Journal of Communication Disorders 76 (2018) 91–100

Contents lists available at ScienceDirect

Journal of Communication Disorders

journal homepage: www.elsevier.com/locate/jcomdis

Does early object exploration support gesture and language development in extremely preterm infants and full-term infants?

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ARTICLE INFO

Keywords:
Preterm infants
Object exploration
Gestures
Word comprehension
Vocal production

ABSTRACT

Background: An increasing body of research on typically and atypically developing infants has shown that motor skills play an important role in language development. To date, however, the role of specific object exploration skills for early gesture and vocabulary development has not been investigated in extremely low gestational age infants (ELGA, GA $<$ 28 weeks), who are at greater risk for motor and language delays than full-term (FT) infants.

Purpose: This longitudinal study examined relations between 6-month active exploratory behaviors and 12- month word comprehension, gestures and vocal production, controlling for cognitive performance and neonatal condition (ELGA vs FT).

Methods: Forty infants, 20 ELGA and 20 FT, and their mothers participated in the study. Mother-infant play interaction was video-recorded at 6 and 12 months. Oral and manual object exploration at 6 months and spontaneous gestures and vocal production at 12 months were coded. Word comprehension was evaluated with the Italian version of the MacArthur-Bates CDI parent questionnaire at 12 months. Cognitive performance was examined with the Griffiths Mental Developmental Scales at 6 months and the Bayley-III Scales at 12 months.

Results: Regression analyses showed that after accounting for cognitive performance and neonatal condition, oral exploration was related to word comprehension, and manual exploration to gestures and vocal production in the overall sample.

Conclusions: Cascading effects of specific object exploration skills on gestures and language comprehension and production in preterm infants and FT infants are discussed. Clinical implications for early assessment of and interventions involving object exploration skills, which may affect language development, are considered for the preterm population.

1. Introduction

From neuroconstructivist and dynamic systems perspectives, language development is an experience-dependent process, resulting from complex interactions among multiple different abilities, including motor skills (D'Souza, D'Souza, & Karmiloff-Smith, 2017; Hockema & Smith, 2009. Along these lines, Iverson (2010) argued that the achievement of specific early motor skills, such as the acquisition of independent upright sitting, independent locomotion, and the ability to explore objects provides infants with

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https://doi.org/10.1016/j.jcomdis.2018.09.004
Received 7 March 2018; Received in revised form 18 July 2018; Accepted 23 September 2018
Available online 28 September 2018

opportunities to practice skills relevant for general communicative development and the acquisition of language. In recent years, empirical evidence for this theoretical view has been growing.

Much of the current literature has focused on relations between early gross motor attainments (e.g., sitting, walking) and communicative and linguistic abilities (e.g., gestures, vocalizations, receptive and expressive vocabulary; LeBarton & Iverson, 2016; Libertus & Violi, 2016; Oudgenoeg-Paz, Volman, & Leselman, 2012; Walle & Campos, 2014). By contrast, less attention has been paid to the relations between fine motor skills (e.g., object exploration) and communicative and language development, with a few studies suggesting that active object exploration plays a key role in language development both in typically developing (TD) children (Ruddy & Bornstein, 1982) and children with autism spectrum disorder (ASD) and other developmental delays (Hellendorn et al., 2015). These relations have been relatively unexplored in extremely low gestational age preterm infants (ELGA, GA < 28 weeks of gestation), who often show difficulties in communicative, linguistic and motor skills (Benassi et al., 2016; de Kievet, Piek, Aarnoudse-Moens, & Oosterlaan, 2009; Sansavini et al., 2014; Stolt, Makila et al., 2014; Stolt, Matomaki et al., 2014; Zuccarini et al., 2016, 2017). Two studies have found relations between active exploratory behaviors in the first year and global cognitive and linguistic skills at 2 years of age in preterm infants (Ruff, McCarton, Kurtzberg, & Vaughan, 1984; Zuccarini et al., 2017). However, developmental relations between active exploratory behaviors in the first year and early communicative-linguistic skills (word comprehension, gestures, vocal production) remain undocumented and poorly understood, both in preterm infants and TD infants. The present study intends to address this issue.

1.1. Motor development and communicative-language skills in typical and atypical development

A growing body of evidence has highlighted the existence of relations between early motor skills and communicative-linguistic abilities. The central claim of these studies was that changes in motor skills provide infants with opportunities for acting in the world, gathering information and learning (Gibson, 1988). According to this theoretical perspective, developing motor skills shape the dynamic interactions between infant and environment in the first years of life (Smith, 2005) and have cascading effects on a wide range of domains, including language (Iverson, 2010). Among early motor skills, specific gross motor milestones, such as unsupported sitting and walking, appear to play a critical role in communicative and linguistic development in TD infants (Libertus & Violi, 2016; Oudgenoeg-Paz et al., 2012; Walle & Campos, 2014) and in infants at risk for developmental disorders (e.g., for ASD; LeBarton & Iverson, 2016; West, Northrup, Leezenbaum, & Iverson, in press).

