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Newborns' preference for goal-directed actions

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ABSTRACT

The central role of sensory-motor representations in cognitive functions is almost universally accepted. However, determining the link between motor execution and its sensory counterpart and when, during ontogenesis, this link originates are still under investigation. The aim of the present study is to investigate whether at birth this link is already present and 2-day-old newborns are able to discriminate between visual cues indicating goal-directed or non-goal-directed actions. Here, with a preferential looking technique, a hand grasping a ball was the observed movement and we orthogonally manipulated the three factors necessary to successfully reach the goal: (a) presence of the ball, (b) direction of the arm movement, and (c) hand shaping. Results indicated that newborns orient more frequently and look longer at a hand shape for whole hand prehension but only when the movement is directed away from the body and toward the external world. In addition, newborns prefer the away from the body movement only when the object is present. We argue that newborns prefer a movement directed toward the external world only when it may develop into a purposeful movement because of the presence of the to-be-grasped object. Overall, our results support the existence of primitive sensory-motor associations since the first days after birth.

1. Introduction

Much evidence has been collected demonstrating the role that functional identity between motor command and sensory consequences of motor execution plays in cognitive functions (e.g., Rumiati & Caramazza, 2005). There are many examples of sensory-motor neurons in the primate brain, connecting a hand/mouth goal-related action with the sight of the to-be-grasped object (canonical neurons; Rizzolatti & Luppino, 2001) or with the sight or sound of another individual executing that same action (mirror neurons; e.g., Rizzolatti & Luppino, 2001).

What is particularly interesting in the sensory-motor association is that it is based not on the way the action is executed but on its goal (e.g., Rizzolatti & Craighero, 2004). Therefore, if a specific canonical neuron fires during execution of a precision grip, it will fire during the observation of every small object requiring a precision grip to-be-grasped, and not only in relation to the vision of a specific object. Consequently, it has been proposed that sensory-motor representations code the goal of the action, and that their activation allows the brain to fast and efficiently categorize stimuli and events on the basis of previous motor experience, permitting the individual to plan and predict their own action outcomes (Rizzolatti & Craighero, 2004).

According to the hypothesis of the experience-dependent nature of sensory-motor representations, the ability to link motor execution and its sensory-motor counterpart should not to be present at birth because newborns would have no experience of goal-directed hand actions. How-

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ever, a series of experiments using ultrasound imaging contradicts the latter common-sense notion. Apparently, starting already at 14 weeks of gestation, movements are not random but fetuses direct about two thirds of their hand movements toward targets in the uterus – their own faces and bodies, the wall of the uterus, and the umbilical cord (Sparling, Van Tol, & Chescheir, 1999). Furthermore, prenatal behavior shows indications of a proto-integration between different sensorimotor systems. Movements of the hand occur around the mouth with frequent subsequent sucking, movements to specific body parts occur with frequent subsequent molding of the hand around those body parts and movements to the uterine wall are often followed by flattening and sliding of the palm against it. In addition fingering, grasping, and manipulation of the umbilical cord frequently occur (Sparling & Wilhelm, 1993; Sparling et al., 1999). Recently, a study reported a kinematic analysis of fetal movements in uterus (Zoia et al., 2007), indicating that, by 22 weeks of gestation, movements seem to show the recognizable form of intentional actions, with kinematic patterns that depend on the goal of the action. In particular, it was found that, by 18 weeks of gestation, movement duration and time to peak velocity are similar for mouth and eyes. In contrast, by 22 weeks of gestation, the amplitude of peak velocity for movements directed to the mouth is higher than to the eyes, and peak velocity for movements to the eyes is earlier and lower than that to the mouth, suggesting that the fetus "knows" that the mouth is bigger and less delicate than the eyes. Note that movements not directed to a specific goal do not show any obvious kinematic patterning and differ greatly at all gestational ages from those that are goal-directed. These differences suggest the development of a process in which the sensory consequences of a movement are anticipated and used to plan an action related to the nature of the target (Zoia et al., 2007).

