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ABSTRACT

In the present study, infants between 4 and 6 months of age were observed in daycare centers, either on their own or in the presence of another infant. Our goal was to explore the potential continuity between motor activity observed in early social situations and communication development. In order to investigate the influence of body posture on the opportunities of interaction with social environment, we also compared two conditions: infants were lying on a playmat or seated in bouncers. Our results suggest that infants modified their posture, movements and gaze behavior in dyadic situations compared to situations alone, reflecting a *multimodal social tropism.* Moreover, infants' positioning influenced the modality they engaged in the relationship with the other. This work highlights the need to analyse multimodal characteristics of interactions and to add posture variations as a key variable to better understand how infants develop communicative intention toward their peers.

1. Introduction

Motor development appears interrelated with communicative development from infancy (Iverson, 2010), whether it finds its expression in behavioral or physiological rhythmic synchronization, imitation processes or through the emergence of goal-directed actions. This relationship seems to rely on a developmental continuity between specific motor and communicative behaviors, involving features of intentionality, for example between the action of reaching for an object and pointing gestures. The multimodal nature and dynamics of language acquisition, in particular if we focus on the role of gestures in social interactions (e.g., in children: Perucchini et al., 2022; in adults: Hostetter & Alibali, 2010), also invites researchers to consider motor function as a key resource for the development of communicative skills. The aim of our study was to investigate how infants' motor behavior may shape the emergence of communication in the rarely studied context of interactions between peers at 4–6 months of age, a period during which this communicative repertoire may show the first signs of intentionality. In parallel, we addressed the question of the adult's influence on this development through the use (or not) of childcare equipment, which widely influences body posture and the opportunities of exploring the environment.

From their first days of life, newborns have the ability to coordinate their motor movements with external rhythms, through different modalities. The rhythm of their arm and leg movements can for instance synchronize with the dynamics of adults' speech (Condon & Sander, 1974), facial expressions and gaze directions (Trevarthen, 2011). Infants can also synchronize their vocalisations with the rhythm of their partner's signals, whether the latter involve auditory and/or tactile modalities (Northrup & Iverson, 2020;

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Provasi et al., 2014). This sensori-motor synchronization is of great importance for the development of social interactions (Bell, 2020), leading to early forms of conversations with caregivers. Infants are also able to reproduce various facial and finger movements modelled by the adult, for example tongue protrusion, from their first weeks of life. This has been defined as neonatal imitation in the milestone study carried out by Meltzoff and Moore (1977) in infants between 12 and 21 days of age. Although there has been long-standing controversy over the claim that newborns imitate, due to the great variability in the procedures used and the data itself (Slaughter, 2021), the development of imitation is considered as a precious support for communication and social learning.

In addition to responding to the partner's actions, young infants can initiate previously imitated movements during social interactions (Nagy & Molnar, 2004). These motor sequences were found to be accompanied by repeated eye contact and heart rate deceleration – whereas imitation response was accompanied by heart rate increase. The authors have suggested that this pattern could characterize response-seeking behavior from the infants, reflecting their capacities to actively sustain some attentional dialogue with the adult. It is generally agreed that this very early relationship between motor and communicative functions is mediated by the existence of common neuronal networks (Rizzolatti & Sinigaglia, 2010) and by the interdependent maturation of these two systems (Iverson, 2010). Mirror neurons have been described as the ultimate example of this connection between motor function and communication (Rizzolatti & Sinigaglia, 2010), allowing social resonance from which infants can build communicative skills, including language (Salo et al., 2019).

Later on, infants' motor activity still constitutes a valuable indicator of their exploration of the physical and social environment. Jover et al. (2019) have recently shown that foot, hand, and head movements of 6-month-olds reflected the interaction dynamics with the mother, in the context of an experimental design alternating silent and singing phases. Infants' motor activity, head movements in particular, was found to decrease when the mother sang and to increase when she stayed silently smiling at her child. This result was suggested to reflect infants' attentional engagement during dyadic interactions, although there was much interindividual variability for foot and hand movements. Infants' motor activity also seems to be modulated by the distance from the partner during the interaction and by his/her identity: the frequency and mean velocity of infants' foot and face movements for example decrease when a stranger sings at a distance, whereas they tend to augment with the mother (Scola et al., 2015).

In addition, using body motion sensors and eye-tracking in infants, Robertson and his colleagues have highlighted the coupling between spontaneous body movements and looking behavior. Rapid bursts of lateral head movement were found to precede shifts of gaze during free looking in 3-month-olds (Robertson et al., 2007), thus possibly facilitating visual exploration and the development of attentional capacities. This may be of particular importance in social contexts, as infants come to experience more complex visual interactions with others. Gaze behaviors of mothers and infants indeed become increasingly coordinated over the first year of life (Northrup & Iverson, 2020), a phenomenon regarded as bidirectional, i.e. supported by both mothers and infants. This dyadic coordination relates to the concept of joint attention: individuals are able to focus at the same time on the same external object or event, and can therefore respond to and/or direct the overt visual behavior of a partner. This is a fundamental step in communicative development (e.g., Cochet & Byrne, 2016), setting in during the second half of the first year (Bard et al., 2021). Such a common ground is the prerequisite for joint actions, in which each partner benefits from a joint outcome and/or from the interaction in itself (Cochet & Guidetti, 2018).

