



Object engagement and manipulation in extremely preterm and full term infants at 6 months of age



Mariagrazia Zuccarini^{a,*}, Alessandra Sansavini^a, Jana M. Iverson^b, Silvia Savini^a, Annalisa Guarini^a, Rosina Alessandroni^c, Giacomo Faldella^c, Tiziana Aureli^d

^a Department of Psychology, University of Bologna, Via Berti Pichat 5, 40127 Bologna, Italy

^b Department of Psychology, University of Pittsburgh, USA

^c Neonatology and Neonatal Intensive Care Unit – S. Orsola-Malpighi Hospital, Department of Medical and Surgical Sciences, University of Bologna, Italy

^d Department of Neuroscience, Imaging and Clinical Sciences, University of Chieti-Pescara, Italy

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ABSTRACT

Delays in the motor domain have been frequently observed in preterm children, especially those born at an extremely low gestational age (ELGA; <28 weeks GA). However, early motor exploration has received relatively little attention despite its relevance for object knowledge and its impact on cognitive and language development. The present study aimed at comparing early object exploration in 20 ELGA and 20 full-term (FT) infants at 6 months of age during a 5-minute mother-infant play interaction. Object engagement (visual vs manual), visual object engagement (no act vs reach), manual object engagement (passive vs active), and active object manipulation (mouthing, transferring, banging, turn/rotating, shaking, fingering) were analyzed. Moreover, the Griffiths Mental Development Scales 0–2 years (1996) were administered to the infants. Relative to FT peers, ELGA infants spent more time in visual engagement, and less time in manual engagement, active manipulation, mouthing, and turning/rotating. Moreover, they had lower scores on general psychomotor development, eye & hand coordination, and performance abilities. Close relationships emerged between manual object engagement and psychomotor development. Clinical implications of these results in terms of early evaluation of action schemes in ELGA infants and the provision of intervention programs for supporting these abilities are discussed.

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1. Introduction

Preterm children, defined by the World Health Organization as born before 37 weeks of gestational age (GA), are at risk for developmental difficulties, delays, and impairments, even in the absence of cerebral damage (Saigal & Doyle, 2008; Sansavini, Guarini, & Caselli, 2011). In the early years of life, they are more likely to lag behind full-term (FT) infants in motor skills,

* Corresponding author.

E-mail addresses: mariagrazia.zuccarini@unibo.it (M. Zuccarini), alessandra.sansavini@unibo.it (A. Sansavini), jiverson@pitt.edu (J.M. Iverson), silvia.savini3@unibo.it (S. Savini), annalisa.guarini@unibo.it (A. Guarini), rosina.alessandroni@aosp.bo.it (R. Alessandroni), giacomo.faldella@unibo.it (G. Faldella), t.aureli@unich.it (T. Aureli).

language, and cognitive development (Sansavini et al., 2014). In later years, they may also show neuropsychological deficits in the domains of attention, memory, and executive function, learning disabilities, and behavioral problems, especially with regard to emotional control (Aarnoudse-Moens, Smidts, Oosterlaan, Duivenvoorden, & Weisglas-Kuperus, 2009; Aylward, 2002; Bhutta, Cleves, Casey, Craddock, & Anan, 2002). These delays increase as a function of neonatal immaturity, medical complications, and cerebral damages, and affect up to 50% of preterm children with lower gestational ages (very low-VLGA- <32 weeks and extremely low-ELGA- <28 weeks) or birth weight (very low-VLBW- <1500 g and extremely low-ELBW- <1000 g) (Aylward, 2002; Johnson, Wolke, Hennessy, & Marlow, 2011; Marlow, Roberts, & Cooke, 1993; Sansavini, Savini et al., 2011).

Several authors have underscored the importance of identifying and describing early behaviors that can affect subsequent development in the preterm population (Rose, Feldman, & Jankowski, 2009; Sansavini, Guarini, & Caselli, 2011). Research has demonstrated that the motor domain is frequently compromised in very preterm children from the first months of life (de Kievet, Piek, Aarnoudse-Moens, & Oosterlaan, 2009). Thus, the principal goal of the present study was to contribute to our understanding of these motor difficulties by investigating early manual object exploration and its relationship to cognitive abilities in ELGA infants.

1.1. Motor development in preterm children

Motor delays are frequently observed among preterm infants from early in life, presumably because of the early interruption of neurological and physical maturation in utero and the subsequent postural constraints imposed by the prolonged recovery in the Neonatal Intensive Care Unit (NICU). As described in de Kievet et al.'s (2009) meta-analytic review, preterm children obtain lower scores in early gross motor and fine motor skills with respect to FT samples, and this gap is more evident between VLGA and ELGA children. In a recent longitudinal study (Sansavini, Savini et al., 2011), ELGA infants showed difficulties in locomotor, eye-hand coordination, and non verbal performance abilities compared to VLGA and FT peers, with an increase in these difficulties and rate of impairments from 6 to 24 months of corrected age. Another longitudinal study (Sansavini et al., 2014) found an increasing divergence in the developmental trajectory of motor skills – both fine and gross – in ELGA infants from 12 to 30 months of corrected age in comparison to that of a FT group, confirming that the motor domain may be particularly compromised in ELGA infants. In addition, there is no indication of improvement within the first three years of life. Delays with respect to FT peers persist at preschool and school age in fine and gross motor development, particularly in balance skills, ball skills, and manual dexterity (de Kievet et al., 2009).