Very recently, a kinematic study was performed in five pairs of twin fetuses (Castiello et al., 2010), demonstrating that, by the 14th week of gestation, fetuses display movements specifically aimed at the co-twin and that the kinematic profiles of these movements are similar to those of self-directed movements aimed at the eye-region, the most delicate region of the body. That indicates that movements directed toward the co-twin are the result of motor planning rather than the accidental outcome of spatial proximity. The indication that fetuses treat the co-twin as a special kind of target suggests that in twin pregnancies motor control might extend to incorporate information from intra-pair stimulation (Castiello et al., 2010).

Based on kinematic data, it seems that intrauterine behavior, as that of newborns, is focused on providing the activity-dependent input to the sensory system, which allows infants to discover the possibilities and constraints of the different actions on which their planning can be based (von Hofsten, 2009). This behavior is preceded by an earlier phase, in fetal development, during which non-goal-directed movements, are frequently executed (Sparling & Wilhelm, 1993), rendering it possible to explore the relation between movements and proprioception.

The constant association between motor command and perception of its sensory consequences may allow the contingency between the two events to be coded, determining the emergence of goal-directed actions (Zoia et al., 2007). If so, the link between motor execution and its sensory counterpart might be present since birth. The aim of the present study is to investigate whether in 2-day-old newborns this association is already present and, in particular, whether newborns are able to discriminate between visual stimuli that cue purposeful movements and visual stimuli that do not.

There was a further problem that arises from the fact that fetuses and naive newborns should have no visual experience of the consequences of their movements and thus should lack the capability to link their motor experience with visual consequence. We might find the answer to this problem in a series of studies that showed that in newborns the link between motor experience and the related visual consequences is immediately accessible. These studies made use of the intersensory paired-preference procedure (Streri & Gentaz, 2003, 2004). In it, newborns (few days old) are given an object to explore manually (without visual control) during the habituation phase. Then, the tactual object is removed and infants are shown the familiar object paired with a new one. Results revealed that the mean looking time is longer for the novel object than for the familiar one.

If goal-directed behavior is already present in fetuses (Zoia et al., 2007), and the link between motor experience and its related visual experience is present at birth (Streri & Gentaz, 2003, 2004), it is plausible that newborns could discriminate visual cues indicating goal-directed actions from visual cues indicating non-goal-directed actions.

To support the hypothesis that the origin of sensory-motor representations is the contingency between execution of goal-directed actions and perception of sensory-related information available to fetuses, it is necessary to demonstrate that recognition of at least some basic characteristics discriminating between goal-directed and non-goal-directed actions is already present at birth. The most basic characteristic of a movement is its direction, which renders it possible to discriminate if it is directed away from the body (e.g., extension of the arm) or toward the body (e.g., flexion of the arm). Extending the arm is a necessary prerequisite for reaching something, whereas its flexion usually corresponds to a return to a rest position. Furthermore, during hand/object interaction the hand shape dramatically changes, depending on whether the direction of the movement is toward an object or away from it. To leave a previously grasped object is an unspecific action, which is executed almost in the same way independently of the intrinsic properties of the object. In contrast, movements directed toward an object would end in a hand-object interaction, which is critically specified by the intrinsic properties of that particular object (e.g., Jeannerod, 1994). Therefore, only movements toward objects can be defined as goal-directed actions.

On the basis of these considerations, we tested 2-day-old newborns by using the preferential looking technique for action observation. In one condition the newborn was shown two hands approaching a ball with different hand shapes, one hand dynamically shaping in a whole hand prehension, the other in a pinch position (we named this experimental condition "Away from the body"). In the other condition a new group of newborns was shown exactly the same two actions but played backward ("Toward the body"). Thus, the only difference between these two experimental conditions was in the direction of the movement with respect to the body.

Another necessary characteristic discriminating between goal and non-goal-directed actions is the presence of the object, which is the goal of the action. Therefore, two other groups of newborns were submitted to two new experimental conditions replicating the previously described ones ("Object present"), the only difference being that the object was erased via software from the original videos ("Object absent") (Fig. 1).

