Discrimination of biomechanically possible and impossible hand movements at birth

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Abstract

The development of human body perception has long been investigated, but little is known about its early origins. This study focused on how a body part highly relevant to the human species, namely the hand, is perceived a few days after birth. Using a preferential-looking paradigm, 24- to 48-hr-old newborns watched biomechanically possible and impossible dynamic hand gestures (Experiment 1, N = 15) and static hand postures (Experiment 2, N = 15). In Experiment 1, newborns looked longer at the impossible, compared to the possible, hand movement, whereas in Experiment 2 no visual preference emerged. These findings suggest that early in life the representation of the human body may be shaped by sensory-motor experience

Introduction

From early in life, interacting with other people requires the ability to efficiently determine their identities, actions, emotions, and intentions. Much of this information can be inferred from their faces. Accordingly, behavioral and neurophysiological studies with infants have shown that remarkable abilities to detect faces and to recognize facial identities are present from the 1st day of life, with neurofunctional specialization of face-processing mechanisms increasing across the 1st year (Hoehl & Peykarjou, 2012; Johnson, Grossmann, & Cohen Kadosh, 2009).

Besides faces, the human body is also a rich source of social information. The past few years have brought a remarkable increase in research on the neural basis of visual perception of the human body in adults (see review by Peelen & Downing, 2007). Crucially, individuals have direct access to visual information provided by their own body, as well as by the bodies of other people, from the very beginning of postnatal life. Therefore, it is plausible to assume that bodies, like faces, represent a highly salient stimulus category within an infant's visual environment. Nonetheless, the investigation of whether and how newborn infants attend to, and perceive, body parts other than faces has received little attention.

Infants' perception of the whole body form has been extensively investigated using dynamic point-light displays (PLDs). Berthental and colleagues (Bertenthal, Proffitt, & Cutting, 1984; Bertenthal, Proffitt, & Kramer, 1987) demonstrated that from 3 months of age infants discriminated between PLDs depicting a walking person from displays of identical absolute motions with scrambled spatial relations, but failed to do so when the same displays were static. This evidence is not confined to the whole body, but extends to single body parts, as 6-month-old infants, but not 2- and 4-month-olds, looked longer at human hand PLDs with light dots on the hand joints, than to PLDs in which light dots were placed at nonjoint locations (Fox & McDaniels, 1982). Finally, sensitivity to the bio- mechanics of PLDs of human movements has been observed also by means of event-related-potential recordings in 5- (Marshall & Shipley, 2009) and 8- month-old (Reid, Hoehl, Landt, & Striano, 2008) infants.

In their directed attention model, Hoehl et al. (2009) suggested that an infant's ability to detect biological motion might be crucial for the early emergence of social functions, allowing infants to attend to the social components of the environment while discarding information not relevant for social communication (Hoehl et al., 2009). Similarly, Johnson (2006) proposed that the detection of biological motion is an intrinsic inborn capacity of the visual system, which allows human and nonhuman neo- nates to detect and preferentially attend to other animals. In line with this hypothesis, human neonates look longer at biological dynamic PLDs than nonbiological dynamic PLDs, even when the displays show a walking unfamiliar animal, that is, a hen (Simion, Regolin, & Bulf, 2008). Also, newly born chicks selectively respond to PLDs depicting the motion of conspecifics (Regolin, Tommasi, & Vallortigara, 2000). Overall, evidence gathered with PLDs suggests that early in life, infants seem to be able to recognize the human form, which might be related to an inborn predisposition to attend to bio- logical motion. In turn, this predisposition may support infants' understanding of how moving parts are related to each other.

This picture seems to contrast with evidence gathered using realistic videos or animations of the human body. Although rich visual cues pro- vided by real bodies might facilitate body perception in infants, so far there is no evidence that infants under the age of 8–9 months are able to discriminate between possible and impossible human body movements in realistic displays. Christie and Slaughter (2010) reported that 9-month-olds, but not 6-month-olds, discriminated canonical versus scrambled animated bodies. Eight-month-olds, in particular those with high fine motor skills, discriminated between biomechanically possible and impossible arm movements and preferred the impossible ones (Reid, Belsky, & Johnson, 2005). Similarly, 12-month-olds looked longer at the elbow of a virtual agent performing impossible, rather than possible, arm movements (Morita et al., 2012). Furthermore, it is not until the age of 18months that infants distinguish between static pictures of typical and scrambled bodies (Slaughter & Heron, 2004; Slaughter, Heron, & Sim, 2002).