These findings stress the importance of further investigating diverse aspects of motor functioning and identifying early motor delays, which may have possible cascading effects on several developmental domains beyond the motor system. For instance, 6-month-old VLGA infants, who present signs of neck, elbow and trunk hyperextension due to their poor regulation of muscle tone (but not to permanent neurological damage), scored significantly lower on cognitive measures 6–18 months later (Wijnroks & van Veldhoven, 2003). Motor scores in 12-month-old ELBW infants predicted cognitive performance at 4 years (Burns, O'Callaghan, McDonnell, & Rogers, 2004). Moreover, motor skills at 6 years in VLBW children were the best predictor of learning disabilities and poor cognitive performance at 8 years (Marlow et al., 1993). A strong predictive relationship between motor skills and cognitive outcomes has also been observed in typical development: gross motor skills assessed from 4 months to 4 years through a parental questionnaire were predictive of IQ measures between 6 and 12 years (Piek, Dawson, Smith, & Gasson, 2008).

1.2. Early fine motor exploration abilities in preterm children

Motor development in preterm infants has been primarily investigated using global measures and standardized assessments. However, a more fine-grained analysis is needed in order to determine *how* infants use their motor repertoires when relating to external objects. To this end, infants' exploration of objects should be observed. As noted by several authors (Ruff, 1984; Rochat, 1989; Bushnell & Boudreau, 1993; Needham, 2000; Baumgartner & Oakes, 2013) manipulative skills such as holding and mouthing allow infants to discover a range of object properties that advance their knowledge at both perceptual and functional level, thus contributing to object categorization, a foundational ability for subsequent cognitive and language development (Oakes & Madole, 2000). Not only does the current manipulation of the object reveal infants' exploratory ability; so also does their attention to the object before initiating the manual contact with it. According to Ruff (1986), the time spent in looking at the object before reaching for it reflects the time is needed to organize an exploratory response and thus is a part of the ability to deal with object properties. Latencies to reach for and grasp an object after its first presentation decreases with increasing age and improved exploratory abilities (Ruff, 1986). This measure may also be relevant for further cognitive development since, as underscored by Perone, Madole, Ross-Sheehy, Carey & Oakes (2008) and later by Baumgartner & Oakes (2013), it is related to the infant's recognition of object appearance features.

Given the well recognized motor difficulties in premature infants and the possible negative effects of delayed object exploration on development, it would be of a great value to determine whether preterm infants differ from FT infants in the organization and deployment of manipulative schemes for object exploration and whether these abilities may be related to cognitive performance. Existing research on this topic is relatively sparse. Kopp (1976) assessed a variety of object-related action schemes in low risk preterm infants at 8 months, revealing that they displayed the same types of manipulative actions and spent similar proportions of time engaging in these actions compared to FT infants. Nevertheless, the durations

of individual action schemes were not similar in the two groups. In particular, mouthing was lower in preterm than FT infants, suggesting that differences existed in the general manner in which the two groups explored the objects. In an extension of Rose, Gottfried, and Bridger (1978), Rose, Gottfried, and Bridger (1979) and Rose (1981) work, which showed that preterm differed from FT infants in cognitive abilities such as perceptual discrimination, recognition memory, and tactual-visual transfer, Ruff, McCarton, Kurtzberg, and Vaughan (1984) hypothesized that preterm infants were impaired in learning from haptic contact with objects relative to their FT peers. Comparison of the duration of a variety of action schemes (e.g. mouthing, rotating, transferring) in the two groups at 9 months revealed no differences. However, a sub-group of the high-risk preterm infants characterized by neurological abnormalities at birth and in the first 6 months of life showed significantly lower durations of handling and, in particular, rotating, fingering and transferring, compared to the low-risk preterm and the FT infants, who were very similar to one another. In addition, high-risk preterm infants' poorer performance was related to their cognitive status (Bayley MDI) at both 7 and 24 months.

1.3. The Present Study

The work of Ruff et al. (1984) underscores the importance of using detailed behavioral coding schemes to examine motor development in preterm infants and of focusing on exploratory abilities. The present study was therefore designed to address two aims.

The first aim was to examine early fine motor exploration abilities of ELGA infants. To this end, we conducted a fine-grained analysis of behaviors used by ELGA and FT infants at 6 months of age when engaging manually with objects during play interactions with their mothers. Since the latency to the first contact with the object reflects time needed for organizing an exploratory response, we also measured visual engagement with the object before the first occurrence of any behavior. Within visual engagement, we distinguished between time spent looking at the object before starting any movement toward it (i.e., the time needed for planning an intentional movement) and the time needed to reach for and grasp the object (i.e., the time needed to execute the movement until grasping the object). We expected that the ELGA group would exhibit significantly less active object manipulation than the FT group in terms of both the time spent manipulating and the types of manipulation schemes employed. Moreover, we expected that, compared to FT group, the ELGA group would spend significantly more time attending to the object prior to initiating movement toward it and significantly more time reaching for and grasping the object.

Our second aim was to investigate whether there were concurrent relationships between exploratory skills and cognitive development at 6 months. Once infants are capable of more sophisticated sensorimotor schemes and become more proficient in their implementation, they refine their activities. In this way, manipulating objects may enhance information collection and support cognitive development (Ruff et al., 1984). Thus, we employed a standardized tool, the Revised Griffiths Mental Development Scale 0-2 years (GMDS-R, Griffiths, 1996), which is commonly used in follow-up programs to assess global and specific psychomotor abilities in the first two years of life. We expected to find a positive relationship between the duration of more advanced manipulation schemes and global psychomotor development, with a particular link to the eye-hand coordination subscale. Conversely, we expected to find a negative relationship between this subscale and the time spent attending to the object before manipulating it.