Research has also documented concurrent and predictive associations between global fine motor skills and language development. These relations have been observed in TD children (Houwen, Visser, van der Putten, & Vlaskamp, 2016), in children with intellectual disabilities (Houwen et al., 2016), developmental disorders (Hellendorn et al., 2015) or language impairments (Estil, Whiting, Sigmundsson, & Ingvaldsen, 2003; Hill, 2001; Iverson & Braddock, 2011; Leonard & Hill, 2014, and in infants at risk for ASD (LeBarton & Iverson, 2013).

Among early fine motor skills, active object exploration via mouthing and manipulating, has turned out to be particularly relevant for later development (Bornstein, Hahn, & Suwalsky, 2013). Active object exploratory behaviors allow infants to detect and extract a range of information about objects' features (such as shape, texture, weight) and functions (Baumgartner & Oakes, 2013; Lederman & Klatzky, 1993; Lobo, Kokkoni, de Campos, & Galloway, 2014; Ruff, 1984). Through early object exploration experiences, infants can create categories and build semantic representations of objects (Antonucci & Alt, 2011) that are foundations of complex functions such as cognition and language (Bornstein et al., 2013; Ruff et al., 1984). Long lasting effects of active exploration on psychological functioning in TD children (Bornstein et al., 2013) have been documented, confirming its pivotal role in development. Detecting objects' characteristics through active object exploration allows infants to gradually learn to perform actions with objects, combine actions, and relate objects functionally (Lockman, 2000). Evidence for this exploration-action pathway comes from work showing that delays in active object exploration were related to difficulties in constructing sequences of functional actions with objects in infants at HR for ASD and infants with ASD (Christensen et al., 2010; Landa, Holman, & Garrett-Mayer, 2007).

Despite this evidence, only few studies have examined the impact of active object exploration on communicative-linguistic development. Ruddy and Bornstein (1982) found positive correlations between active object exploration in the first year of life and expressive vocabulary at 12 months in TD infants. In addition, actions with objects were reported at the MB-CDI toward the end of the first year of life, before their corresponding gesture or word (Capirci, Contaldo, Caselli, & Volterra, 2005; Caselli, Rinaldi, Stefanini, & Volterra, 2012), and they predicted word comprehension at the end of the first year and word production at the end of the second year (Bavin et al., 2008; Sansavini et al., 2010). Similar results have been reported for atypical populations. For example, Hellendorn et al. (2015) showed that active object exploration and actions with objects were a mediator of relations between fine motor skills and receptive and expressive vocabulary in preschool children with ASD and other developmental delays. Moreover, production of functional actions with objects at 10 months was associated with word comprehension at 12 months and with word production at 24 and 36 months in infants at risk for ASD (Sparaci, Northrup, Capirci, & Iverson, 2018).

These findings demonstrate the existence of relations among active object exploration, functional actions with objects and language development; however, the relations between active object exploration, that precedes functional actions with objects, and early communication skills, i.e. gestures and receptive vocabulary, besides expressive vocabulary, have not been deeply investigated.

1.2. Motor development and communicative-language attainments in preterm infants

Several studies have shown that preterm birth is a risk factor for motor, communicative, and language delays (Sansavini, Guarini, Savini et al., 2011; Sansavini, Guarini, & Caselli, 2011) with a greater risk associated with very and extremely preterm birth (de

Kievet et al., 2009; Loi, Marchman, Fernald, & Feldman, 2017; Sansavini, Savini et al., 2011, 2014; Stolt, Matomaki et al., 2014). Delays in global motor skills have been reported in the preterm population (de Kievet et al., 2009). In particular, ELGA infants exhibited lower scores in locomotor and eye-hand coordination skills from 6 to 24 months, compared to very preterm and full term (FT) infants (Sansavini, Savini et al., 2011).

Regarding specific motor skills, such as object exploration, a reduced variety of exploratory behaviors, i.e. less banging, fingering and cyclical movements, has been reported in very preterm infants throughout the first 2 years of life (Lobo, Kokkoni, Cunha, & Galloway, 2015). Lower duration of exploratory behaviors and less advanced exploratory abilities at 6 months and a different developmental pattern in oral exploration between 6 and 9 months have also been found in ELGA infants, compared to FT infants (Zuccarini et al., 2016). Specifically, duration of oral exploration remained low between 6 and 9 months in ELGA infants, whereas it was higher at 6 months and decreased from 6 to 9 months in FT infants (Zuccarini et al., 2017).