Such data, demonstrating how infants' motor activity interweaves with their involvement in interactive episodes, can be interpreted in the framework of embodied cognition (Robertson & Johnson, 2009; Smith & Gasser, 2005; Thelen, 2000), which emphasizes the interplay between the individual's sensorimotor abilities, in constant interaction with the environment, and cognitive development. More precisely, Kee (2020) has proposed that "changes in the infant's body, along with the new prospects for perception and action that such changes entail, condition higher order cognitive achievements in abstract thought, imagination, communication, and social cognition" (p.136). Body movements can be regarded in this perspective as a repertoire of communicative potential: although not necessarily associated with communicative intention per se, they may provide the "interactive 'triggers' for caregiver responses" (Salter & Carpenter, 2022) and thus contribute to the social scaffolding upon which infants develop multimodal language (see also Matthews et al., 2012). Goal-directed social actions may indeed emerge gradually through the exercising of motor function and in close relationship with the constant influence of social environment. Clearly, the partner's reactions play a key role in this process: by interpreting and providing a response to the infant's motor behavior, verbal inputs in particular (Chang et al., 2016), the adult frames the emergence of meaning within the interaction (Bruner, 1990). Mothers' verbal responses as their 13-month-olds shared an object with them were for example shown to vary as a function of infants' locomotor status (crawler or walker), which impacted the form of infants' object bids (stationary or moving). Mothers of crawlers were twice as likely not to respond as were mothers of walkers and the latter responded with action directives (i.e., suggesting to perform an action with the object) more often than mothers of crawlers (Karasik et al., 2014).

The significant relationship between motor skills and the development of socio-cognitive abilities (see also Leonard & Hill, 2014) appears thus mediated by the adult. Similarly, the development or ritualization (Tomasello & Call, 1997) of "purely" motor actions into communicative signals has been previously described in the literature, for example in reference to the development of pointing gestures (Cochet et al., 2014). Changes in the characteristics of reaching movements were indeed reported in 8-month-olds depending on the social context: when the adult was present, the frequency and intensity of reaching for out-of-reach objects increased, whereas infants did not reach for these objects when they were alone (Ramenzoni & Liszkowski, 2016). The authors then indicated that infants "use instrumental actions for communicative purposes", which could be considered as a prerequisite for the emergence of imperative pointing. This example relates more globally to the development of intentional communication: the production of an intentional signal relies on the presence of a social partner, in association with attention-getting and visual orienting behaviors. The signal is also likely to be repeated and/or adjusted (including with other modalities) until the recipient's reaction is regarded as satisfactory (e.g., Leavens et al., 2005). Such criteria defining an explicit communicative intention can hardly be validated before 8 months of age, but as previously described, the reciprocal and multimodal adjustments that characterize early interactions between infants and their caregivers may constitute pre-intentional forms of communication, providing in the first months of life the basis for developing intersubjective intentionality and symbolic representations (Beebe et al., 1997; Trevarthen, 2011).

The relationship between motor function and communicative development also rests upon the different opportunities given to infants for exploring the surrounding world. Postures play a major role in this dynamics. In particular, developmental and material constraints impact infants' perception of the environment (Franchak, 2019), offering more or less possibilities of multimodal exploration (Thurman & Corbetta, 2019). Posture variations influence for example gaze orientation: looking at a social partner's face is facilitated by seated postures, and all the more so if the child is carried in the arms or placed in a highchair, compared to lying postures. As the child is raised closer to the adult's height, direct gaze toward the partner becomes indeed less demanding, leading to easier opportunities of joint attention (Franchak et al., 2018). Perception of facial expressions is also facilitated. In addition, seated postures favor manual interactions with objects (Soska & Adolph, 2014) and gradually allow the production of communicative gestures, which is itself linked to language development (e.g., Iverson & Goldin-Meadow, 2005). This developmental cascade has been highlighted in longitudinal studies showing for instance a significant correlation between the emergence of independent sitting between 3 and 5 months of age and higher receptive vocabulary size at 10 and 14 months of age (Libertus & Violi, 2016). Cultural practices also influence this developmental cascade: the variability in mothers' proximity to infants and in everyday opportunities to practice sitting and/or use postural support was found to significantly impact 5 month-olds' sitting proficiency in five different countries (Karasik et al., 2015). Globally, cross-cultural comparisons reveal that installation supports are largely used in occidental cultures (Pin et al., 2007), which may explain the smaller proportion of time spent each day in independent sitting positions (i.e., without any support), compared to African infants of the same age (Bril & Sabatier, 1986; Franchak, 2019). Everyday familial practices also vary of course within a same country, playing a significant role in infant motor development.

The aim of the present study is two-fold. First, we propose to explore the continuity between motor activity observed in early social situations and the development of intentional communication by analyzing whether infants' spontaneous motor behavior is influenced by the presence of a peer. The vast majority of developmental studies involving infants before their first birthday focus on interactions with adults, the mother in particular. Here we analysed peer interactions in an attempt, to some extent, to free the observation from adult scaffolding and familiar dyadic routines. Moreover, while a great deal of research on the emergence of intentional communication has focused on gestures from around 9–11 months of age, we aimed to investigate in earlier stages how motor behavior develops into goal-directed actions or even into more structured communicative signals (Jover et al., 2019). In addition, since the multimodal characteristics of social interactions can be impacted by posture variations, a second objective was to take infants' positioning into account and determine its potential influence on the interactions. We used installation supports to manipulate positioning and thus compare two conditions: infants on a playmat or in bouncers.