The present study was designed as an extension of Ruff et al. (1984), but with some key methodological differences. Only ELGA infants were included in the preterm sample in order to ensure that it included infants at very high risk for developmental delays and neuropsychological impairments. Importantly, however, infants in the ELGA sample were free from neurological damage, making them good candidates for investigating the role of severe prematurity in development. ELGA and comparison FT infants were observed at 6 months of age (i.e., at an earlier age than that investigated in previous studies), when reaching and grasping abilities enable infants to progress from unimodal object exploration (oral or visual or manual) to multimodal exploration. Finally, we examined object exploration during a mother-infant play interaction with a set of age-appropriate objects to enhance the ecological validity of the results.

2. Method

2.1. Participants

Forty infants were recruited for this cross-sectional study. The first group included twenty monolingual Italian ELGA infants (11 females, 55%; 9 males, 45%), born at the Neonatal Intensive Care Unit (NICU) of the University of Bologna, in a region located in the centre of Italy. The ELGA infants were recruited into the study if, at birth, they met three primary medical criteria: (a) gestational age (GA) ≤ 28 weeks, determined by the date of the mother's last menstrual period and confirmed by first-trimester early ultrasonography; (b) no indication of major cerebral damage [i.e., periventricular leukomalacia (PVL), intra-ventricular haemorrhage (IVH) $> \text{II}$ grade, hydrocephalus] as detected by ultrasound scan (US) and confirmed by magnetic resonance imaging at 40 weeks of GA when indicated by the US outcome, and/or no indication of congenital malformations; and (c) no indication of visual [retinopathy of prematurity (ROP) $> \text{II}$ grade, blindness] or hearing impairment [mono or bilateral hearing loss evaluated by otoacoustic emissions]. The mean GA of the ELGA infants was 25.7 weeks ($SD = 1.4$; range = 23–28) and their mean birth weight (BW) was 803 grams ($SD = 191$; range = 509–1093).



Fig. 1. Pictures of the objects available for the mother–infant interaction session.

Some ELGA infants had medical complications at birth: these included small for gestational age (SGA, $n = 2$, 10%, defined as a birth weight below the 10th percentile according to the Italian Neonatal anthropometric charts, Bertino et al., 2010), respiratory distress syndrome needing mechanical ventilation (RDS, $n = 20$, 100%), bronchopulmonary dysplasia (BPD, $n = 12$, 60%, defined as need of supplemental oxygen at 36 weeks of post-conceptual age), IVH of grade I or II detected by US ($n = 1$, 5%), ROP of grade I or II ($n = 13$, 65%), and hyperbilirubinemia treated with phototherapy ($n = 16$, 80%). In addition, 17 ELGA infants (85%) had persistent hyperechogenicity (HE) of white matter (≥ 14 days) as indicated by US; however, none of these ELGA infants developed PVL because, in all instances, the HE had been completely resolved at 3 months of corrected age (CA). Mean hospitalization length was 91.4 days ($SD = 32$; range = 49–152).

Fifteen ELGA infants (75%) were first-born and five (25%) second or later born. Six infants (30%) were twins. The sample of ELGA infants is best described as distributed across the general range of socioeconomic status (SES) strata, estimated from parental highest level of educational attainment. Twelve mothers (60%) had a middle/low educational level (completed high school or at least basic education) and eight (40%) had a high educational level (completed University/Master's degree). The mean age of mothers was 36.2 years ($SD = 4.8$; range = 27–44).

The second group included twenty monolingual Italian healthy FT infants (11 females, 55%; 9 males, 45%) recruited from two hospitals located in two regions in the centre of Italy. Fourteen infants (7 females, 7 males) were recruited from Bologna University Hospital (the same site where the preterm newborns were recruited) and six (4 females, 2 males) were recruited from Chieti Hospital. The two FT subgroups did not differ on gender or on the sociodemographic variables reported below. All FT infants had experienced normal birth ($GA \geq 37$ weeks and $BW \geq 2500$ grams), had no peri-natal asphyxia, no history of major cerebral damage, congenital malformations, and/or visual or hearing impairments. They had a mean GA of 39.5 weeks ($SD = 1.5$; range = 37–42) and a mean BW of 3339 grams ($SD = 445$; range = 2500–4200). Mean hospitalization length was 2.7 days ($SD = 0.9$; range = 2–5). Fifteen (75%) were first-born and five (25%) second or later born. Two (10%) infants were twins. Nine mothers (45%) had a middle/low educational level and eleven (55%) had a high educational level. The mean age of mothers was 34.4 ($SD = 3.0$; range = 30–41). Chi Square and independent sample t-tests revealed no differences between ELGA and FT infants on gender, birth order, mother's age and level of education, or presence of twins.

2.2. Procedure and measures

During the first contact with the parents, the purpose of the study was explained. At 6 months of age, all infants were videotaped for five consecutive minutes in interaction with their mothers in a quiet room at the Day-Hospital of the NICU of Bologna University (all ELGA infants and 14 FT infants) or at the Psychology Department at Chieti-Pescara University (6 FT infants). We provided the dyads with a set of age-appropriate infant toys (two rattles, three toys for teething, a musical toy, a colourful fruit ring toy), which differed in colour, shape and other surface features (e.g. sound), but were all similarly capable of eliciting the whole repertoire of the exploratory patterns we considered (see Fig. 1). The mother sat on a chair in front of her infant, who was seated in a highchair at a distance of about 20–30 cm (see Fig. 2). All infants were observed in the same position, in order to reduce the influence of the body orientation on the reaching and grasping movements (Carvalho, Tudella, Caljouw & Savelsbergh, 2008). Mothers were asked to use the toys that were provided and to play with their infants as they usually did at home. In line with the ecological aim of the current study, we left the mothers free to select which and how many objects to present to the infant. The interactions were filmed using one digital camera placed diagonally to the highchair and in front of the infant so that his/her face and all the movements of his/her arms and hands were visible. The camera was stationary and powered with remote control in order to limit interference due to the presence of an unfamiliar person during the observational sessions.