Delays in the communicative-linguistic domain have also been reported in very preterm and extremely preterm infants. Relative to FT peers, lower gesture-action production at 12 months (Ortiz-Mantilla, Choudhury, Leevers, & Benasich, 2008), slower development of gesture-action production, word comprehension, and word production at repeated assessments across the first and the second years of life (Sansavini, Guarini, Savini et al., 2011; Sansavini, Guarini, & Caselli, 2011; Stolt et al., 2016; Stolt, Makila et al., 2014), and lower word production in the second year (Foster-Cohen, Edgin, Champion, & Woodward, 2007; Schults, Tulviste, & Haan, 2013; Stolt et al., 2017) were consistently reported on the MB-CDI across different countries and languages in very and extremely preterm infants, but were less consistently observed in preterm infants with a wider gestational age range (< 37 weeks GA) (Cattani et al., 2010; Perez-Pereira, Fernandez, Resches, & Gomez-Taibo, 2013). Recent studies using direct observation, which provides more detailed information about context and rate of production, highlighted that pointing, giving, representational gestures, and words were performed by a lower percentage of ELGA infants compared to FT infants at 12 months (Benassi et al., 2016). Less advanced vocal production during the first year of life and delays in first word production at 12 months were also observed in very preterm infants relative to FT infants (D'Odorico, Majorano, Fasolo, Salerni, & Suttora, 2011; Torola, Lehtihalmes, Heikkinen, Olsen, & Yliherva, 2012). Thus, very and extremely preterm infants appear particularly vulnerable in the domain of communication and language from early in development.

Despite theoretical considerations and empirical studies highlighting relations between both motor and language domains (Iverson & Thelen, 1999; Iverson, 2010) and motor and language impairments (Hill, 2001; Leonard & Hill, 2014), relatively few studies have examined these associations in the preterm population. A study by Suttora and Salerni (2012) reported that global gross and fine motor skills at 12 months, assessed through the Bayley Scales of Infant Development (BSID), were related to the production of pointing gestures in very preterm infants at the same age. Associations between global fine motor skills on the BSID-III at 12 months, pointing, and representational gesture production at the same age have also been found in ELGA infants (Benassi et al., 2016). Furthermore, the total gestures summary score of the MB-CDI (which includes actions with objects) measured in the first half of the second year predicted language skills at 2 years of age (Sansavini, Guarini, Savini et al., 2011; Sansavini, Guarini, & Caselli, 2011; Stolt, Makila et al., 2014) and was associated with language development at 5 years of age in very and extremely preterm children (Stolt et al., 2016).

Even fewer studies have specifically examined relations between active object exploration and language development in the preterm population. Siegel (1981) found that object exploration assessed with a standardized test during the first year of life was related to receptive and expressive vocabulary at 24 months. Investigating spontaneous object exploration through direct observation, Ruff et al. (1984) showed that active object exploration, and in particular, manual exploration at 9 months, was related to cognitive skills at 24 months in preterm infants with neural abnormalities. More recently, Zuccarini et al. (2017) documented significant associations between active object exploration, specifically oral and manual, at 6 months and global language and cognitive skills at 24 months respectively in ELGA infants without cerebral damage.

Overall, these findings suggest that specific active exploratory behaviors in the first year of life play a key role in language development. What remains unclear is whether active exploratory behaviors, such as oral and manual exploration, relate to early communicative-linguistic behaviors in ELGA infants who are known to be at heightened risk for communicative and motor delays compared to FT infants.

1.3. Current study

The present study was conducted to address the following questions: are there longitudinal associations between 6-month active exploratory behaviors and early communicative-linguistic behaviors (i.e. word comprehension, gestures, vocal production) assessed at 12 months in ELGA and FT infants? Are these relationships maintained after accounting for cognitive performance and neonatal condition? Assuming that active oral and manual exploration provides new opportunities to explore the environment and supports the construction of semantic representations (Antonucci & Alt, 2011) and the development of complex linguistic and cognitive functions (Zuccarini et al., 2017), we expected that active exploratory behaviors with objects at 6 months would be positively associated with spontaneous communicative-linguistic behaviors at 12 months after accounting for cognitive performance and neonatal condition.

In addition, although oral exploration is very frequent at 6 months, manual exploration is more complex in terms of visuo-motor and bi-manual coordination, more powerful in gathering and coordinating information about objects, and more effective in eliciting joint gaze-hand attention and naming during parent-infant play interaction (Yu & Smith, 2013). We thus investigated whether there were specific associations between oral and manual exploration respectively and 12-month communicative-linguistic skills. In particular, we hypothesized that because manual exploration is more advanced at the motor, cognitive and socio-communicative levels, it would be more closely related to gesture and vocal production.

2. Methods

2.1. Participants

The data presented here come from a larger longitudinal study on language, cognitive and motor development in ELGA infants. Study participants included 20 ELGA infants (11 females) and 20 healthy FT infants (9 females). All infants had no history of major cerebral damage and/or congenital malformations, or visual or hearing impairments, were monolingual, and were living in the Emilia-Romagna region. The ELGA sample had a mean GA of 25.7 weeks (SD = 1.4; range = 23–28) and a mean birth weight (BW) of 803 g (SD = 191; range = 509–1093); the FT sample had a mean GA of 39.5 weeks (SD = 1.2; range = 38–42) and a mean BW of 3476 g (SD = 464; range = 2500–4200; see Benassi et al., 2016, for further details). No significant differences were found between the ELGA and FT groups on gender, birth order, maternal educational level, and maternal age.

