050), and at 1;6 (r = .560, p <.050). Pointing gestures produced at 1;3 in the attending condition were positively correlated with later expressive vocabulary at 1;6.

These results reveal a relationship between communicative productions uttered during the attending social condition (i.e., attending is related to later vocabulary development). As mentioned in Section 3.1, this condition is the one that triggers the infant's highest communicative efficiency. Communicative productions uttered in non-attending (i.e., looking at neither the infant nor the stimulus) and baseline conditions (jointly sharing looking at the stimulus and the infant) did not relate to later expressive vocabulary development scores. Thus, only productions during attending task condition were taken into account for the predictive regression analysis.

A set of simple regression analyses were run with either expressive vocabulary at 1;3 or expressive vocabulary at 1;5 as dependent variables, in order to test whether these measures are systematically connected (in a linear relationship) with the number of simultaneous pointing-speech combinations (G-S in Table 2), gesture-only productions (G), or speech-only productions (S). As noted before, only data gathered during the attending condition were used in order to determine whether the appearance of simultaneous gesture-speech combinations predicts later language development. Table 2 shows the results of the nine regression analyses. They reveal that the ability to produce simultaneous gesture-speech combinations at 1;0 explains 24.9% of the variance in CDI expressive vocabulary scores at 1;3 ($R^2 = .249$; $R^2_{adjusted} = .205$) [β=.499, t(18)=2.376; $p < .050$], and 28.8% of the variance in CDI scores at 1;6 months ($R^2 = .288$; $R^2_{adjusted} = .246$) [β=.537, t(18)=2.622; $p < .050$]. This means that the presence of gesture-speech combinations uttered at 1;0 explains 28.8% of the variance of the variable reflecting expressive vocabulary at 1;6. Also, the ability to produce isolated pointing gestures at 1;3 explains 69% of the variation in CDI scores at 1;6 ($R^2 = .69$; $R^2_{adjusted} = .671$ [β=.830, t(18)=6.145; $p < .001$].

	Expressive vocabulary at 1;3 R^2 statistic (%)	Expressive vocabulary at 1;6 R^2 statistic (%)
Production at 1;0		
G-S	24.9 * (p = .030)	28.8* (p = .018)
G	(p = .456)	(p = .75)
S	(p = .464)	(p = .605)
Production at 1;3		
G-S		(p = .347)
G		69** (p< .001)
S		(p = .630)

* p < .05; ** p < .01

Table 2. A series of regression analyses predicting infants' vocabulary at 1;3 and 1;6 based on early communicative productions at 1;0 and 1;3 during the attending condition.

These results show that the early use of gesture-speech combinations at 1;0 may predict later expressive vocabulary at 1;3 and 1;6, while on the other hand, pointing-only productions seem to better predict later language development at 1;6.

4. Discussion and conclusions

This study set out to investigate whether the early appearance of multimodal communicative abilities (speech and gesture), can predict later vocabulary development. A sample of nineteen infants were assessed in an experimental context which was designed, following Liszkowski's et al. (2008) procedure, to elicit infants' communicative responses and which simulated several patterns of social interaction with the adult. The children spontaneously used a broad sample of their gesture and speech communicative modalities in order to attract the adult's attention to the object of interest. Similarly to Liszkowski et al. (2008), we found effects of age and experimental condition on the pointing and communicative behavior of children at 1;0 and 1;3. Children tended to use more complex communicative abilities (meaning simultaneous gesture-speech combinations) in one of the experimental conditions, that is, when the adult attended to neither the stimulus-object nor the child.

First, our results showed the more frequent use of gesture-only productions at 1;0 and a more frequent use of gesture in combination with speech at 1;3. This supports the conclusion that children seem to develop the ability to fully integrate gesture and speech around their one-word period (Butcher & Goldin-Meadow, 2000), and in the transition from babbling stage to one-word period (with a significant increase at 1;3) (Esteve-Gibert & Prieto, in press, 2013). Thus, as they grow up, children progressively deploy more complex abilities, such as gesture-speech combinations, and learn to do so in more demanding situations such as those simulated by one of the experimental conditions described here, i.e., when they seek to call the attention of an inattentive adult. In sum, the results show that speech in coordination with gestures is used by children as early as 1;0. But simultaneous gesture-speech combinations are well integrated at 1;3, and this strong communicative resource is used by children at 1;3 to actively attract adults' attention.