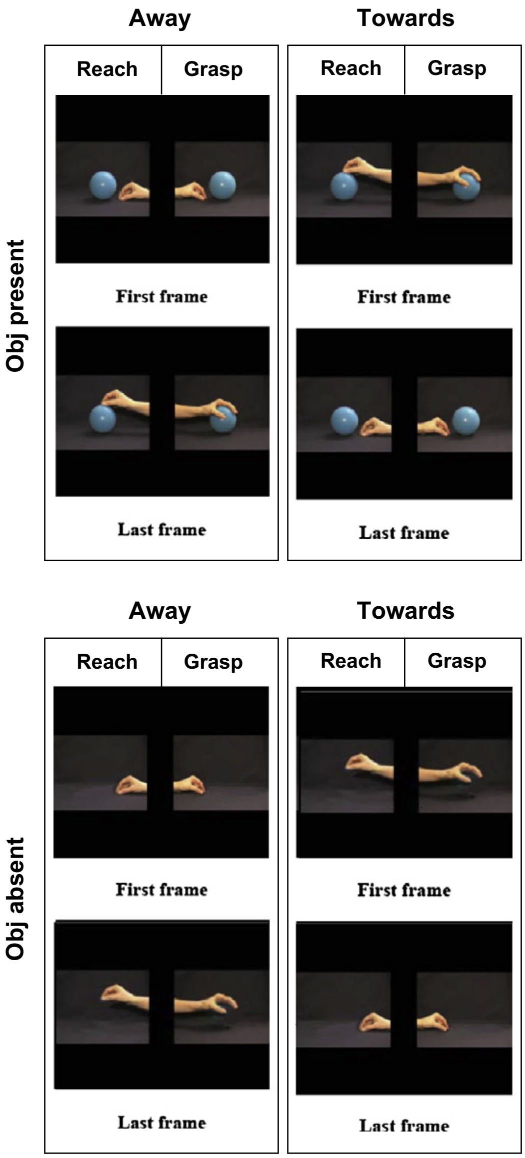

Fig. 1. Stimuli used in the experiment. The first and the last frame of the 4 s digital videos, continuously looped, are shown for the different experimental conditions.

2. Materials and methods

2.1. Participants

Fifty-six 2-day-old newborns (32 males; 26–78 h) mean age = 41 h-old, SD = 6.5, recruited from the maternity ward of the Pediatric Clinic of the University of Padova participated in the study. All of them met the screening criteria of normal delivery, had a birth weight between 2550–4720 g, and an Apgar score between 9 and 10 at 5 min. Additional 24 infants were tested, but were not included in the final sample because 11 did not complete testing due to fussiness, five changed their state during testing, three were discarded due to an error of the experimenter and five showed a strong position preference (during the test they looked more than 80% of the time at one direction). Newborns were tested only if awake and in an alert state, and after their parents had provided informed consent. The responsible office of the Pediatric Clinic of the University of Padova licensed all experimental procedures.

Fourteen participants were randomly assigned to one of the four experimental conditions individuated by the orthogonal manipulation of the two between-subjects factors, namely: Direction of the movement (Away from the body vs. Toward the body) and Object (present vs. absent).

2.2. Stimuli and procedure

Stimuli were presented on a 30 in. Apple Cinema HD Display (2560 × 1600 pixels resolution and with a refresh rate of 60 Hz) placed at a distance of 30 cm from the infant. Each stimulus covered an area of 22 × 24.2 cm and was presented on the right or on the left of the display monitor. The distance between the two stimuli was 8 cm. Each stimulus consisted of a 4 s digital video recording of a hand movement, looped for 2 min. During each experiment, infants were submitted to two trials differing for the position of the stimuli. The initial side of the two stimuli (left or right) was counterbalanced across participants. The two paired stimuli were always shown in both left and right positions, the position being reversed from the first presentation to the second presentation. The newborn sat on the experimenter's lap, 30 cm in front of the screen. The experimenter holding the baby was naive to the hypothesis being tested and the stimuli being presented and was instructed to fix his/her gaze on a camera located on the ceiling throughout the experimental session. The infant's eyes were aligned with a red flickering LED, located between the two stimuli, which was used to attract newborns' attention before the starting of each trial. A video camera, located above the display, recorded participants' eye movements to monitor their looking behavior on-line and to allow off-line coding of their fixations. To prevent interference from irrelevant distractors, peripheral vision was limited by two black panels placed on both sides of the infant.