2.2. Procedure

For the current study, relationships between 6-month measures of object exploration and 12-month measures of communicative-linguistic abilities, i.e. word comprehension, gestures, and vocal production, were analyzed. ELGA infants were observed at their corrected ages (referred to the presumed date of birth at 40 weeks of GA). Mean ages of assessment of the ELGA and FT groups were respectively 6 months and 3 days (SD = 7 days) and 12 months and 6 days (SD = 9 days) corrected age for ELGA infants; 6 months and 5 days (SD = 12 days) and 12 months and 3 days (SD = 9 days), for FT infants, with no significant differences between groups at 6 months, [ELGA infants: M = 6.03, SD = .23; FT infants: M = 6.17, SD = .40; $t(1, 38)$ = -1.32, p = .20] nor at 12 months [ELGA infants: M = 12.20, SD = .35; FT infants: M = 12.15, SD = .32; $t(1, 38)$ = .50, p = .62].

All infants were observed in a dedicated room located at the Unit of Neonatology of the University of Bologna. The aim of the study was described to the parents during the first meeting. The study was approved by the Research Ethical Committee of the University and the University Hospital of Bologna. All parents of the ELGA and FT infants were informed about the study and provided informed written consent for participation to the study, data analysis, and data publication.

2.2.1. Data collection for object exploration at 6 months and gestures and vocal production and 12 months

At 6 months, mother-infant play interaction was videotaped for 5 consecutive minutes. Mothers sat on a chair in front of their infants seated in a highchair at a distance of about 30 cm. Mothers were told to play with their infants as they used to do at home with a set of age-appropriate toys prepared by the examiner (two rattles, three toys for teething, a musical toy, a colorful fruit ring toy).

At 12 months, mother-infant play interaction was videotaped for 30 consecutive minutes. Mothers and infants sat on a mat close to a mirrored wall. Mothers were given same play instructions as at 6 months. An age-appropriate set of toys was provided by the examiner (a car, a ball, animal toys and books).

2.2.2. Assessment of word comprehension at 12 months

At 12 months, parents filled in the long form of the "Primo Vocabolario del Bambino (PVB) – Gesture and Words" questionnaire (Caselli & Casadio, 1995; Caselli, Bello, Rinaldi, Stefanini, & Pasqualetti, 2015), that is the Italian version of the MacArthur-Bates CDI (Fenson et al., 1994, 2007). The PVB questionnaire has been widely used in research investigating language development of full-term (Caselli et al., 2012; Sansavini et al., 2010) and preterm infants (Cattani et al., 2010; D'Odorico et al., 2011; Sansavini, Guarini, Savini et al., 2011; Sansavini, Guarini, & Caselli, 2011; Suttora & Salerni, 2012). Parents returned the completed questionnaire in person or mailed it back to the examiner. In the present study, we analyzed word comprehension. The vocabulary checklist consists of 408 words representative of the first words produced by infants. The parents were asked to check the words their infant understands. Each checked item received a score of 1.

2.2.3. Assessment of cognitive skills at 6 and 12 months

At 6 months, cognitive skills were assessed with the performance (PERF) subscale of the revised Griffiths Mental Developmental Scales 0–2 years (GMDS-R, Griffiths, 1996). This instrument provides a General Development Quotient (GQ) of infants' abilities with a mean of 100.5 and SD of 11.8 and five subscale quotients (Locomotor, Eye & Hand Coordination, Personal & Social, Hearing & Language, and cognitive Performance). The GQ and PERF scores were computed by referring to the original English standardized scores since an Italian standardization is not yet available.

At 12 months, cognitive skills were assessed with the cognitive scale of the Bayley Scales of Infant and Toddler Development, Third Edition (BSID-III, Bayley, 2006). The BSID-III provides standardized composite scores for each of the three domains assessed (cognitive, fine and gross motor, receptive and expressive language), with a mean of 100 and SD of 15. We referred to the normative values of the original standardization (Bayley, 2006) since Italian normative values for the BSID-III are available only after 13 months of age (Ferri, Orsini, & Stoppa, 2009). Both the GMDS-R and the BSID-III have been frequently used for clinical and research purposes in Italian studies on preterm and FT infants (Benassi et al., 2016; Sansavini, Savini et al., 2011, 2014; Zuccarini et al., 2016, 2017).

Table 1
Description of active exploratory behaviors coded at 6 months and spontaneous communicative behaviors (gestures and vocal production) coded at 12 months.