We hypothesized, first, that motor intentionality may act in the service of social interactions, i.e., that infants will modify their posture, gaze and movements in dyadic situations compared to situations alone. Second, we expected to observe an influence of infants' installation equipment on the frequency and variability of motor behavior. Finally, we also hypothesized interaction effects: the presence of a peer will impact infants' motor behavior differently depending on their positioning, i.e., the bouncers may foster visual interactions and the playmat may stimulate particularly the production of hand and foot movements.

2. Method

2.1. Participants

In total, 13 infants (6 girls and 7 boys) aged between 4 and 6 months-old (M = 4 months 27 days; SD = 25 days; min = 3 months 25 days; max = 6 months 11 days) were observed in their daycare centers, in four different situations: (i) infant alone, lying on a playmat, (ii) infant alone in a baby bouncer, (iii) infant with a peer, both on the mat, (iv) same dyad, each one in a baby bouncer. All infants, recruited in 5 different municipal daycare centers, met the following criteria: they were born at full term and raised in monolingual French middle-class families. In addition, the experimenter, who is also a pediatric physiotherapist (FC), observed beforehand each infant's motor activity for a period of 15–20 min to exclude the possibility of atypical motor development. Several factors were assessed based on motor evaluations proposed by pediatric clinicians (Amiel-Tison, 1999; Le Métayer, 2009), including for example postural control, range and quality of motor repertoire, persistence of reflexes, postural asymmetries, etc. No infant was excluded from our final sample based on these observations.

One infant, alone in this age range in his daycare center, was observed with an older peer (7 months 4 days), who was not included in the final data set. Moreover, due to the absence of some infants, the dyadic situations could not be observed for two participants (one dyad) on the playmat and for four participants (two dyads) in the bouncers.

All parents gave their written informed consent for the participation and videorecording of their children. This research received ethics approval from Toulouse University Human Research Ethics Committee (Reference Number: IRB 00011835–2019-11-26-198).

2.2. Procedure

Observations took place in the daycare centers, in the playrooms that were familiar to the infants. A playmat (approx. 2*2 m) surrounded by some cushions was used to define the observation area, apart from the other children. All the proximate toys and visual stimulations (e.g., play arch, poster, mirrors) were removed or masked. After the preliminary observation (see above), participants were observed in the presence of the researcher, seated behind the camera, and a familiar childcare assistant, who was nonetheless asked not to interact with the infants, unless they started crying or showed any signs of fussiness. The four situations were proposed successively, in a counterbalanced order across the participants. The initial objective was to record 5 min per situation, but this duration was reduced when infants were no longer in quiet alert states (see the Results section for details). If the four situations could not be observed on a single day (which concerned four infants), a second recording took place at the latest the following week.

On the playmat, infants were lying on their backs, perpendicularly to the camera. In the dyadic situation, participants were observed in the same position, apart from one another by a distance of 20 cm in a top-to-tail configuration (see Fig. 1). Each infant was thus positioned at the other's right, the shoulders aligned with the partner's hips, which allowed them to touch and look at each other. In the baby bouncers, infants were placed in the same position as in the playmat situation, perpendicularly to the camera. They were leaning at a 45-degree angle to the floor, secured with a comfortable strap. In the dyadic situation, similar bouncers were used within the same dyads, positioned in opposite directions so that infants could see each other and touch, each one being in the other's right hemifield (see Fig. 1). The distance between participants was thus similar in both situations (playmat and bouncers).

Questionnaires were proposed to the parents and daycare staff at the end of the study in order to assess global variables like the number of siblings, type of family structures and daily routines likely to influence infants' motor and social development (e.g., use of different positioning equipment, time spent on the ground with free movements, time spent held in the arms, etc. See Franchak, 2019). None of these variables was found to influence the dependent measures; given the low sample size (only 8 completed questionnaires could be collected) and the exploratory nature of the study, we will not present these data in the present article.

2.3. Analyses

We established a behavioral repertoire based on the existing literature and on our own observations of infant behavior, especially given our expertise in pediatric physiotherapy (FC). The repertoire included six variables: (1) gaze direction, (2) infants' postures, (3) general body movements, (4) hand and foot movements, (5) facial expressions, and (6) vocalisations. All modalities of these variables are described in Table 1. Postures and movements (variables 2, 3 and 4) were defined based on Prechtl General Movement Assessment (Prechtl, 2001), a neurodevelopmental tool mainly used to identify infants at risk for neuromotor deficits through the evaluation of qualitative and quantitative aspects of motor repertoire, from birth to 20 weeks of age (see also Einspieler et al., 2016). For gaze direction, facial expressions and vocalisations, we identified general modalities that did not request the use of technological tools or specialized software in order to facilitate data collection. Note that the initial repertoire included additional modalities, which were either suppressed due to low occurrences (e.g., ventral decubitus position) or regrouped into single homogenous modalities (e.g., self-touching movements were initially divided into touching one's own foot and touching other body parts). All the behavioral modalities of the final repertoire were observed in at least half of the participants in at least one of the four situations. The recordings were analysed with ELAN software (https://archive.mpi.nl/tla/elan).