Overall, evidence obtained with realistic body animations and PLDs converges to suggest that infants' ability to recognize and disambiguate the body form, and its postures, is critically affected by dynamic information. In light of this evidence, in the current study, we investigated visual perception of static and animated realistic images of a human body part (the hand) in few-day-old infants. This issue is important because recent evidence suggests that during the 1st year of life, infants begin to make relatively sophisticated attributions about human hands. By 6 months of age, they interpret familiar manual actions performed by others as goal directed (Biro & Leslie, 2007; Woodward, 1998), and at 7–10 months they can attribute causal agency to human hands (Saxe, Tzelnic, & Carey, 2007). Also, Craighero, Leo, Umilt□a, and Simion (2011) found that when presented with a video of a hand grasping a ball, neonates looked longer at the hand when moved from the body forward to the ball, namely the goal-directed action, than when the hand moved away from it, or when the ball was absent. These findings suggest that 2-day-old infants are able to discriminate between goal-directed and non-goal-directed hand gestures. However, the origins of visual perception of hands are still largely unexplored.

The presence of an early predisposition to pay attention to hands has been proposed to be highly relevant to the development of active learning of the association between the execution and perception of human actions, and in turn to the under- standing of actions (Del Giudice, Manera, & Keysers, 2009). In line with this, primitive sensory- motor associations may mediate newborns' prefer- ence for goal-directed over non-goal-directed actions performed by a human hand (Craighero et al., 2011). Here, we focused on the role of dynamic information in triggering the sensitivity of few-day-old infants' to the form of the hand. To this end, by using a preferential-looking paradigm, we tested the ability of newborns to discriminate between biomechanically possible and impossible dynamic hand gestures (Experiment 1) and static hand postures (Experiment 2). This study differs from earlier research on body perception because it focuses on the perception of possible and impossible postures and gestures of the hand, rather than the whole human body, and differs as well from earlier research with newborns (see Craighero et al., 2011) as it focuses on hand movements per se, rather than goal-directed or non-goal-directed hand actions.

Infants' sensory-motor experience varies for different parts of the body. In the uterus, fetuses acquire extensive sensory-motor experience of their hands, by exploring themselves and the uterine environment (Piontelli, 2010; Zoia et al., 2007). During the third trimester of gestation they are capable of making full hand closures and grasping their own fingers as well as the umbilical cord (Jakobo- vits, 2009; Kurjak et al., 2004; Kurjak et al., 2005; Sparling, Van Tol, & Chescheir, 1999). After birth, infants spend a great amount of their waking time looking at their own hands (White, Castle, & Held, 1964), which fall within their limited visual field. Interestingly, newborns not only actively attempt to control arm movements in order to keep their hands visible, but they also move their hands sig- nificantly more when they can watch them, showing a clear preference for hands in motion (Van der Meer, 1997; Van der Meer, van der Weel, & Lee, 1995; von Hofsten, 2004). Thus, among the different body parts, hands, like faces, seem to be visually salient for newborns, as witnessed by their ability to capture attention.

Experiment 1

Using an infant-controlled preferential-looking paradigm, Experiment 1 examined whether neonates are able to discriminate between biomechanically possible and impossible hand gestures. Infants watched two video clips, each displaying a hand in motion: one with the fingers curling toward the palm (possible hand closure), and the other with the fingers moving backwards toward the back of the hand (impossible hand closure).