Active exploratory behaviors	
Oral exploration	Infant brings an object to the mouth with the hand and the object is in contact with the lips, tongue or mouth.
Manual exploration	Infant transfers an object from one hand to the other (Transferring), turns or rotates an object with wrist or finger rotation (Turn Rotating), or runs the fingertips over the surface of the object (Fingering).
Gestures	
Deictic	*Pointing:* clear extension of the index finger toward a proximal or distal object for the purpose of sharing attention or requesting. *Showing:* holding up the object toward the partner while making eye contact. *Giving:* extension of the arm with the object in hand and directed toward the hand of another person.
Conventional	Ritualized gestures (e.g., blowing a kiss to someone) or culturally defined gestures (e.g., NO with the head, HELLO with the hand).
Representational	Gestures that stand for a specific referent; the primary semantic content does not change with context. Can be produced with an object (e.g., DRINK, i.e., the infant brings a cup to his mouth) and without an object (e.g., TELEPHONE, i.e., the infant bringing the hand to the ear).
Vocal production	
Vocalizations	Utterances composed of a vowel, a syllabic consonant, a consonant-vowel or vowel-consonant sequence in which the consonant is a glide or glottal.
Babbling	Utterances containing at least one consonant-vowel sequence, in which the place and manner feature of the true consonant do not change, or at least two true consonants differing in place or manner of articulation.
Words	Utterances resembling an adult word (plausible phonetic shape), potentially relevant to the ongoing situation (plausible context of use), and meeting at least 3 of the following 4 criteria: occurring at least 2 times, being phonetically similar to the target, having a specific referent, or being recognized by the caregiver.

2.3. Coding

2.3.1. Object exploration skills

Six-month-old infants' exploratory behaviors performed during the 5-minute play interaction session were coded, frame by frame, by a trained coder blind to infant group membership, using a computer-based video interface system (INTERACT version 9, Mangold International GmbH, 2012). A coding scheme designed by Zuccarini et al. (2017) was applied. The coding scheme included four mutually exclusive categories of object exploration behaviors (holding, oral exploration, manual exploration, and manual rhythmic exploration). We refer to the work of Zuccarini et al. (2017) for an exhaustive description of the object exploration coding scheme. For the aim of the present study, we specifically analyzed oral and manual exploration (detailed descriptions are reported in Table 1), since these specific active exploratory behaviors were found to be related to global language and cognitive skills in FT infants and preterm infants at 2 years of age in previous studies (Ruff et al., 1984; Zuccarini et al., 2017).

2.3.2. Gestures and vocal production

Twelve-month-old infants' spontaneous (not elicited by a mother's request) communicative behaviors produced during the 30-minute play interaction session were coded, frame by frame, by a trained coder blind to infant group membership, using a computer-based video interface system (INTERACT version 9, Mangold International GmbH, 2012). A coding scheme, adopted by Benassi et al. (2016) to code gesture and vocal production was applied.

Following Capirci, Iverson, Pizzuto, and Volterra, (1996), deictic, conventional and representational gestures spontaneously produced were coded and summed together to obtain a global measure of gesture production. For the aim of the present study, among deictic gestures, pointing, showing, and giving gestures were included in the analyses since they are used to share an object/interest with a partner and are important precursors of language development (Bavin et al., 2008; Capirci & Volterra, 2008; Iverson & Goldin-Meadow, 2005). Requesting/reaching, that is a gesture with a more instrumental function (Camaioni, 1997), was not included in the analyses. Vocal utterances spontaneously produced by the infants, that function communicatively in the context of mother-infant interaction (Bates, Camaioni, & Volterra, 1975; Harding & Golinkoff, 1979), were coded as vocalizations, babbling or words (see Table 1 for a detailed description) and summed together to obtain a global measure of vocal production. A detailed description of coded gestures and vocal production is reported in Table 1.

2.3.3. Intercoder reliability

To obtain intercoder reliability, 20% of the video-recordings, randomly selected in equal numbers from the ELGA and FT groups, was independently coded by a second trained observer. Cohen's Kappa was calculated on the durations of the categories of the object exploration coding scheme (see Zuccarini et al., 2017) at 6 months, obtaining a mean K value of .82, and on gestures and vocal production at 12 months, obtaining a mean K value of .91 (gestures, $K = .92$; vocal production, $K = .90$). Values higher than 0.80 are considered an index of very good agreement (Landis & Koch, 1977).

Table 2
Means, SDs, ranges, *F*, *p*, and *partial eta-squared* ($\eta_p{}^2$) values for ANOVAs for 6-month proportional durations (percentages) of oral exploration, manual exploration, and GMDS-R PERF scores, and for 12-month word comprehension (number of words understood), gestures (rate per 10 min of gestures), vocal production (rate per 10 min of vocal production) and BSID-III cognitive composite score. Significant results are in bold.