The asymmetry of posture, defined as a preferred orientation toward one side of the body relative to its midline (i.e., left/right lateral decubitus or dorsal decubitus with head turned left/right) was assessed using individual laterality index. This index corresponds to the ratio of the difference in the duration of right- and left-sided postures on the total duration of the considered postures. This index varies between −1 and 1, a positive sign reflecting a right-sided preference and a negative sign a left-sided one. The absolute value of the index reflects the intensity of the preference. The same index was used to evaluate the asymmetry of hand and foot movements, defined as the preferred use of the left or right limb for the modalities involved (see Variable 4 in Table 1). Our objective, through the analysis of these asymmetries, was to assess infants' potential orientation and sensitivity toward their peers.

2.4. Observation reliability

First, all the video recordings were coded by the main observer (FC) based on the final repertoire. Second, 20 % of the data (i.e., 8 recordings, including 2 for each situation) were coded by another researcher in order to calculate Cohen's Kappa coefficients for each variable. Coefficients were found to vary from 0.73 for general body movements to 0.96 for vocalisations. Discrepancies between the

Fig. 1. Positioning in dyadic situations, on the playmat and in the baby bouncers.

Table 1
Behavioral repertoire.
A refers to the focal infant and B to the infant partner in the dyadic situations.

Variables	Modalities
(1) Gaze direction: the infant directs his/her gaze at a specific referent for at least 1 s.	Infant's own hands Partner's hands and/or face Partner's other body parts Childcare assistant Camera/Researcher Other direction or not identified
(2) Posture: body position held for a minimum of 1 s.	Supine (dorsal decubitus), head turned right Supine (dorsal decubitus), head turned left Right lateral decubitus Left lateral decubitus
(3) General body movements: movements of the 4 limbs and trunk, lasting a minimum of 0.5 s.	Trunk extension Rolling of pelvis and lower limbs/trunk flexion Hip flexion with stretched legs Right foot kicking Left foot kicking Right arm swiping Left arm swiping Fidgetys Excitation burst Wiggling-oscillating
(4) Hand and foot movements: specific movements of 1 and/or 2 hands or 1 and/or 2 ft, lasting a minimum of 0.5 s.	Hand-to-mouth contacts Other self-touching gestures Contact initiated with the partner's hand Contact initiated with the partner's face Contact initiated with other parts of the partner's body Reaching gestures (without contact) Grasping Quick and dense finger movements
(5) Facial expressions	Smile Crying Lips movements
(6) Vocalisations	Any production of vocal sounds different from crying

two coders were resolved through discussion and joint observation of the videos.

3. Results

3.1. Sample description

All the 13 participants were observed in at least one of the dyadic situation, but only 7 infants could be observed in the four situations. Final data included 11 infants in the playmat situations (alone and in dyads) and 9 infants in the bouncer situations (alone and in dyads). The mean duration of observations was 3 min 49 s (SD = 1 min 49 s; min = 43 s; max = 6 min 34 s); Student's paired t-tests did not reveal any significant difference between the four situations (see Table 2). Analyses were however performed on behavioral frequencies and on proportions of durations to standardize the comparisons. The significance threshold was set at $p < .05$.

Results are organized into several groups of variables, from postural behavior to gaze direction, in order to determine to what extent each behavior is influenced by the presence of a partner and by positioning, and/or by the interaction between these two factors.

3.2. Postural behavior

All infants spend most of the time in a supine position, with head turned to the right or to the left. On the playmat, the lateral decubitus position was also observed for 7 infants in the situation alone and 4 infants in the dyadic situation. As a consequence, the

Table 2
Mean durations of observation depending on the situation.

Situation	N	Mean duration of observation	SD
1 Playmat alone	11	3 min 54 s	1 min 50 s
2 Bouncer alone	9	4 min 26 s	1 min 14 s
3 Playmat dyad	11	2 min 59 s	1 min 55 s
4 Bouncer dyad	9	4 min 8 s	2 min 4 s

changes of postures seemed more frequent on the playmat than in the bouncers, with one change every 16 s on average on the playmat ($SD = 0.043$) and every 26 s in the bouncers ($SD = 0.024$), although this difference did not reach significance level ($t(13) = 1.810$, $p = .09$).

When they were on their own, infants spent an equivalent amount of time in right- and left-sided postures (M right = 47 % of time, $SD = 0.32$, $N = 20$), whereas right-sided postures were more frequent than left-sided ones in dyadic situations (M right = 74 % of time, $SD = 0.26$, $N = 20$). The calculation of laterality index confirmed a significant difference between the two situations ($t(19) = 3.256$, $p < .001$), with a clear right-sided preference in the dyadic situation ($M = 0.481$, $SD = 0.48$, vs. $M = -0.067$, $SD = 0.64$ in the situations alone), i.e., reflecting a postural orientation toward the partner.

3.3. General movements

Infants were found to produce on average 1 movement (all categories of movement considered) every 9 s in the situations alone ($M = 0.11$, $SD = 0.10$) and 1 movement every 5 s in the dyadic situations ($M = 0.22$, $SD = 0.39$), but the difference was not significant ($t(19) = 1.26$, $p = .22$). The differences were not significant either when analyses were performed on each category of movements. The presence of a partner was not found to significantly impact the laterality of general movements either ($t(19) = 0.84$, $p = .41$).