The experiment began with the LED flickering at the center of the display. As soon as the infant fixated on the LED, a second experimenter, who monitored the infant's eyes through the video camera, started the trial by pressing a key on the computer keyboard. This action automatically turned off the LED, and the two stimuli appeared simultaneously on each side of the display. The stimuli remained on as long as the infant fixated one of them. When the infant shifted his/her gaze away from the display for more than 10 s, the stimuli were removed and the LED was turned on. Again, LED fixation gave indication to the experimenter to start the second trial. This procedure, called "infant-control preferential looking technique," has previously been used in many studies (e.g., Farroni, Csibra, Simion, & Johnson, 2002; Simion, Regolin, & Bulf, 2008).

The experimenter, who was blind with respect to the stimuli and could not see them in the infant's corneal reflections, observed the infant's eyes during each trial and coded fixations on each stimulus by pressing two different push buttons depending on whether the newborn looked at the right or the left position.

Videotapes of the infants' eye movements were subsequently analyzed by an independent observer, unaware of the stimuli presented, to establish inter-observer reliability. For each stimulus and each trial, the number of orienting responses and the total fixation time was recorded. Four experimental conditions were carried out. They derived from the orthogonal manipulation of three factors, Type of Movement (Grasping vs. Reaching) as a within-subjects factor, Direction of Movement (Away from the body vs. Toward the body) and Object (present vs. absent) as between-subjects factors.

Stimuli presented during the condition Object present/Away from the body consisted of two videos of the same hand approaching the same blue ball (diameter 10 cm). In one video the hand started in a pinch shape and subsequently grasped the ball (without lifting it) with a natural hand shaping during the reaching phase (Grasping), in the other video the hand reached the ball by maintaining the initial pinch shape both during the reaching phase and during the landing onto the superior part of the object (Reaching). In the condition Object present/Toward the body, the newborn was shown exactly the same videos but played backward. Thus, the only difference between the videos of the two conditions was in the direction of the movement of the hand, maintaining every unspecific dissimilarity possibly determining the preference. In the condition Object absent/Away from the body, the videos were those of the condition Object present/Away from the body, but the object was erased via software. In the condition Object absent/Toward the body, the videos were those of the condition Object present/Toward the body, but the object was canceled via software. Therefore, the only difference between the videos was in the presence/absence of the object (Fig. 1).

In order to simplify stimulus definition, from now on we make use of the same name for the two hand shaped stimuli: Grasping, when the hand changes from a pinch shape to a grasp shape or vice versa, and Reaching, when the hand maintains its pinch shape.

3. Results

The mean estimated reliability between on-line and off-line coding of newborns was 0.96, $p < 0.001$ (Pearson correlation). Thus inter-observer reliability was high enough for allowing us to submit the data to statistical analysis.

The average total fixation time and the average number of orienting responses for Grasping and Reaching stimuli were calculated for each participant and for each experimental condition and were submitted to two analyses of variance (ANOVAs). In them, Direction of Movement (Away from the body vs. Toward the body) and Object (present vs. absent), were between-subjects factors, whereas Type of Movement (Grasping vs. Reaching) was a within-subjects factor. Pairwise comparisons with the Newman–Keuls method were conducted whenever appropriate. The significance level was always set at 0.05.

As for the total fixation time, the main factor Type of Movement was significant, $F(1, 52) = 12.98$, $p = 0.001$, indicating that newborns looked longer at Grasping (mean = 44728 ms, SD = 25408) than at Reaching (mean = 34994 ms, SD = 19153) stimuli. The same was true for number of orienting responses, $F(1, 52) = 18.64$, $p < 0.001$, Newborns oriented more frequently at Grasping (mean = 16, SD = 6.2) than at Reaching stimuli (mean = 14, SD = 5.4). This significant effect may be simply attributed to a perceptual difference between the two stimuli in term of the screen area covered by the two different hand shapes. The Grasping stimulus depicted an open hand, so that the area of the screen occupied by it was larger as compared to the Reaching stimulus depicting a close hand.

The main factor Direction of Movement was also statistically significant, $F(1, 52) = 4.16$, $p = 0.04$, indicating that the total fixation time was significantly longer for Away from the body movements (mean = 44,341 ms, SD = 22,307) than for Toward the body ones (mean = 35,381 ms, SD = 15,651). The same effect was significant also for number of orienting responses. Newborns oriented more frequently to Away from the body movements (mean = 17, SD = 6.7) rather than to Toward the body ones (mean = 12, SD = 4.4), $F(1, 52) = 16.45$, $p < 0.001$. This difference may be attributable to the confound that the Away from the body movement was always represented from the periphery of the screen to its center, while the Toward the body movement was always represented from the center to the periphery.