	ELGA (n = 20)			FT (n = 20)			ANOVA		
	Mean	(SD)	Range	Mean	(SD)	Range	*F*	*P*	$\eta_p{}^2$
6- month skills									
Oral exploration	8.7	(11)	0-37.2	21.1	(18.2)	0-81.8	6.85	**.013**	.153
Manual exploration	5.9	(7.3)	0-23.9	7.3	(7.3)	0-29	.36	.55	.009
GMDS-R PERF score	93.1	(18)	64-117	108	(12)	72-126	9.51	**.004**	.200
12- month skills									
Word comprehension (MB-CDI)	75.2	(53.9)	0-170	118.6	(87.1)	19-297	3.48	.070	.086
Gestures	4.7	(5.3)	0-22	8.6	(7.5)	.3-33.6	3.50	.069	.084
Vocal production	18.1	(11.4)	3.6-46.8	22.5	(16)	3.7-47.3	1.00	.323	.026
BSID-III cognitive composite score	94.5	(11.5)	75-120	104.8	(10.7)	85-120	8.55	**.006**	.184

2.4. Statistical analyses

SPSS 21.0 for Windows, with a significance level set at 5%, was used to perform statistical analyses. The Kolmogorov-Smirnov test was used to check violations of assumption of normal distribution. Due to small variations in session length across groups, at 6 months proportional durations of oral and manual exploratory behaviors were calculated by dividing the total duration of each behavior by the total session duration; at 12 months, gestures and vocal production were converted to rates per 10 min by dividing the total frequency of each behavior by the length of observation in minutes, then multiplying it by 10.

ANOVAs were conducted on proportional durations of oral and manual exploratory behaviors and cognitive performance score at 6 months and on mean rates for 10 min of gestures and vocal production, number of words understood, and cognitive composite scores at 12 months to examine differences between the ELGA and FT samples.

Multiple linear regression analyses were conducted to determine whether 6-month oral and manual exploratory behaviors were related to 12-month word comprehension, gesture and vocal production. Six-month cognitive performance standardized scores and neonatal condition (ELGA vs. FT) were included in the models as covariates. Thus, 6-month oral exploration, manual exploration, GMDS-R PERF score and neonatal condition were entered as predictors of 12-month word comprehension (first regression), gestures (second regression) and vocal production (third regression).

3. Results

Descriptive analyses and statistical comparisons between the ELGA and the FT group are presented in Table 2.

With respect to their FT peers, at 6 months ELGA infants spent a lower percentage of time in oral exploration and had lower cognitive performance (GMDS-R PERF) score (see Table 2); at 12 months they had lower scores for number of words understood and of gestures produced (tendency, $p \leq .07$), and lower BSID-III cognitive composite scores (see Table 2).

3.1. Relations between active exploratory behaviors and communicative-linguistic attainments

To investigate whether there were longitudinal associations between 6-month oral and manual exploration and 12-month word comprehension, gestures and vocal production, three multiple linear regression analyses were performed. Six-month cognitive performance (GMDS-R PERF) and neonatal condition were also included in each of the models to account for potential effects of these variables.

The first model explained 22% of the variance in 12-month word comprehension, $R^2 = .22$ [$F(1, 38) = 3.65$, $p = .014$]. Six-month oral exploration was a significant predictor of 12-month word comprehension ($\beta = .35$, $p = .048$): a one unit increase in 6-month oral exploration proportional duration was associated with a 1.57 point increase in 12-month word comprehension score (see Table 3). By contrast, 6-month manual exploration, 6-month GMDS-R PERF score, and neonatal condition were not significantly related to 12-month word comprehension (see Table 3).

The second model explained 22% of the variance in 12-month gesture production, $R^2 = .22$ [$F(1, 38) = 3.68$, $p = .013$]. Six-month manual exploration ($\beta = .44$, $p = .006$) predicted 12-month gesture production. A one unit increase in 6-month manual exploration proportional duration was associated with a .40 point increase in rate per 10 min of gesture production at 12 months (see Table 3). Six-month oral exploration, 6-month GMDS-R PERF score, and neonatal condition were not significantly related to 12-month gesture production (see Table 3).

The third and final model explained 31% of the variance of the 12-month vocal production, $R^2 = .31$ [$F(1, 38) = 5.40$, $p = .002$]. Six-month manual exploration ($\beta = .61$, $p < .001$) predicted 12-month vocal production: a one unit increase in 6-month manual exploration proportional duration was associated with a 1.17 point increase in rate per 10 min of vocal production at 12 months (see Table 3). Six-month oral exploration, 6-month GMDS-R PERF score, and neonatal condition were not significantly associated with 12-

Table 3
Results of multiple linear regression analyses for 12-month word comprehension, gestures, and vocal production. Six-month oral exploration, manual exploration, GMDS-R PERF score, and neonatal condition were included as predictors. Significant predictors ($p < .05$) are in bold.