Moreover, infants' positioning did not influence the frequency of general movements ($M = 0.17$, $SD = 0.21$ in the playmat situations; $M = 0.22$, $SD = 0.43$ in the bouncer situations; $t(13) = 0.38$, $p = .71$). However, the frequency of trunk flexions was found to decrease in the bouncers compared to the playmat situations ($t(13) = 2.161$, $p = .05$), with an average of 1 flexion every 18 s on the playmat ($M = 0.054$, $SD = 0.076$) and 1 flexion every 77 s in the bouncers ($M = 0.013$, $SD = 0.023$).

3.4. Hand and foot movements

The frequency of hand and foot movements was globally influenced by infants' positioning ($t(13) = 2.56$, $p = .02$), with an average of 1 movement every 7 s in the playmat situations ($M = 0.15$, $SD = 0.072$) and 1 movement every 12 s in the bouncer situations ($M = 0.082$, $SD = 0.039$). Further analyses revealed that this difference was only observed in the dyadic situations ($t = 4.082$, $p < .001$, see Fig. 2), mainly due to contact movements directed toward the partner (i.e., contact movements included 3 modalities: touching the

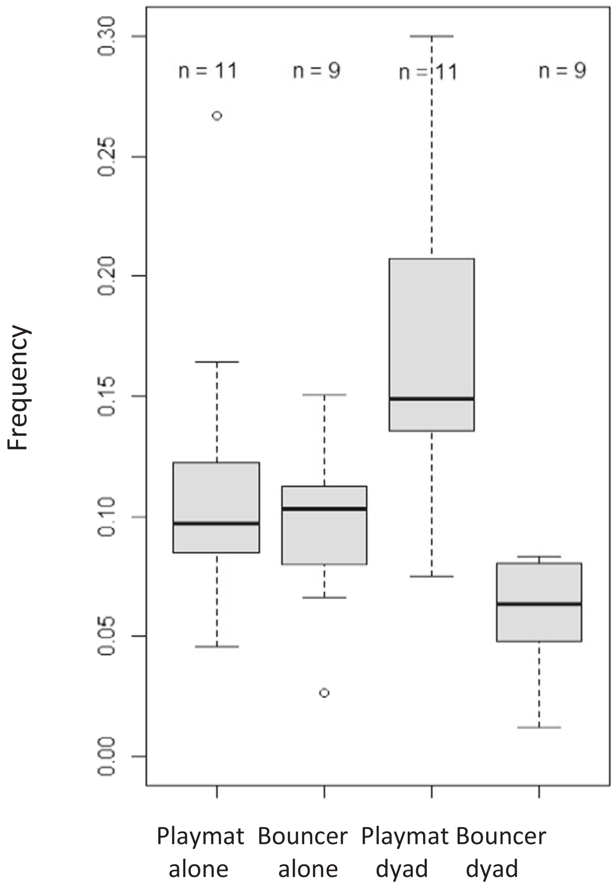

Fig. 2. Frequency of hand and foot movements in the 4 situations.

partner's hand, face other body parts). In the playmat situation, all infants initiated a contact with the partner's body and 91 % of them also produced at least one of the other contact modalities. Contact movements were produced on average every 27 s ($M = 0.037$, $SD = 0.049$). The production of these movements was not correlated between partners of the same dyads ($R = 0.25$, $p = .69$), although a tendency was observed for contact movements on the partner's body ($R = 0.804$, $p = .10$). By contrast, contact movements were not produced by any participant in the bouncer situations.

Similar analyses focusing on the movements without contact showed no significant effect of positioning nor of the partner's presence. These movements were produced on average every 9 s on the playmat alone ($M = 0.114$, $SD = 0.059$, $N = 11$), every 10 s in the bouncer alone ($M = 0.097$, $SD = 0.037$), every 5 s on the playmat in dyad ($M = 0.183$, $SD = 0.09$) and every 16 s in the bouncer in dyad ($M = 0.059$, $SD = 0.023$).

Moreover, the use of a global laterality index for all movements revealed a right-handed asymmetry in dyadic situations ($M = 0.34$; $SD = 0.59$), different from the pattern observed in the situations alone ($M = 0.15$; $SD = 0.52$; $t(18) = 3.947$, $p < .001$). The distinction of specific index for each movement highlighted again the role of contact movements in this difference, since their laterality index reached an average of 0.84 ($SD = 0.39$). The asymmetry of movements without contact was not significantly influenced by the presence of a partner ($M = -0.15$; $SD = 0.52$ in the situations alone; $M = 0.053$; $SD = 0.55$ in the dyadic situations; $t(19) = 1.76$, $p = .09$).

3.5. Gaze direction

All infants directed their gaze toward the partner in the dyadic situations, representing on average 23.4 % of total time ($SD = 19.1$ %) toward the partner's body and 34.8 % of total time ($SD = 27.4$ %) toward the partner's hands and/or face. These gazes were produced at the expense of gazes toward the camera ($M = 18{,}1$ % of total time; $SD = 17.0$ % in the situations alone vs. $M = 9.2$ %; $SD = 8.4$ % in the dyadic situations; $t(19) = 2.09$, $p = .05$). Durations of gazes directed toward the referent and toward the infant's own body were equivalent in the two situations. Moreover, looking at the partner seemed to be a reciprocal behavior, as revealed by a positive and significant correlation between the frequency of gazes directed to the partner within dyads (proportions of duration: $R = 0.86$; $p = .003$).