As in many studies on preterm infants' development in the first two years of life, assessment of the ELGA infants was done using the corrected age to account for their level of neurobiological maturation (Johnson & Marlow, 2006; Sansavini,



Fig. 2. Picture of the position of the dyad during the interaction session.

Guarini & Caselli, 2011). An independent sample t-test revealed that the ELGA and the FT samples did not differ significantly in the age at which they were observed (corrected age of ELGA infants: $M = 6.0$; $SD = 0.2$; range = 5.6–6.5; chronological age of FT infants: $M = 6.2$, $SD = 0.4$, range = 5.7–7.3).

After the mother–infant play interaction, all infants were individually administered the revised Griffiths Mental Development Scale 0–2 years (GMDS-R, Griffiths, 1996). This scale is designed for use with children 0–2 years; it requires approximately 45 minutes to be administered and evaluates five domains: Locomotor, Personal–Social, Hearing & Language, Eye & Hand Coordination, Performance. The Locomotor subscale (54 items) examines postural control, gross motor skills, and the ability to control and coordinate movements. The Personal & Social subscale (58 items) examines social competence and independence. The Hearing & Language subscale (56 items) examines auditory discrimination and communicative–linguistic comprehension and production. The Eye & Hand Coordination subscale (54 items) examines the ability to follow, reach for, and grasp objects, and fine motor skills. The Performance subscale (54 items) examines cognitive functions for planning and completing intentional actions and representing objects mentally. The GMDS-R is frequently used in Europe for clinical evaluation of preterm infants (Johnson & Marlow, 2006; Sansavini, Guarini & Caselli, 2011). It yields standardized domain scores (sub-quotients, SQ, $M = 100$, $SD = 16$) and a composite General Development Quotient (GQ, $M = 100.5$, $SD = 11.8$). GQ and SQ scores were calculated using the tables of standardized scores for the English population since an Italian standardization of this scale is not yet available.

The study met ethical guidelines for human subjects protections, including adherence to the legal requirements of the study country, and received a formal approval by the local Research Ethical Committee. Moreover, all parents of the ELGA and FT infants gave informed written consent for participation to the study, data analysis, and data publication.

2.3. Coding

Mother–infant play interaction (5 minutes) was coded from videotapes frame by frame (the video had 24 frames per second) in a single pass. A time-linked, computer based video interface (Interact) was used by a trained coder blind to infant group membership. Three specific codes – object engagement, visual object engagement, and manual object engagement – consisting of mutually exclusive categories listed in Table 1, were devised to analyze infants' object exploration skills.

We defined Object Engagement (OE) as any engagement with an object that lasted at least one second. It included time spent by the infant attending to the object after its presentation (indicated by the direction of the head and the eyes toward the object), but before contacting it (*Visual Object Engagement* – VOE) and the time spent manipulating the object (*Manual Object Engagement* – MOE). Therefore, VOE occurred when the infant had no physical contact with the object but was looking at it while MOE involved a continuous physical contact with the object. In addition, *No Engagement* (NOE) was assigned to episodes in which the infant had no physical or visual contact with the object or in absence of any object; and *No code* was assigned to frames that could not be coded due to the infant's fussiness or because the infant's behaviors were not visible (e.g., the mother's body partially blocked the camera's view of the child; see Table 1).

Table 1

Object engagement, Visual Object Engagement, and Manual Object Engagement coding schemes.

Coding scheme	Categories	Categories description
Object Engagement	VOE	Infant has no physical contact with an object but he/she has a looking contact with it
	MOE	Infant has a physical contact with an object
	NOE	Infant has no physical or looking contact with an object or any object is present
	No Code	Infant cries or his/her behaviors are not visible to the camera
Visual Object Engagement	VOE no act	Infant looks at the object shown by the mother but he/she does not move his/her hands in order to reach it
	VOE reach	Infant begins to move his/her hands toward the object in order to reach for and eventually to grasp it
Manual Object Engagement (types of object manipulation)	Hold (P)	Infant is holding, touching an object or carrying it from a side to another one or his/her hand is resting, open-palmed, on it
	Mouth (A)	Infant explores an object with his/her lips, tongue or mouth
	Transfer (A)	Infant grasps an object with one hand, then grasps it with the other hand, while releasing the hand initially grasping the object
	Bang (A)	Infant with an empty hand or holding an object makes firm contact with another object or surface
	Turn Rotate (A)	Infant turns or rotates an object with wrist or finger rotation
	Shake (A)	Infant executes a repeated arm movement (up-and-down or side-to-side motion) while holding an object
	Finger (A)	Infant runs her/his fingertips over the surface of the object
	Other Active (A)	Infant is actively engaged with an object but her/his behaviour does not logically fall in any category
	Mouth Transfer (A)	Infant mouths and transfers an object at the same time
	Mouth Finger (A)	Infant mouths and fingers an object at the same time
	Mouth Turn (A)	Infant mouths and turns an object at the same time
	Transfer Turn (A)	Infant transfers and turns an object at the same time
	Transfer Finger (A)	Infant transfers and fingers an object at the same time
	No Manipulation	Infant has no physical contact with any object
	No Code	Infant cries or his/her behaviors are not visible to the camera

Note: VOE: Visual Object Engagement; MOE: Manual Object Engagement; NOE: No Engagement; P: Passive; A: Active.