As for the total fixation time, the following 2-way interactions were significant: Type of Movement × Direction of Movement, $F(1, 52) = 11{,}00$, $p = 0.002$, and Direction of Movement × Object, $F(1, 52) = 19.17$, $p < 0001$. Newborns showed the same significant trend for number of orienting responses both for Type of Movement x Direction of Movement, $F(1, 52) = 13.62$, $p < 0.001$, and Direction of Movement × Object, $F(1, 52) = 10.96$, $p = 0.002$. The three-way interaction Type of Movement × Direction of Movement × Object was not significant both for total fixation time and for number of orienting responses.

Pairwise comparisons of the Type of Movement × Direction of Movement interaction revealed that newborns preferred to orient to and to look longer at Grasping only when the movement was directed Away from the body (mean total fixation time = 53,690 ms, SD = 29,332; mean number of orienting responses 19.5, SD = 6.6) and not when it was directed Toward the body (mean = 35,767 ms, SD = 16,975; mean number of orienting responses = 12.5,

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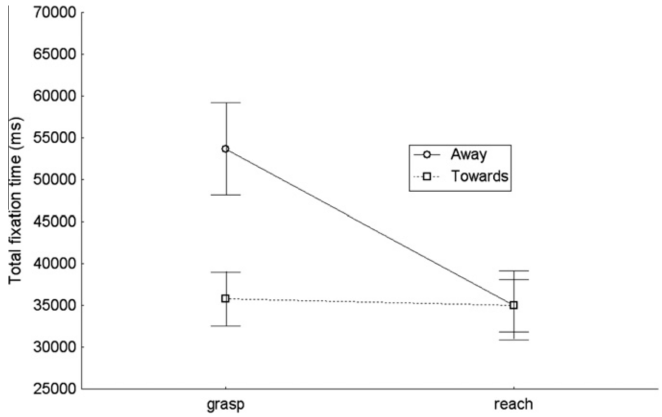

Fig. 2. The significant interaction Type of Movement × Direction of Movement for total fixation time. Whiskers indicate standard error of means. Ordinates are in milliseconds. Grasp: Grasping stimulus; Reach: Reaching stimulus; Away: direction of the hand movement away from the body; Toward: direction of the hand movement toward the body.

SD = 5.8). No significant difference was present for Reaching between the two directions of the movement (Away from the body mean = 34,993 ms, SD = 21,727; mean number of orienting responses = 15, SD = 3.1; Toward the body mean = 34,995 ms, SD = 16,588; mean number of orienting = 12, SD = 3.5) (Fig. 2).

Pairwise comparisons of the Direction of Movement × Object interaction revealed that newborns preferred to orient to and to look longer to the Away from the body movements only when the object was present (Away from the body, mean = 57,837 ms, SD = 23,690; number of orienting responses, mean = 19, SD = 1.2; Toward the body, mean = 29,654 ms, SD = 8333; number of orienting responses, mean = 10, SD = 1.2). No preference for a specific direction of movement was found when the object was absent (Away from the body, mean = 30,846 ms, SD = 8940; number of orienting responses, mean = 16, SD = 6.3; Toward the body mean = 41,109 ms, SD = 19,200; number of orienting responses, mean = 15, SD = 5.4) (Fig. 3).

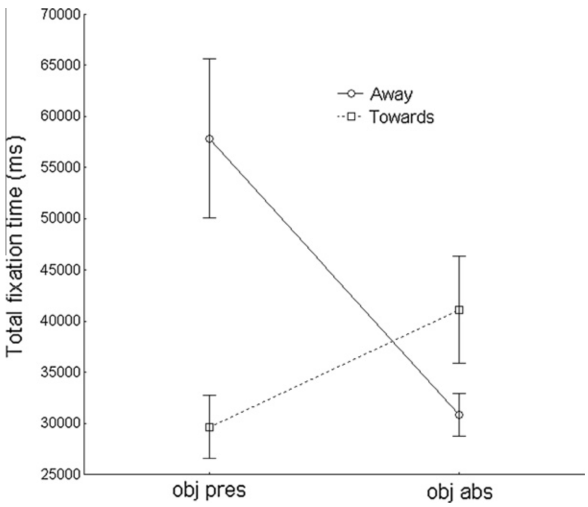

Fig. 3. The significant interaction Object × Direction of the Movement for total fixation time. Whiskers indicate standard error of means. Ordinates are in milliseconds. Obj pres: object present; Obj abs: object absent; Away: direction of the hand movement away from the body; Toward: direction of the hand movement toward the body.