Method

Participants

Fifteen (nine females) healthy, full-term infants, 16–96 hr old (M = 41 hr), were recruited from the Neonatal Ward at the San Gerardo Hospital in Monza. Seven additional infants were tested but excluded from data analysis because of fussiness (n = 6) or position bias (i.e., looking more than 85% of the time in one direction; n = 1) during test trials. Participants' birth weight ranged between 2,530 and 3,720 g, and their Apgar score was at least 8 at 5 min. The Apgar scale (Apgar, 1953) evaluates the condition of newborns at 1 and 5 min after birth. A score of 0–2 is assigned for their activity, pulse, grimace (reflex irritability), appearance (skin color), and respiration; a total score of ≥ 7 indicates that the neonate is in a normal state and does not need medical attention. All of the infants were tested when in an alert and attentive state. The study was approved by the Ethics Committees of the San Gerardo Hospital and of the University of Milano- Bicocca. Parents gave their written informed consent.

Stimuli

Stimuli consisted of two videos showing a moving hand on a black background: (a) a biomechanically possible whole-hand closure and (b) a biomechanically impossible whole-hand closure. Each stimulus comprised seven frames, extracted from the video recording of a real human hand per- forming a whole closure toward the palm, that is, possible movement. The first two frames were the same for both possible and impossible stimuli; the remaining frames were modified using Photoshop software (Adobe Systems, San Jose, CA) to create the impossible stimulus. Frame 1 depicted a vertical hand, fingers straight up, and the palm facing the viewer. As the hand made a 90° rotation on the vertical axis, Frame 2 presented a sideway hand with the thumb in front and the other fingers aligned vertically. For the possible stimulus, Frames 3–7 depicted a hand closing with the fingers bending so as to close gradually toward the palm. For the impossible stimulus Frames 3–7 showed the fin- gers moving unnaturally backward, toward the back of the hand. The fingers' angle and phalangeal joint displacements of each frame were matched across the two stimuli (see Figure 1a; see also the online Supporting Information). A croma-meter was used to measure the luminance of three different points of the hand depicted in the seven frames. The obtained values were constant across all of the frames (M = 136 cdm^2, range = 123–145). Each frame lasted 571 ms. Possible and impossible 4-s videos were presented bilaterally and played continuously in a loop. The dimension of the hands ranged between 13.3° and 16.6° of visual angle in height and between 5.4° and 9.2° in width. In each frame, the inner portion of the hands was 8 cm (i.e., a visual angle of 6.5°) from the central fixation point.

In order to measure the perceived possibleness of the stimuli, 20 adults (5 males; M_{age} = 30.85 years, SD = 6.81) rated the videos on a 5-point Likert scale (2/+2 = totally disagree/agree, 0 = neither agree nor disagree) judging whether "The movement I see is possible." Participants agreed that the possible movement was possible (M = 1.95), and the impossible movement was impossible (M = 2 , p < .001, Wilcoxon test). Participants were also asked to rate each frame of the possible and impossible conditions (randomly presented) as to whether “The posture/gesture I see is possible.” No difference emerged between the possible and impossible conditions for Frames 1–2–3 and 5 (all ps > .1), as all depicted a possible posture. Participants’ ratings differed between the two conditions for Frames 4–6–7 (all ps < .011, Wilcoxon test), as they depicted an impossible posture in the impossible condition. The smoothness of the stimuli was assessed by calculating a pixel-by-pixel cross-correlation across successive frames in each video using MATLAB (The Mathworks Inc., Natick, MA), which provided a measure of the physical similarity across frames. The comparison between the magnitude of the cross-correlations confirmed that possible (M = 2.046 9.31) and impossible (M = 2.104 1.06) stimuli did not differ in smoothness (Mann–Whitney, U = 12.5, Z = 0.88, p = .38).

Apparatus

Participants were tested in a dimly lit room located in the Neonatal Ward. Stimuli were presented on a 27-in. monitor (1,920 9 1,080 pixel resolution, refresh rate = 60 Hz). An undergraduate student unaware of the aim of the study sat with the infant on the lap in front of the monitor at a distance of about 30 cm. The position of the infant’s head was checked through a television placed above the monitor showing the stimuli, and infants’ eyes were recorded by a video camera. The television received a visual input from the video camera that fed into a laptop computer, which recorded the video stream of the infant’s gaze. A second experimenter controlled the laptop receiving the video input, and used it to run the experiment, designed with E-prime 2 (Psychology Software Tools, Sharpsburg, PA). A monitor and video camera were framed with black panels, and dark curtains were pulled at the side in order to minimize any distraction during the testing session.