When considering the different positionings, we found no significant difference in the duration of gazes directed toward the partner between the playmat and the bouncer situations (respectively $M = 24.2$ %, $SD = 17.5$ %; $M = 33.0$ %, $SD = 28.6$ %; $t(6) = -1.03$, $p = .31$). However, we observed a contrast between the gazes directed toward the partner's body and those directed toward the partners's hands and/or face: while there was no difference between the situations on the playmat and in bouncers for the first variable ($t(6) = 1.53$, $p = .18$), infants were found to look more frequently at the partner's hands and/or face in the bouncer situation than in the playmat situation ($t(6) =2.48$, $p = .05$, see Fig. 3). The distinction between these variables also showed that the correlations between the frequency of the partners' gazes within dyads were only significant in the bouncer situations (gazes toward the body: $R = 0.97$, $p = .03$; gazes toward face/hands: $R = 0.98$, $p = .02$), and not in the playmat situations (gazes toward the body: $R = -0.38$, $p = .95$; gazes toward face/hands: $R = 0.66$, $p = .23$).

3.6. Other variables

First, there was no simple effect of the partner's presence on the production of facial expressions (in terms of frequency or duration). However, further analyses distinguishing the different positionings showed some interaction effects: the total duration of facial expressions (all modalities included), as a proportion of total observation, was more important when infants were on the playmat in dyads ($M = 0.12$, $SD = 0.11$) than when they were on the playmat alone ($M = 0.02$, $SD = 0.02$; $t(6) = 3.03$, $p = .03$). In the bouncers, there was no significant difference in the duration of facial expressions when infants were alone ($M = 0.033$, $SD = 0.02$) and in dyads ($M = 0.047$, $SD = 0.031$; $t(6) = 1.48$; $p = .17$). Analyses of the frequency of facial expressions and analyses focusing on each facial expression separately (see Table 1) did not show any significant difference between the 4 situations.

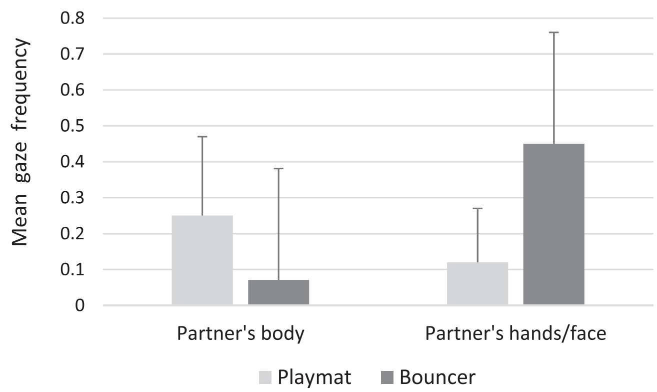

Fig. 3. Mean Frequency of gaze directed toward the partner's body and the partner's hands or face.

Moreover, we did not find any significant correlation between the frequency of facial expressions and the gazes directed toward the partner, but we did find a positive correlation in the bouncer situations between the frequency of smiles and the duration of gazes toward the partner, both toward the body ($R = 0.77$, $p = .02$) and toward the face/hands ($R = 0.81$, $p = .008$). These correlations were not significant in the playmat situations (gazes toward the body: $R = -0.15$, $p = .65$; gazes toward face/hands: $R = -0.28$, $p = .79$).

Second, on average, infants produced 1 vocalisation every 37 s when they were alone on the playmat ($M = 0.028$, $SD = 0.029$), 1 vocalisation every 50 s alone in the bouncer ($M = 0.020$, $SD = 0.017$), 1 vocalisation every 42 secondes in dyads on the playmat ($M = 0.024$, $SD = 0.020$), and 1 vocalisation every 37 secondes in dyads in the bouncers ($M = 0.027$, $SD = 0.022$). The analyses did not reveal any effect of the partner's presence on the frequency or duration of these vocalisations. Moreover, there was no significant correlation between the partners' respective vocalisations, in terms of frequency, but results revealed a negative correlation for the duration of vocalisations of the partners in the bouncer situation ($R = -0.96$, $p = .04$). There was a similar tendency in the playmat situation ($R = -0.65$, $p = .06$).

4. Discussion

In the present study, we described the motor behavior of 4- to 6-month-old infants placed in interaction situations and in different positionings, in their daycare centers. We conducted a multimodal analysis focusing on posture, general body movements, more specific hand and foot movements, facial expressions, vocalisations and gaze directions. We thus aimed at exploring the relationships between motor function and communication, first, in situations that are not characterized by the asymmetry of interactions between infants and adults, and second, in a developmental period that has somehow been overlooked in the scientific literature compared to the end of the first year, traditionally associated with the emergence of intentional communication (Tomasello et al., 2007). Our results, although they have some limitations that warrant consideration (see below), suggest that infants' motor behavior is influenced both by the presence of a peer and by postural variables induced by the environment. This section endeavors to illustrate how infants' social and physical world may act in concert to offer key milestones for the development of communication.

The presence of a peer has had several effects on infants' behavior, which could be synthesized in this exploratory work as a multimodal social tropism, i.e., infants directed their gaze and oriented their posture and movements toward the other infant. More precisely, while infants on their own spent an equivalent amount of time in right- and left-sided postures, we observed a right-sided preference for postures in dyadic situations, the other infant being systematically placed on the right. General body movements were not characterized by significant asymmetries, but hand and foot movements also showed a right-sided asymmetry, largely due to reaching gestures and contact gestures, but not exclusively. Infants thus seem to orient their motor activity toward the other, whom they may consider as a social partner or at least as a source of interest. Even if patterns of laterality are generally neither stable nor strong in the first months of life (Cochet, 2016), more precise measures of individual motor asymmetries would be necessary to understand these laterality effects. It would also be important in future studies to vary the infants' positions to determine whether the presence of a partner on the left side elicit left-sided postures and gestures.