12-month variables	6-month predictors	B	β	P
1. Word comprehension	Oral exploration	1.57	.35	**.048**
	Manual exploration	−.41	−.04	.792
	GMDS-R PERF score	1.33	.30	.070
	Neonatal condition	3.92	.03	.877
2. Gestures	Oral exploration	.10	.24	.158
	Manual exploration	.40	.44	**.006**
	GMDS-R PERF score	.08	.20	.228
	Neonatal condition	.88	.07	.698
3. Vocal production	Oral exploration	.06	.07	.675
	Manual exploration	1.17	.61	< **.001**
	GMDS-R PERF score	.09	.10	.494
	Neonatal condition	.79	.03	.857

month vocal production.

4. Discussion

The findings presented above provide new evidence that specific active exploratory behaviors are related to early communicative-linguistic skills, i.e. word comprehension, gestures and vocal production, documenting that 6-month oral and manual object exploration plays a key role in these relationships for both ELGA and FT infants. They also highlight the existence of some specificity in these relations: 6-month oral exploration was associated with 12-month word comprehension and 6-month manual exploration with 12-month gestures and vocal production.

4.1. Relations between active exploratory behaviors and communicative-linguistic development

The first main finding of the current study was that active object exploratory skills at 6 months were linked to word comprehension, gestures, and vocal production at 12 months. Previous studies with TD infants have found associations between active object exploration and expressive vocabulary (Ruddy & Bornstein, 1982) and between action with objects, word comprehension, and word production (Bavin et al., 2008; Sansavini et al., 2010) in the first and second years of life. Associations between object exploration and global linguistic skills at 24 months have also been reported for the preterm population (Siegel, 1981; Zuccarini et al., 2017). In addition, associations between total gestures, including action with objects, on the MB-CDI in the first half of the second year and language skills at 2 (Sansavini, Guarini, Savini et al., 2011; Sansavini, Guarini, & Caselli, 2011; Stolt, Makila et al., 2014) and 5 years of age (Stolt et al., 2016) have been shown in very and extremely preterm children.

Our study expands these previous findings in several ways, demonstrating that active object exploratory skills are longitudinally related both to 12-month word comprehension and spontaneous vocal production in ELGA infants as well in FT infants. Furthermore, it documents the existence of associations between active object exploration and gesture production in both populations. These findings suggest that the ability to explore objects actively has potential cascading effects on early communicative-linguistic development. Indeed, they provide evidence for the hypothesis that early sensorimotor experiences are foundational for conceptual and linguistic knowledge (Wellsby & Pexman, 2014) and for spurring communicative and linguistic growth (Smith, 2003).

Consistent with our expectations, oral exploration was related to word comprehension, and manual exploration to gestures and vocal production. Oral exploration allows infants to gather information about objects from very early in life and lays the basis for object recognition and representation (Meltzoff & Borton, 1979). At 6 months, it is the most frequent exploratory pattern compared to emerging manual exploration (Lobo et al., 2015; Zuccarini et al., 2016). Thus, it appears to support the very early phases of language development, and particularly word comprehension, which develops earlier and drives the emergence of word production (Fenson et al., 1994). Manual exploration is a more complex and more advanced exploratory pattern, characterized by greater independence of the two hands and increased bimanual coordination compared to oral exploration (Ruff, 1984). In this study, manual exploration was linked both to gestures and to vocal production, communicative-linguistic behaviors requiring advanced motor coordination of the arms and hands (gestures) and the speech articulators (vocal production; Iverson & Thelen, 1999; Fagan & Iverson, 2007). Manual exploration also provides infants with enhanced information about objects' characteristics compared to oral exploration (Ruff, 1984; Soska, Adolph, & Johnson, 2010). In other words, manual exploration allows infants to capture the properties of objects in rich, multimodal detail, which in turn supports the construction of semantic representations of objects. These activities in turn set the stage for learning and naming objects (Yee, Chrysikou, Hoffman, & Thompson-Schill, 2013) and for performing functional actions with objects (Lockman, 2000).

The association between manual exploration with gestures and vocal production identified here brings new evidence to the model of continuity between production of action schemes and gestures and words, where functional actions sequences become gradually decontextualized and produced in gestural and/or vocal modalities (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Capirci et al., 2005; Volterra, Capirci, Caselli, Rinaldi, & Sparaci, 2017). In particular, our findings underscore the role of active object exploration that precedes and supports the development of functional actions with objects and gestures. Indeed, object exploration becomes progressively sophisticated and differentiated during the first year of life and it gradually integrates knowledge of objects' characteristics with knowledge of objects' use by exploring objects and observing their use in daily contexts (Lobo et al., 2014, 2015; Sparaci et al., 2018).