The presence of two significant interactions, both for total fixation times and number of orienting responses, involving the factor Direction of Movement allowed us to exclude that the significance of its main effect could be simply due to unspecific perceptual differences between the videos, that is to perceptual differences between a movement from the center of the screen to its periphery and from the periphery to the center. Furthermore, the significance of the interaction Type of Movement × Direction of Movement indicated that, if the significance of the main effect Type of Movement was due to a perceptual difference between the two stimuli, newborns perceived this difference only when the direction of movement was Away from the body.

4. Discussion

Results showed first that different hand shapes are discriminated only when the movement was directed away from the body. Note that a movement away from the body is a necessary prerequisite for reaching something. Second, the away from the body movement was looked longer only when the object was present. That is, the direction of the movement assumed a specific meaning only when it might develop into a purposeful movement, the potentiality of which was determined by the presence of the to-be-grasped object.

Very interestingly, as indicated by the lack of significance of the interaction Object × Type of Movement, the presence or absence of the object did not influence the capacity to discriminate between different hand shapes. The preference found for Grasping with respect to Reaching cannot, therefore, be attributed to the movement suitability in grasping the ball: this preference was present independently of the presence of the ball. There are many developmental findings indicating that others' action recognition depends on action experience (Hauf, 2007; Sommerville & Woodward, 2005; Sommerville, Woodward, & Needham, 2005), and we consider the lack of significance of the interaction between different hand shapes and presence/absence of the object to be a further result in this direction. No doubt 2-day-old newborns have absolutely no knowledge of the most suitable type of hand shaping for successfully grasping a ball, and, therefore, they are not able to visually recognize it.

Also, it must be noted that the absence of a significant three-way interaction between presence of the object, direction of the movement, and type of movement indicated that the two 2-way significant interactions signal the presence of two effects that are additive in nature. That is, in newborns the preference for the grasping stimulus when the movement is directed away from the body (Fig. 2), and the preference for the away from the body movement when the object is present (Fig. 3) are based on independent processes.

The first possible interpretation of the result indicating that different hand shapes discrimination depended on movement direction is that the perceptual or kinematic differences between the grasping and the reaching videos were detected only when these are present in the final part of the observed movement. That would be the reason why they were detected only in the ''Away from the body'' movement. In effect, in the final part of the ''Toward the body'' movement, the two videos were very similar. If this explanation is correct, it would mean that 2-day-old newborns automatically oriented their attention toward the final part of the observed movement.

This possibility is very interesting in itself, because it resembles a recent finding in adults (Flanagan & Johansson, 2003) and in 12-month-old infants (Falck-Ytter, Gredebäck, & von Hofsten, 2006), indicating that during action observation individuals direct their eyes (and therefore their attention) longer at the area where the action is directed to, than at the other regions of space. The hypothesis is that each observed action is mapped onto the motor representation of that same action, allowing one to understand its meaning and to predict its outcome (Rizzolatti & Craighero, 2004). Because in visually guided actions, for planning and control purposes, gaze usually leads the hand to objects to-be-grasped, one may maintain that in action observation the same proactive gaze behavior is present. This hypothesis necessarily implies that the development of proactive eye movements is dependent on action development. Therefore, infants are not expected to predict others' action goals before they can perform the actions themselves. This possibility was demonstrated by an experiment showing that, during video presentations in which toys were moved by an actor's hand into a bucket, proactive goal-directed eye movements are present in 12-month-old but not in 6-month-old infants (Falck-Ytter et al., 2006). In effect, 6-month-old infants do not yet systematically move objects from a position to another: If they pick up an object and displace it, they almost always move it to the mouth (see von Hofsten, 2009).