To better capture the infant's attempt to organize the exploratory response when attending to an object, we refined the latency measure previously used by Ruff (1986) and Perone et al. (2008) by distinguishing *Visual Object Engagement (VOE)* into two types: *VOE no act*, which occurred when the infant looked at the object shown by the mother but did not move his/her arms in order to reach it, and *VOE reach*, assigned when the infant began to move his/her arms toward the object shown in order to reach for and eventually grasped it (see Table 1).

To describe *Manual Object Engagement*, types of object manipulation behaviors (each lasting at least 1 second) were coded using a scheme based on prior work by Ruff (1984; see Table 1). These included actions that are commonly performed at 6 months of age and are potentially relevant for the process of exploring object properties (see Table 1).

With the exception of *Hold*, which was considered passive manipulation, the other behaviors were considered active because they involved overt manipulation of the object using the fingers, hands, arms, and/or mouth. As with engagement, we marked *No manipulation* when the infant had no physical contact with any object, and *No code* when coding was impossible.

The temporal duration of each category was used as the primary dependent measure in the analyses. The only exception was the transfer category, which was measured as a frequency. To take into account small (but no significant) variability in session length across groups (ELGA: $M = 290.05$ s, $SD = 26.45$; FT: $M = 299.50$ s; $SD = 2.24$), the duration of each category in each session was transformed into proportional duration by dividing the total duration of each category by the total session duration. Frequency per minute was calculated for analyses of the transfer category.

2.4. Reliability

Intercoder reliability was assessed by having a second trained observer who independently coded a randomly selected 20% of the videorecordings, in equal numbers from the ELGA and FT groups. We used Cohen's Kappa to calculate reliability on the durations of each category in each of the coding systems. We obtained a mean value of .85 (object engagement, $K = .95$; visual object engagement, $K = .93$; manual object engagement, $K = .82$); values higher than 0.80 indicate almost perfect agreement (Landis & Koch, 1977). Instances of disagreement were identified and resolved by a third coder, who chose one of the two classifications proposed by the first two coders.

2.5. Statistical analyses

Statistical analyses were run using SPSS 21.0 for Windows. Significance level was set at 5%. Violation of assumptions was assessed using the Kolmogorov-Smirnov test for normality and the homogeneity of variance test. Analyses of variance (ANOVAs) were run in order to compare proportional durations of ELGA and FT infants on the categories of the object

Table 2

The Table summarizes mean, SD, range, F, p and partial eta-squared (η^2p) values for ANOVAs and ANCOVAs on proportional durations (%) of types of object engagement, visual object engagement and manual object engagement categories. In bold the significant results.

	ELGA (n = 20)			FT (n = 20)			ANOVA			ANCOVA ^a		
	M	SD	Range	M	SD	Range	F	p	η^2p	F	p	η^2p
Object Engagement												
VOE	32.19	20.96	3.23–76.84	15.89	8.53	2.45–30.95	10.37	0.003	0.214	6.92	0.012	0.158
MOE	55.37	21.98	12.78–97.04	77.23	13.09	37.83–97.61	14.59	<0.001	0.278	11.40	0.002	0.236
NOE	4.19	5.45	0–19.96	4.76	10.07	0–44.95	0.05	0.826	0.001	–	–	–
NoCo	5.37	7.84	0–21.68	1.96	4.87	0–22.17	3.29	0.077	0.080	–	–	–
Visual Object Engagement												
VOE no act	19.37	16.08	1.45–61.74	7.31	4.31	1.83–14.04	10.70	0.002	0.220	8.21	0.007	0.182
VOE reach	12.72	9.43	.84–34.23	7.52	5.35	0–19.69	10.49	0.002	0.216	–	–	–
Manual Object Engagement												
Passive	35.53	14.40	11.45–60.40	42.29	14.72	16.62–75.42	2.15	0.151	0.053	–	–	–
Active	20.63	13.08	1.16–48.29	35.69	16.68	17.27–87.50	10.09	0.003	0.210	6.19	0.017	0.143
NoMa	35.48	22.69	3.23–81.13	19.69	12.68	2.45–55.57	7.39	0.010	0.163	5.85	0.021	0.136
NoCo	5.54	6.86	0–23.34	2.03	4.86	0–22.17	3.49	0.070	0.084	–	–	–

Note: VOE: Visual Object Engagement; MOE: Manual Object Engagement; NOE: No Engagement; NoMa: No Manipulation; NoCo: No Code.

^a ANCOVAs controlling for the GQ score.