Procedure

Newborns were tested using a preferential-looking paradigm with an infant-controlled procedure (Horowitz, 1975); details of the criteria and parameters were based on earlier studies investigating newborns’ visual preferences (e.g., Farroni, Menon, Rigato, & Johnson, 2007; Macchi Cassia, Turati, & Simion, 2004). When neonates were settled, at ease on the experimenter’s lap and facing the monitor, the experimental session started. Each trial started with a red flickering circle (1.6°) appearing at the center of the monitor on a black background. The red circle blinked (300 ms on and 300 ms off) and was used to catch infants’ attention and attract their gaze. As soon as infants looked at the screen, the flickering circle was turned off and the experiment started. Infants were presented with two trials: in each trial, two stimuli were shown bilaterally. Left–right position of the stimuli was counterbalanced across trials and participants. The trial ended when infants watched each stimulus at least once for a minimum of 1 s, and shifted their gaze away for more than 10 s. At this point, the experimenter turned off the stimuli and the central red circle started flickering again so as to attract the infant’s attention. The gaze direction and fixation times were coded online by an experimenter, blind to the specific position of the stimuli on the screen. Thus, the number of orienting responses and total fixation times (i.e., sum of all fixations) on the stimuli were recorded as the dependent variables (Cohen, 1972, 1973). Video recordings of the infant’s eye movements were subsequently coded offline by an observer blind to the hypotheses of the study and the stimuli shown. Interrater reliability was calculated on 50% of the infants. Cohen’s Kappa revealed a substantial agreement between coders (p < .001.).

Results and Discussion

Normality of data distribution was checked through a Kolmogorov–Smirnov test (p > .20). Total fixation times and number of orienting responses to the possible and impossible hand movements were compared through two-way analyses of variance (ANOVAs) with trial presentation (first vs.

second) and the hand closure type (possible vs. impossible) as within-subject factors. The ANOVA on total fixation times revealed a main effect of hand closure type, $F(1, 14) = 6.015$, $p < .028$, with newborns looking longer at the impossible movement ($M = 109.45$ s, $SD = 56.17$) than at the possible one ($M = 82.49$, $SD = 40.37$; Figure 1b). No other effect was significant (all $ps > .2$). Also, the ANOVA on number of orienting responses revealed a main effect of hand closure type, $F(1, 14) = 4.846$, $p < .045$, whereby infants oriented their gaze more often to the impossible ($M = 25.27$, $SD = 9.62$) than to the possible ($M = 22.87$, $SD = 8.97$; Figure 1b) movement. The Trial Presentation x Hand Closure Type interaction did not reach significance, $F(1, 14) = 3.921$, $p = .068$. No other effect approached significance (all $ps > .31$).

To investigate the relation between post-natal experience and preferential-looking performance, we correlated the age of infants with their preference score for the impossible stimulus, that is, the fixation time on the impossible stimulus divided by the total fixation times on both stimuli. The correlation (Pearson) was not significant, $r(13) = .155$, $p = .58$. Thus, although postnatal time can only be considered as a proxy of visual exposure to hand movements, in our data, postnatal time alone does not explain infants' preference for the impossible hand closure.

Overall, these findings show that when newborns are presented with whole-hand closure movements differing only in their anatomical plausibility, they orient more often and look longer at the bio- mechanically impossible movement than at the possible one. Thus, newborns seem to be able to visually discriminate between a movement for which they have accumulated extensive sensory- motor experience and a movement not experienced before.

Experiment 2

Experiment 2 explored the ability of neonates to discriminate between possible and impossible static hand postures. If dynamic information is crucial to drive neonates' discrimination of possible and impossible hand gestures, no visual preference should be obtained under static conditions. Instead, a visual preference for the impossible hand posture would indicate that neonates are able to discriminate between a possible hand posture and an impossible one, even when the posture is static.

Method

Participants

Fifteen (nine females) healthy, full-term infants, 22–97 hr old ($M = 49$ hr), took part in the study. Seven infants were tested but not included in the sample because they became fussy ($n = 4$) or showed a position bias ($n = 3$). Participants' birth weight ranged between 2,670 and 4,050 g, and their Apgar score was at least 8 at 5 min.