If the present results can be interpreted as a newborns' attention bias toward the spatial region reached by the observed moving stimulus, a crucial difference between this behavior and the proactive gaze should be pointed out. Proactive gaze requires the ability to perform the observed action, to take into account the kinematics of the observed movement (biological vs. mechanical motion), and to discriminate the presence or absence of the hand holding the moving object (human agent vs. self-propelled) (Falck-Ytter et al., 2006; Flanagan & Johansson, 2003). In contrast, newborns' attention bias could be utterly unspecific and present only when the observed movement is repeated. Such an attentional bias could be explained by newborns' motor knowledge accumulated during their intrauterine life through execution of goal-directed actions. This motor knowledge includes the necessity to focus attention onto the goal of the action before movement planning. Therefore, it is plausible that newborns could also be able to focus their attention toward the end point of an observed movement. An interesting way to explore this possibility could be to investigate if the attention imbalance is present also when the observed movement is not a biological one (Craighero, Umiltà & Simion, *in preparation*), given the experimental evidence that 2-day-old newborns prefer biological to nonbiological motion (Simion et al., 2008).

The attention unbalance hypothesis, if confirmed, might indicate that goal-relatedness, explicit only at the end of every goal-directed action, drives the way to execute and observe actions from the early days of life, maybe providing the basis for the future proactive gaze behavior.

However, a more intriguing interpretation might be that newborns, based on their motor knowledge, are able to discriminate between actions toward, and actions away from the body. That would imply that their sensory-motor system is already able to predict that only a movement directed away from the body and toward the external word determines a sensory feedback. Because it is claimed that the early phases in motor development are aimed at providing activity-dependent input to the sensory-motor system (von Hofsten, 2009), it is possible that attention of a newborn is directed mainly to movements that are likely to satisfy this requirement, even when just observed. Among the movements used as stimuli in the present experiments, the one that would produce, if executed, the greatest sensory-motor feedback is the whole hand stimulus when it is directed toward the ball for grasping it.

This latter interpretation is further supported by the second result of the present experiment: the Away from the body movement is looked longer at only when the object is present. That is only when the object is present an away from the body movement may be considered a goal-directed (transitive) action providing a sensory feedback.

The research of sensory-motor feedback by newborns is documented by evidence necessarily challenging the traditional way to consider neonatal behavior in terms of reflexes rather than actions. The most convincing one is related to reaching. It is known that successful reaching does not appear until around 4 months of life. However, an experiment on newborns demonstrated that their spontaneous arm-waving movements are far from being exclusively random (van der Meer, 1997). Furthermore, the same behaviors observed prenatally (Sparling & Wilhelm, 1993; Sparling et al., 1999; Zoia et al., 2007) are present in newborns: They move their arms toward attractive objects in front of them (von Hofsten, 1984) and put their fin-

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gers or thumbs into their mouth, opening their mouth in anticipation of the arrival of the thumb (Lew & Butterworth, 1995).

It has been proposed that research of activity-dependent input to the sensory-motor and cognitive systems allows the newborn infant to begin exploring the relation between commands and movements, between vision and proprioception, thus discovering the possibilities and constraints of their actions (von Hofsten, 2009). Given the available evidence that properties of action execution serve also action observation, it is conceivable that in the present task newborns are attracted by the stimulus potentially richest in sensory-motor feedback.

Results of the present study indicated that 2-day-old newborns were sensitive to visual cues hinting at the presence of a purposeful movement, which suggests that in the early days of life sensory-motor associations are already present, although in a primitive form. In particular, the present findings indicated that different visual cues (e.g., the hand shape for whole hand prehension, a big ball, a movement directed away from the body), suggesting the same action (e.g., reaching and grasping a big ball by means of a whole hand prehension), are separately considered and they do not yet contribute to a unitary sensory-motor representation of the cued action. The direction of the movement would separately interact with type of movement on one side and presence of the object on the other side, even though the intrinsic properties of the object are not yet associated with a congruent hand shape. Arguably, this latter association requires a specific motor knowledge that newborns still lack. Although further research is necessary to confirm this prevision, the present study no doubt opens a new and interesting perspective in the investigation of the development of sensory-motor representations and, in particular, of the role that goal-relatedness has in this process.

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