Moreover, the frequency of general movements and the frequency of hand and foot movements were not significantly impacted by the presence of a partner when we analysed simple effects. Including the different positionings in the picture nevertheless revealed that infants produced more hand and foot movements when they were on the playmat in the presence of a peer. Again, this was largely due to reaching gestures and contact gestures, which were produced (in terms of movements initiation) by all participants and tended to be correlated between partners of the same dyads when they involved contact on the body (this was not the case for contact movements on the partner's face or hands, which were more scarce). The tactile modality was only engaged in the playmat situations, although infants were within direct reach of the partner in both situations. Initiating contact movements in the bouncers may have been more demanding, compared to the playmat situation, as it required some degree of trunk bending. The frequency of trunk flexions was indeed lower in the bouncers than in the playmat situations, even if the overall frequency of general movements was not significantly influenced by infants' positioning. Reaching movements were also only observed in dyadic situations on the playmat. The question remains if this result may reflect infants' emerging sensitivity toward their peers, namely if the above-mentioned greater ease of movement compared to the bouncers is also accompanied by some degree of social intentionality. Eight-month-olds were for example reported to reach toward out-of-reach objects only in the presence of adults (Ramenzoni & Liszkowski, 2016), suggesting early forms of intentional request gestures. The setting of the present study did not include any object and reaching movements were always directed toward the partner, but it might be informative in future research to add a condition with attractive objects, to gain more understanding on the referential and intentional nature of these manual movements. In particular, it would help determine whether the greater freedom of movements on the playmat has led to contact movements happening first by chance, before being repeated as a support for peer interactions. The dynamic properties of a movement directed toward an external object may then differ from a movement directed toward the partner.

Visual behavior provides another clue of this social attraction: in dyadic situations, infants spent on average more than half of the time gazing toward the partner (including gazes toward the body and toward the hands and/or face). Intentional control of visual attention is effective from four months of age, reflected in the ability to inhibit and select specific visual stimuli (Mundy & Jarrold, 2010). The present results thus suggest that infants orient specifically their interest in the presence of a peer, a fundamental prerequisite for the development of joint attention. Moreover, the distinction between the gazes directed toward the partner's body and those directed toward the partner's hands and/or face has revealed that infants looked more frequently at the partner's hands and/or face in the bouncer situations than in the playmat situations (the frequency of gazes toward the partner's body was similar in both situations). The frequencies of gazes directed toward the partner within dyads were also strongly correlated in the bouncer situations, highlighting early forms of reciprocity in social attention. In the playmat situations, the correlation was not significant. Effect of posture on the ability to follow and process visual stimuli has long been documented, even in newborns (Fredrickson & Brown, 1975). Our findings are in line with previous studies focusing on child-mother interactions, showing that the frequency and duration of gazes toward the mother are more important when infants are in installation equipment like bouncers or high chairs than when they are in free motor situations (Deák et al., 2014; Yu & Smith, 2013). Seated postures (or "on-shoulder" position) facilitate the perception of a « social visual field », thus supporting the motor cost of initiating and sustaining peer interaction (Franchak et al., 2018).

The greater coordination of gazes with the partner compared to the playmat situation may also explain the reduced frequency of hand and foot movements in the bouncers, in line with the description of motor inhibition associated with infants' attentional states (Robertson & Johnson, 2009). Previous results have for example shown a decrease in the frequency of infants' motor behavior when their mothers were singing (Jover et al., 2019), a context that recruited their attentional resources. Peer interactions would then also be demanding in this regard, with infants' positioning playing the role of a mediating variable. In addition, the duration of gazes toward the partner was correlated with the frequency of smiles produced by the infant in the bouncers and not in the playmat situations, strengthening the social nature of this behavior.

However, our results did not reveal any effect of the partner's presence on the frequency or duration of vocalisations, which might contradict the hypothesis of infants' social adjustment in dyadic situations. Moreover, we found a negative correlation for the duration of vocalisations within dyads, indicating that the more time an infant spent vocalising, in proportion of the total observation time, the less time did his/her partner. This could be interpreted as a general attentional effect: the perception of the other's vocalisations may represent a focus of interest likely to limit one's own production. Even if the different positionings did not significantly influence the overall frequency of vocal production, this negative correlation was especially strong in the bouncer situations, which required more visual attention resources compared to the playmat situations (see above); integrating the auditory modality could then have been even more demanding, resulting in fewer vocalisations. This result could also be interpreted as evidence of early sensitivity to the rhythmic coupling in social interactions. From 2 months of age, infants indeed begin to engage in proto-conversations with their caregivers, i.e., reciprocal vocal exchanges that involve turn-taking and limited overlaps between the partners (Gratier et al., 2015). This coordination dynamics, which remarkably develops in the first year of life (Hilbrink et al., 2015) and plays an important role in infants' cognitive and affective development (Jaffe et al., 2001), could then also apply to peer interactions. Further analyses will be necessary, however, to describe vocal production in terms of prosodic features such as intonation contour or amplitude modulation and thus search for more subtle differences between the four situations.