Stimuli

The penultimate frames (Frames 6) from the possible and impossible videos used in Experiment 1 were selected as a stimuli for Experiment 2, as they were the most representative frames of the possible and impossible gestures, respectively, based on adults' ratings (see Experiment 1, Method section). Hand dimensions were 14° (height) x 9° (width); hands were shown bilaterally on a black back- ground at a distance of 6.5° from the central fixation point.

Apparatus and Procedure

Apparatus and procedure were the same as for Experiment 1 - Interrater reliability (Cohen's Kappa) calculated on 50% of the infants ($p < .001$).

Results and Discussion

We checked normality of data distribution through a Kolmogorov–Smirnov test ($p > .20$), and performed two ANOVAs with trial presentation (first vs. second) and hand closure type (possible vs. impossible) as within-subjects factors on total fixation times and number of orienting responses. Neither of the two analyses revealed any significant main effect or interaction (all ps > .1). Thus, newborns did not look longer at either the impossible (M = 74.99 s, SD = 23.49) or possible (M = 90.77, SD = 26.68; Figure 1c) hand posture, and made a similar number of orientations toward the two stim- uli (impossible: M = 21.93, SD = 7.7; possible: M = 23.53, SD = 8.85; Figure 1c). Similar to Experiment 1, there was no correlation (Pearson) between chronological age and preference scores for the impossible stimulus, $r(13) = .323$, $p = .240$.

To compare the results of Experiments 1 and 2, two three-way ANOVAs were performed on the total fixation times and the number of orienting responses, with trial presentation and hand closure type as within-subject factors, and experiment as between-subjects factor. The ANOVA on total fixation time revealed a significant Experiment 9 Hand Closure Type interaction $F(1, 28) = 8.891$, $p < .007$. No other effect attained statistical significance (ps > .19). As for the number of orienting responses, an Experiment 9 Hand Closure Type interaction, $F(1, 28) = 6.925$, $p < .02$, and an Experiment x Hand Closure Type 9 Trial Presentation interaction, $F(1, 28) = 5.393$, $p < .03$, were significant, with no other effect attaining significance (ps > .31). These results confirmed that in Experiment 1, but not in Experiment 2, infants looked longer and made significantly more orienting responses to the impossible hand closure movement compared to the possible one. Overall, these results indicated that newborns' preferential response to the impossible hand closure relied on the dynamic information provided by the moving hand.

General Discussion

Although many studies have explored face processing abilities shortly after birth (Johnson & Morton, 1991; Turati, Macchi Cassia, Simion, & Leo, 2006), very little attention has been devoted to investigating how neonates process visual information related to other human body parts, such as the hands (see Craighero et al., 2011). Here, we showed that when dynamic information is available, newborns orient more frequently and look longer at the realistic animation of an impossible hand closure, compared to a possible one. This preferential response vanishes when the dynamic information is lacking. These findings indicate that newborns' ability to detect and recognize the body form is not confined to faces; rather, it extends to other salient body parts, such as the hands, whenever they are in motion. Thus, it seems that in order to understand the origins and the development of body perception, the analyzed body part also matters, with more salient body parts being favored over less salient ones.

In line with previous evidence on newborns (Vinter, 1986) and older infants (Bertenthal et al., 1984; Christie & Slaughter, 2010), our findings high-light the importance of motion in supporting body perception. Notably, the role of motion in our study was not that of enhancing the overall stimulus saliency and attracting the newborn's attention, as overall looking times did not differ between Experiments 1 and 2 ($p > .2$). Rather, it seems that movement provided a critical supplementary source of information about the biological plausibility of the hand gesture, which was not available in static pictures. In this respect, a question that merits further investigation is whether infants would generalize their preferential response to a nonbiological, mechanical object performing a movement analogous to the possible whole-hand closure. This would shed light on the specificity of infants' response to human hand movements.