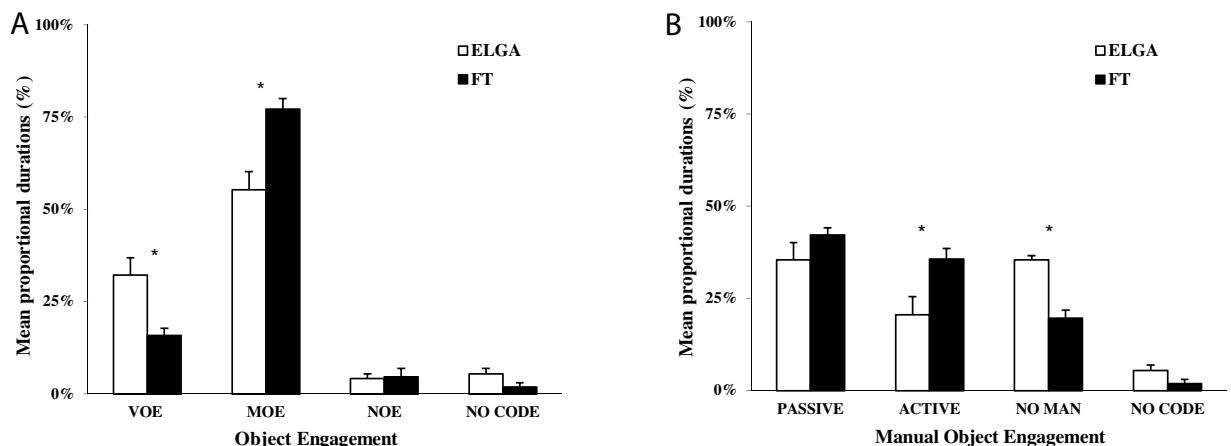


Fig. 3. A Mean proportional durations of types of object engagement of ELGA and FT infants. B Mean proportional durations of types of manual object engagement of ELGA and FT infants.

engagement, VOE and MOE coding systems, and on the Griffiths scores (GQ and SQs). Analyses of covariance (ANCOVAs) were run to control for GQ scores.

Since several active object manipulation (see Table 1) variables were not normally distributed, non-parametric analyses (Mann-Whitney test) were run to compare proportional durations of the ELGA and FT samples. The effect size (r) of the Mann-Whitney's U test was calculated ($r = \frac{Z}{\sqrt{N}}$, where N is the total number of participants in the whole sample); the standard values of r for small, medium, and large sizes are respectively 0.1, 0.3, and 0.5 (Field, 2009, p. 550).

We also computed Pearson's univariate correlations on the full sample in order to evaluate the relationship between psychomotor development (GQ and SQ scores), object engagement, visual object engagement and manual object engagement categories. These correlations were run on variables that differed significantly between the two groups.

3. Results

Descriptive data on object engagement and object manipulation are reported in Table 2.

3.1. Object Engagement

ANOVAs (see Table 2 and Fig. 3A) indicated that compared to their FT peers, ELGA infants spent a significantly greater proportion of time in visual engagement attending to the object before manipulating it (VOE; ELGAs: $M = 32\%$, FTs: $M = 16\%$) and a lower proportion of time manipulating the objects (MOE; ELGAs: $M = 55\%$, FTs: $M = 77\%$). No differences were found

Table 3

The Table summarizes mean, SD, range, U, p and effect size (r) for Mann-Whitney tests on proportional durations (%) of types of active object manipulation. In bold the significant results.

	ELGA (n = 20)			FT (n = 20)			Mann-Whitney test		
	M	SD	Range	M	SD	Range	U	p	r
Mouth	8.7	11.0	0–37.17	22.1	17.3	0–81.82	87.0	0.002	0.484
Transfer ^a	4.2	5.3	0–30	3.4	4.0	0–24	185.0	0.684	0.17
Bang	1.8	3.1	0–13.44	1.8	2.3	0–8.03	184.5	0.665	0.068
Turn Rotate	0.3	0.7	0–2.31	2.3	2.9	0–8.33	114.5	0.010	0.406
Shake	2.8	4.6	0–16.02	3.6	6.0	0–18.51	187.5	0.654	0.071
Finger	1.4	3.6	0–16.34	1.3	3.9	0–17.49	175.0	0.416	0.129
Other Active	0.3	0.9	0–4.08	0.0	0.0	0–0	180.0	0.152	0.226
Mouth Transfer	0.6	1.8	0–7.99	0.9	1.3	0–3.70	162.0	0.237	0.187
Mouth Finger	0.1	0.4	0–1.89	0.2	0.4	0–1.13	190.0	0.638	0.074
Mouth Turn	0.0	0.0	0–0	0.0	0.0	0–0	200.0	1.000	0.000
Transfer Turn	0.3	1.6	0–7.12	0.1	0.4	0–1.81	191.0	0.594	0.084
Transfer Finger	0.1	0.4	0–1.75	0.0	0.0	0–0	190.0	0.317	0.158

^a for Transfer proportional frequencies are reported.

Table 4

The Table summarizes mean, SD, range, F, p and partial eta-squared (η^2p) values for ANOVAs on General Development, Locomotor, Personal & Social skills, Hearing & Language, Eye & Hand Coordination and Performance standardized scores (Griffiths scales). In bold the significant results.

	ELGA (n = 20)			FT (n = 20)			ANOVA		
	M	SD	Range	M	SD	Range	F	p	η^2p
General Development	103	12.1	80–103	112.6	9.5	91–133	7.76	0.008	0.170
Locomotor	98.6	17.6	57–150	107.9	16.9	77–142	2.87	0.098	0.070
Personal & Social Skills	106.4	11.2	92–132	112.3	15.8	88–150	1.89	0.177	0.047
Hearing & Language	118.7	10.6	102–140	120.5	12.4	88–140	0.24	0.625	0.006
Eye & Hand Coordination	97.4	16.5	63–123	109.4	11.5	88–128	7.03	0.012	0.156
Performance	93.1	18	64–117	110.4	9.1	91–126	14.83	<0.001	0.281

between the two groups for No engagement (NOE) and No code (see Table 2). The above differences between ELGA and FT infants in VOE and MOE remained significant when ANCOVAs controlling for GQ score were conducted (see Table 2).