More globally, the description of several modalities highlights the need to use finer-grained analyses and go beyond correlational data in future studies. It will be particularly helpful to examine more precisely the temporal sequences and/or simultaneity of the infants' gazes, movements and vocalisations within dyads. The objective would be to further improve our understanding of multimodal interactive contingency between partners (Beebe et al., 2016) and to help define to what extent the "give and take dance" mentioned by Bell (2020) to illustrate parent-infant synchrony also applies to peer interactions. This may also allow us to clarify the development of pragmatic and communicative functions by investigating how infants begin to play an active role in coordinating dyadic interactions, for example through specific changes in gaze patterns as they complete their vocalisations (Colonnesi et al., 2012; Rutter & Durkin, 1987) or specific body movements to help orient their gaze (Robertson et al., 2007).

It will also be necessary in future research to include more participants, first to increase the statistical power of the analyses and enhance the generalizability of the findings and second, to analyse potential developmental effects. Infants between 4 and 6 months of age were considered as a homogenous group in the present study, despite the richness of the changes going on especially in the first year of life. The small sample size thus constitutes a major limitation here. A different yet related limitation pertains to individual factors likely to affect social and communicative development, such as the type of family structures and number of siblings. Although we took these variables into account, the analyses were performed on a very low number of participants, which still leaves open the question of their actual impact on our pattern of results. Indeed, family structure and sibling relationships, as key components of children's social lives, influence parent-child interactions and children's social and cognitive development (Ambert, 2020). Growing up with siblings offers for example a context in which infants experience proximal and ever-present relationships with another child, with direct effects on the developmental interplay between how infants perceive and act on their environment (Smith & Gasser, 2005). These factors should be assessed in a systematic way in infant studies.

5. Conclusion

Infants experience a stimulating social world from birth, even from prenatal life. Their sensitivity to the other's proposals lead to continuously renewed and enriched dialogues with the adult, allowing communicative intention per se to develop. In the present study, we focused on peer interactions, at a period that precedes the intentional use of communicative signals, as an attempt to fill a gap in the literature about infant development. Our results suggest that infants use a multimodal repertoire to orient their posture, gaze and movements as a function of their social partner and also as a function of the physical opportunities in their environment. The interaction between these social and physical variables has revealed a predominance of the tactile modality in free motor situations (on the playmat), while the visual modality takes the leading role in seated positions. More than a binary distinction however, several modalities seem to interact toward an equilibrium so as not to exceed certain motor and attentional costs. Sustained visual attention can for example be associated with fewer movements and tactile signals. As a consequence, it appears crucial to consider multiple modalities in order to analyse infants' engagement in the interaction.

Moreover, including physical constraints in the picture can have important impact on research in developmental psychology, especially given the widespread use of equipment in occidental cultures. The use of seating devices indeed shapes infants' experiences, although the precise effects are complex. It was for instance shown to be associated with lower levels of language exposure in 4- to 6-

month-old infants (Malachowski et al., 2023), but seated postures also allow infants to look more frequently at the partner's face (Franchak et al., 2018), which facilitates episodes of joint attention and may initiate a developmental cascade leading to increased language learning opportunities (Libertus & Violi, 2016). A key factor that may help disentangle these effects may lie in the adult's will to accompany closely infants' motor development, including the onset of independent sitting, and therefore use supports in adapted stages and frequencies.

This exploratory research may also encourage researchers to carry out studies involving interactions between infants, which have been overlooked in the first year of life, whereas infants do experience multiple interactions beyond the familiar mother-child nest. The dynamics of interactions are likely to differ depending on the partner and their attentional states, varying for example in terms of behavior frequency and kinematic properties, context of production (e.g., initiation vs. response), meaning of the signals, etc. The production of pointing gestures is for example less frequent when 12–24-month-olds interact with a peer compared to adult–infant interaction, although infants initiate joint attention in both cases and do not produce gesture in a non-social condition (Franco et al., 2009). Focusing on motor function before the emergence of intentional communication suggests that infants also adjust their behavior to interact with a peer in earlier stages. This is all the more important as this social adjustment may form the foundation upon which later peer affiliations are built (Fabes et al., 2012). In this context, we believe it is necessary to explore the multimodality of interactions, i.e. to include gaze orientation, postures, general body movements as well as more specific hand and foot movements, vocalisations and facial expressions. Our results have shown that infants' multimodal behavior may gradually come to serve social purpose, through the repetition of the interaction and its consequences, suggesting a developmental continuity with intentional communication (Cochet & Byrne, 2016). A longitudinal study involving a larger sample size will allow researchers to confirm (or not) the existence of this predictive relationship.

Finally, the present results open further perspectives for clinical applications in atypical development. It would be valuable to broaden this study and include children with neurodevelopmental disorders in order to identify which modalities are the most preserved during social interactions (i.e., visual behavior, tactile movements, …) and thus work to support their expressions. In particular, parents and professionals in places of early socialization and education may benefit from these studies and then vary infants' experiences of interaction and positioning in relation to motor development.

Statement of ethics

This study protocol received ethics approval from Toulouse University Human Research Ethics Committee (Reference Number: IRB 00011835-2019-11-26-198).

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CRediT authorship contribution statement

Hélène Cochet: Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Conceptualization. **Flore Chéné:** Writing – original draft, Data curation, Conceptualization. **Michèle Guidetti:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors have no conflicts of interest to declare.

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Data availability

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

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