Evidence of close associations between hand and mouth has been found both in behavioral and neurophysiologic studies. For instance, Bernardis, Bello, Pettenati, Stefanini, and Gentilucci, (2008) have shown that object intrinsic properties (e.g., size) detected during manual exploratory activity affect infants' gestures and vocalizations, such that, for example, infants increased their vocalizations when manipulating or pointing to a large object. Neuroimaging studies (Heiser, Iacoboni, Maeda, Marcus, & Mazziotta, 2003; Iacoboni et al., 1999) revealed that areas of the brain involved in language functions are also involved in motor tasks, suggesting the existence of common underlying neural patterns supporting the representations of hands, arms and vocal tract.

Infant manual exploration may also support the construction of semantic meanings because it influences the language environment. West and Iverson (2017) observed that caregivers' production of object labels was higher during infants' active object manipulation. Moreover, the content of these labels was congruent with objects held by infants. This suggests that more advanced exploratory abilities also elicit caregiver social interaction and language input, which in turn foster infants' communicative and language development. Indeed, it has been shown that manual exploration elicits joint attention to objects and hands as they are manipulating objects, creating a multi-modal pathway for interacting, communicating and learning (Yu & Smith, 2013). Further studies are needed to unravel these relationships.

Finally, neither 6-month cognitive performance nor neonatal condition were significant predictors of 12-month word comprehension, gestures, or vocal production. Thus, despite the fact that ELGA infants showed less advanced exploratory abilities at 6 months and lower cognitive performance both at 6 and 12 months compared to FT peers, close relations between active object exploration and communicative-linguistic development were apparent both in ELGA and in FT infants. These findings are clinically relevant, suggesting that supporting active object exploration could enhance communicative-linguistic skills in infants at risk for language delays regardless of their neonatal condition.

4.2. Limitations

Although the present study provided new insights into developmental associations between active object exploration skills and communicative-linguistic development, some limitations should be acknowledged. First, we specifically examined active object exploration, but other motor attainments related to this skill were not considered. For instance, the achievement of unsupported sitting might be linked to object exploration and to communicative-linguistic development in the preterm population. Future studies should address this question. Second, sample size was relatively small, since it specifically included "healthy" extremely preterm infants compared to full term infants. In order to generalize our results, future studies need to be conducted with a larger sample of preterm infants and with a wider range of gestational ages.

4.3. Conclusions

Taken together, these results enhance our understanding of developmental relations between specific active exploratory behaviors and specific communicative-linguistic behaviors in ELGA and in FT infants. They highlight the importance of assessing early spontaneous exploratory and communicative behaviors via direct observation and use of standardized instruments. The collection of more detailed measures of infants' abilities, especially early motor skills such as active object exploration, may be useful for detecting individual areas of weakness that may affect later development, both within and beyond the motor domain. Early and accurate identification of specific motor delays may also allow for planning and implementation of individualized interventions to support early exploratory abilities aimed at minimizing future impairments in multiple developmental domains.

Authors' contribution statement

Mariagrazia Zuccarini contributed to the conception, design and methods of the study, to data coding and analyses, drafted the manuscript, revised and reviewed it. **Annalisa Guarini** contributed to the conception, design and methods of the study, to data analyses, and critically revised and reviewed the manuscript. **Jana Iverson** contributed to the conception and methods of the study, and critically revised and reviewed the manuscript. **Erika Benassi** contributed to the methods of the study and data coding and reviewed the manuscript for these parts. **Silvia Savini** contributed to methods of the study, data collection and data coding and reviewed the manuscript for these parts. **Rosina Alessandroni** enrolled the preterm sample, collected and supervised medical data. **Giacomo Faldella** supervised medical data collection of the preterm sample and medical aspects of the method. **Alessandra Sansavini** conceptualized and designed the study, the methods, data collection, data coding and data analyses, drafted the manuscript, critically revised and reviewed it, and supervised the study.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Conflict of interest statement

The authors of this article have not reported any financial or non-financial conflict of interest

Acknowledgements

This work was supported by grants from the Italian Ministry of Education, University and Research (grant year 2008, protocol 2008J2WEEK, and title: *PRIN 2008 "Gestures and language in children with atypical and at risk developmental profiles: relationships among competences, mother–child interaction modalities and proposals of intervention"*), the University of Bologna (grant year 2007, protocol STRAT07SAN, title: *Strategic Project 2007 "Early communicative-linguistic and cognitive abilities: risks linked to preterm birth"*), and the University of Bologna innovative project 2017 *Progetto Innovativo nell'Ambito degli Accordi di Cooperazione Internazionali "Implementing a cross-cultural, cross-population and Interdisciplinary methodology for studying development",* awarded to Alessandra Sansavini.

We are grateful to the families and infants who participated in this study and to the health professionals of the Neonatology and Neonatal Intensive Care Unit – S. Orsola-Malpighi Hospital, University of Bologna – who assisted in the conduct of this work. We are grateful to Cucciolo Associazione in Bologna dei Genitori dei Bambini nati pretermine (Association in Bologna of Parents of Preterm Children) for funding the clinical activity and psychological research at the Unit of Neonatology of Bologna University.

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