3.2. Visual object engagement

ANOVAs (see Table 2) indicated that the time spent by the infants attending to the object without moving the arms to reach it was proportionately greater in ELGA infants than in the FT group (VOE no act; ELGAs: $M = 19\%$, FTs: $M = 7\%$). Similarly, the time spent for reaching the object was proportionately greater in ELGA than in FT infants (VOE reach ELGAs: $M = 13\%$, FTs: $M = 7\%$, see Table 2). The difference between ELGA and FT infants in VOE no act remained significant when an ANCOVA controlling for the GQ score was conducted (see Table 2).

3.3. Manual Object Engagement

ANOVAs revealed no significant differences between the two groups in passive manipulation (ELGAs: $M = 35\%$, FTs: $M = 42\%$), while the time spent in active manipulation was significantly lower in ELGA ($M = 21\%$) than FT infants ($M = 36\%$). Furthermore, no manipulation was significantly greater in ELGA ($M = 35\%$) than FT infants ($M = 20\%$; see Table 2 and Fig. 3B). The differences between ELGA and FT infants in active manipulation and no manipulation remained significant after controlling for the GQ score (see Table 2).

Data on types of active manipulation are presented in Table 3. In both groups, the most frequent behaviors were mouth, transfer, shake, finger, and bang, while combined behaviors were uncommon. Relative to FT infants, ELGA infants spent a significantly lower proportion of time mouthing (ELGAs: $M = 8.7\%$, FTs: $M = 22.1\%$) and turning/rotating the object (ELGAs: $M = 0.3\%$; FTs: $M = 2.3\%$).

3.4. Psychomotor development and relationships with object engagement and manipulation

Descriptive data on psychomotor development from the Griffiths Scales are reported in Table 4. Mean GQ and the five domain mean scores (SQs) for both groups fell within the typical range based on available normative data (Griffiths, 1996). However, significant differences between the groups were revealed by ANOVAs, with ELGA infants obtaining significantly lower scores than FT infants on the GQ as well as on the Eye & Hand Co-ordination and Performance subtests (see Table 4).

Relationships between object exploration measures, i.e. object engagement (VOE, MOE, NOE), visual object engagement (VOE no act, VOE reach), manual object engagement (Passive, Active, No Manipulation), and psychomotor development (GQ,

Eye & Hand Coordination and Performance subtest scores) were examined using Pearson's univariate correlations. Significant positive correlations were found between MOE and Eye & Hand Coordination score ($r = .338$; $p = 0.033$) and between active manipulation and GQ ($r = .318$; $p = 0.045$). However, a significant negative correlation was found between VOE and Eye & Hand Coordination score ($r = -.325$; $p = 0.041$) as well as between VOE no act and Eye & Hand Coordination score ($r = -.318$; $p = 0.046$). No correlation was found with VOE reach.

4. Discussion

The current study was designed to investigate the fine motor abilities of ELGA infants at 6 months (corrected age) in comparison to FT infants. We performed a detailed analysis of the actions used by ELGA and FT infants to manipulate objects and we analyzed the time spent by the infant for attending to the object presented as an index of time required to organize the exploratory response. Concurrent relationships between fine-motor exploratory skills and cognitive development were also investigated.

4.1. Manual exploration abilities in ELGA infants

Consistent with our hypothesis, ELGA infants showed significantly less advanced object exploration compared to FT infants. They spent proportionately less time manipulating the objects and more time organizing an adequate motor response, both when initiating the arm movement towards the object and when reaching for it after moving.

Several factors may underlie the differences we observed. First, both neuromuscular immaturity and poor regulation of muscle tone (Wijnroks & van Veldhoven, 2003) likely limit reaching and grasping abilities in ELGA infants, thus possibly hampering the movements suitable for exploration (Ruff et al., 1984; Ruff, 1986; Ruff, Saltarelli, Capozzoli, & Dubiner, 1992). Second, infants' prolonged recovery in the NICU and after discharge (Als et al., 2004; Sansavini, Guarini & Caselli, 2011) may have negative effects on postural development (Van Haastert, de Vries, Helders, & Jongmans, 2006; Sansavini et al., 2014; Wijnroks & van Veldhoven, 2003), which over time may make exploration more difficult to execute. Postural control plays an important role in learning and goal oriented behaviour in infancy (Carvalho et al., 2008; Rochat & Bullinger, 1994). Infants who can sit alone have both hands free to move in the service of the object manipulation (e.g., Berthenthal & Von Hofsten, 1998; Soska & Adolph, 2014); and indeed, the quality of reaching movements improves when infants become proficient in sitting without support (Carvalho, Tudella & Savelsbergh, 2007; Rochat & Goubet, 1995).

The greater proportion of time spent by ELGA infants attending to the object prior to contacting it was related to difficulties both in initiating arm movement towards the object and in reaching for and grasping it. The latency to the first full grasp of the object is thought to correspond to the time required for activating the information-processing system that is necessary for exploration of the object to begin (Ruff, 1986). In this respect, our result is consistent with previous studies showing that preterm infants need longer periods of attention for information processing (Harel, Gordon, Geva & Feldman, 2011; Rose, 1983), and it also brought an innovative contribution by distinguishing the time needed for programming the arm movement toward the object and the time needed to reach for and grasp it. It may be that impairments both in motor and attention abilities combine to make the ELGA infants slower than FT infants in movement planning to grasp objects and in their manipulation.

In addition to quantitative differences in object manipulation, quality of manipulation was different in ELGA compared to FT infants. Indeed, the former group engaged in action schemes for exploring the objects' properties less than the latter, spending more time simply holding the object in their hands. Moreover, when acting, ELGA infants made less use of both age-typical exploration schemes (e.g., mouthing) and of the most advanced motor scheme (e.g., turning/rotating; Ruff, 1984). The smaller proportion of time spent mouthing by ELGA, compared to FT infants, at an age when that behaviour is prominent in typical development, suggests that mouthing is still an emerging skill in 6 month-old ELGA infants.