A second part of our analysis assessed infants' joint engagement abilities expressed in terms of gaze in relation to age and social conditions, and in relation to intended communicative acts. Age and social condition did not show significant effects on gaze patterns (gaze joint engagement vs. simpler gaze patterns). That is, gaze joint engagement patterns do not seem to change significantly from 1;0 to 1;3, probably because the use of infants' gaze engagement to attract attention develops, and has an important impact on development, at an earlier stage (Carpenter et al., 1998; Liskowski et al., 2008). Also, infant gaze patterns do not seem to be dependent on the social condition. By contrast, results for the combined use of gaze with intended communicative utterances did show differences depending on social interaction conditions. First, infants' simpler joint attention patterns on the adult and/or object were coordinated significantly in isolated speech productions during attending conditions (i.e., saying 'aba' while looking only at the object). Second, infants coordinated more complex joint engagement patterns with pointing-speech combinations when the focus of the adult's attention was different from the infant's object of interest (attending condition). That is, when the infant had to make an effort to attract the adult's attention to an object, then complex joint engagement patterns and simultaneous pointing-speech utterances tended to occur together. Thus, the ability to produce simultaneous gesture-speech utterances combined with gaze joint engagement patterns seems to be activated in order to attract the adult's attention in demanding social interactions. In general, these results emphasize the interplay between social factors and infants' multimodal behaviors during language learning.

Third, the study addressed the predictive value of the infants' communicative productions (be it pointing-speech combinations, or pointing-only or speech-only utterances) in relation to later language development. CDI expressive vocabulary measures at 1;3 and 1;6 were positively correlated with the number of simultaneous gesture-speech combinations produced at 1;0 in attending conditions. Also, pointing-only productions at 1;3 were positively correlated with productive vocabulary at 1;6. These early behaviors of multimodal communication at 1:0 have a predictive value for later language development at 1;3 (Murillo & Belinchón,2012). We also report that the use of gesture-speech combinations at 1;0 is related to language development at a later age, namely 1;6. The gesture-only results at 12 months support the fact that pointing gestures constitute a powerful joint engagement ability for infants because they serve to share common knowledge with the adult about a particular referent. (Colonnesi et al., 2010; Liszkowski et al., 2012; Matthews et al., 2012). In general, infants' ability to produce simultaneous gesture-only and gesture-speech combinations at 1;0 is related to better language abilities later, at 1;3 and 1;6.

Many questions still are still open in relation to the nature of the integration of gesture and speech modalities in language development. From the perspective of the dynamic system theory (Thelen & Smith, 1996) regarding the transition between communicative abilities, gesture-speech combinations may serve to practice speech in combination with pointing, which is a better established referential ability at that moment (Pizzuto et al., 2005). Thus, pointing may serve as a dynamic ability to transfer potential referential meaning to speech. This pattern of referential meaning expressed through isolated pointing may progressively transfer to the integration of the two modalities to better associate speech with referential meaning. This ability to share attention with the adult may also serve as a multimodal strategy to reduce the number of distracters from the context in order to signal the real referent of interest. Yu & Smith (2012) noticed that adults and infants create optimal visual moments to reduce distracters from the scene. So that gesture-speech integration may work as an effective communicative strategy to favor learning.

All in all, our analyses have shown that an adult's social interaction clearly influences the quality of an infant's communicative productions. Certain conditions seem to empower the use of more complex abilities, such as the use of simultaneous gesture-speech combinations in combination with gaze joint engagement patterns. These results back up the dynamic emergence of multimodal productions through gesture, speech, and gaze, but also in relation to adult's social interaction cues expressed through gaze (Thelen & Smith, 1996; Iverson & Thelen, 1999; Bloom et al., 2001; Bates & Dick, 2002; Liszkowski, 2008; Vihman, 2009; Valloton, 2010; Andrén, 2011). An important aspect to take into consideration is that only productions uttered in attending conditions were related to later language development. In our sample, only the infant's productions uttered during the attending social condition (i.e., the condition in which the adult attended to the infant and not to the object) were positively correlated with later language development.

In sum, the results of this study provide information about the early use of multimodal communicative strategies and their role as precursors of later language development.

Even though firmer conclusions could be drawn on the basis of a greater sample, the results of this study have revealed important information about early precursors. Gesture-speech integration may be an early indicator of communicative efficiency in those situations where the infant intends to attract an adult's attention to an object. For the first time in life, this early behavior shows the infant's capacity to convey meaning simultaneously in two distinct modalities. That is, pointing in combination with early speech may be a significant early signal of intentional communication, in which semantic, pragmatic, and phonological information are integrated for the first time in development.

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