These findings are consistent with previous research indicating that 8-month-old preterm infants mouthed objects for a shorter time than FT peers (Kopp, 1976) and that 9-month-old high risk preterm infants who were heterogeneous in gestational age and affected by a high degree of neurological damage exhibited significantly reduced duration of turning/rotating and fingering (Ruff et al., 1984). The present study extends these previous findings in two ways. It revealed motor delays by 6 months corrected age, earlier than reported in previous work (Ruff, 1984; Kopp, 1976), and just at a time when the forms of exploratory behaviours described here are emerging. In addition, delays were apparent in ELGA infants who were quite homogeneous for gestational age and neurologically healthy.

Furthermore, since we found a significantly lower manual and higher visual engagement in ELGA infants matched for their corrected age with respect to their FT peers, it appears that ELGA infants do not take advantage of their additional post-natal experience, nor do they reach the same motor developmental level of FT infants when they are matched for neurobiological maturation. Being exposed too early to post-natal environmental stimuli may not necessarily accelerate neuropsychological development. Rather, it may result in delayed or atypical developmental trajectories (Sansavini, Guarini & Caselli, 2011).

4.2. *Links between manual exploration and eye-hand coordination in ELGA infants*

Our results suggest that ELGA infants' engagement with objects at 6 months is delayed. Since all manipulative skills, both manual and oral, require oculo-motor coordination, the delay observed in manipulative skills maybe related to a delay in eye-hand coordination. Although the mean scores of the ELGA group on the Griffiths Scales fell within the typical range, they were significantly lower than those of their FT peers, not only for general developmental quotient and the performance subtest, but also for the eye & hand coordination subtest. Furthermore, eye & hand coordination was positively correlated with manual object engagement, whereas it was negatively correlated with visual engagement and, in particular, with visual no act. Our data thus seem to support the hypothesis that ELGA infants' difficulty in eye-hand coordination underlies their delays in object exploration. Finally, there was a positive correlation between active manipulation and the general developmental quotient. Our findings bring further evidence to an hypothesis proposed in a previous study (Ruff et al., 1984) showing that lower levels of manipulation in preterm infants at 9 months were related to lower cognitive scores at 24 months, which may reduce opportunities to gather information about object properties and impact subsequent categorization and language processes.

4.3. *Limitations*

Although this study has contributed to our understanding of early object exploration and fine motor abilities in ELGA infants, a note of caution regarding the interpretation of the findings is in order. First, our focus on infants' abilities precluded examination of parents' interaction style. The role of the mother is critical in dyadic interactions. Previous studies have shown that the mothers of preterm infants tend to be more controlling of infants' behaviours than mothers of FT infants (Forcada-Guex, Borghini, Pierrehumbert, Ansermet, & Muller-Nix, 2011; Wijnroks, 1999). Furthermore, reciprocal co-regulation with joint attention is generally maintained for shorter periods in ELGA than in FT mother-infant dyads (Sansavini et al., 2015). In the present study, mothers played a key role in the object presentation phase, when they were asked to hold the object in order to show it to the infant. It is possible that the greater proportion of time spent by the ELGA infants in that phase may be related to the greater proportion of time mothers of ELGA infants spent holding the objects, which could in turn affect the infant's tendency to explore. However, we found that ELGA infants were significantly slower than FT infants in movement planning and in reaching for and grasping the object. Therefore, rather than potentially limiting preterm infants' exploration skills, mothers' holding behaviour may be an adaptive and compensatory response to the specific difficulties in organizing the movements towards the objects posed by the infant's immaturity (Levy-Shiff, Sharir & Mogilner, 1989). More consideration of maternal behaviour (e.g. mothers' actions on the object, verbal comments) should be included in further research to shed additional light on infants' behaviour.

Second, in addition to examining motor and cognitive abilities using standardized assessments, other abilities, such as postural and neuromuscular control, attention, and their relationships with manual exploration require further investigation.

Third, we observed infants at a single time point, but longitudinal assessments are required for a more complete understanding of developmental risks faced by ELGA infants due to their early motor delays. As mentioned above, several studies have found a relationship between both the quantity and the quality of manipulation at an early age and later cognitive outcomes both in typical (Ruddy & Bornstein, 1982; Yarrow et al., 1975) and atypical development (Ruff et al., 1984). We found a concurrent relationship between the two domains at an age when exploration is emerging. Monitoring this link at subsequent ages may provide additional evidence for the hypothesized relationships between motor exploratory abilities and cognition.

4.4. *Clinical implications and future directions*

The results of this study have clinical implications for evaluation and intervention programs designed for ELGA infants. Although standardized assessments provide useful measures for clinical purposes, they may not be sensitive enough to capture individual differences in neurocognitive functioning or to predict outcomes in that domain (Lobo & Galloway, 2013; Vohr et al., 2012; Hess, Paps, & Black, 2004). Observing motor schemes as they emerge allows the collection of more detailed measures of the infant's functioning that may be correlated with general and specific psychomotor measures, while adding detailed information about the strengths and weaknesses of the individual infant. Along these lines, specific rehabilitation programs can be implemented in order to intervene at the right moment with the right behavioural targets. Based on our results, intervention tailored to ameliorate early-appearing motor delays may lessen the potential cascading effects of these delays on later-emerging skills.

Conflict of interest

The authors report no conflicts of interest.

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