Further experiments are also needed to clarify the processes underlying newborns' discrimination between possible and impossible hand gestures. A possible clue to this question may come from studies on newborns' preference for faces (Johnson & Morton, 1991) and biological motion in PLDs (Simion et al., 2008). In these studies, neonates' attention is typically directed toward the canonical, possible stimulus. Here, newborns' preference was directed toward the distorted, impossible stimulus. Some studies have shown that newborns' looking times toward faces are mediated by the activation of an orienting mechanism captured by the face pattern located at the periphery of infants' visual field (Macchi Cassia, Simion, & Umilt□a, 2001). This finding has been interpreted as evidence that newborns' looking preferences for faces are generated by a subcortical route, which selectively responds to social stimuli and provides a developmental foundation for what later becomes the adult cortical "social brain" network (Johnson, 2005). In the present study, the impossible hand movement was more efficient than the possible movement in summoning the newborn's gaze, inducing a greater number of orientations and longer overall looking times, that is, maintaining the newborn's fixation. This indicates that newborns did not prefer the hand movements that match their own, and suggests that their attention was presumably triggered by the novelty and unexpectedness of the impossible movement. Therefore, unlike face preference studies, the direction of newborns' preference in the current study was toward the less familiar stimulus, rather than the familiar one. This discrepancy in the direction of visual preference for hand and face stimuli foreshadows the intriguing possibility that perception of faces and hands are mediated by non- overlapping mechanisms from birth. In this regard, in the adult human brain higher level regions of the visual cortex involved in visual perception of faces can be dissociated from regions involved in perception of body parts, including the hands (Pourtois, Peelen, Spinelli, Seeck, & Vuilleumier, 2007).

The finding of a preference for impossible hand movements at birth is in line with the preference that older infants manifest for scrambled animated and static bodies (e.g., Christie & Slaughter, 2010; see review by Slaughter, Stone, & Reed, 2004) and impossible body movements (Morita et al., 2012; Reid et al., 2005). Infants' preference for impossible movements has been explained as being due to the fact that these movements are novel or surprising (Reid et al., 2005; Slaughter et al., 2004). Also, it has been claimed that this preference might be driven by infant's motor skills, in line with the argument that there is a link between infants' ability to per- form motor actions and their understanding or perception of human body movements (Morita et al., 2012; Reid et al., 2005).

Although one could speculate that similar mechanisms engendered by prenatal and/or postnatal sensorimotor experience are at the origins of the consistent direction of visual preferences exhibited by newborns and older infants, it is rather evident that the amount of sensorimotor experience accumulated by newborns is indeed limited. Moreover, we found no association between neonates' preference for the impossible hand gesture and their post-natal age. Therefore, our findings cannot discern whether newborns' preference for the impossible hand gesture is driven by prenatal and/or postnatal sensorimotor experience, or whether it might be attributed to an inborn sensitivity to the shape of the human hand. In the latter case, it could be suggested that an amodal, innate representation of the human body may mediate the early recognition of its shape (see Meltzoff & Moore, 1999). A challenge for future studies would be to investigate whether newborns' discrimination capacity is confined to gestures that are part of their own motor repertoire (e.g., whole-hand closure, as in the current study), or may be generalized to hand gestures that newborns have never experienced before (e.g., pincer grip).

To conclude, the present results provide evidence of newborns' ability to detect and recognize the bio- mechanical properties of hand movements (see Craighero et al., 2011). In particular, the current study is the first to demonstrate that newborn infants discriminate hand movements per se, even when these are not embedded within a goal- directed action such as reaching toward an object. These findings suggest that early in life the ability to recognize the shape of a salient body part, like the hand, is already available and might act as one of the building blocks of the emerging capability to understand the actions of others (Del Giudice et al., 2009).

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References

Apgar, V. (1953). A proposal for a new method of evalua- tion of the newborn infant. Current Researches in Anes- thesia and Analgesia, 32, 260–267.

Bertenthal, B. I., Proffitt, D. R., & Cutting, J. E. (1984). Infant sensitivity to figural coherence in biomechanical motions. Journal of Experimental Child Psychology, 37, 213–230. doi:10.1016/0022-0965(84)90001-8

Bertenthal, B. I., Proffitt, D. R., & Kramer, S. J. (1987). Infants' encoding of kinetic displays varying in relative coherence. Developmental Psychology, 23, 171–178. doi:10.1037/0012-1649.23.2.171

Biro, S., & Leslie, A. M. (2007). Infants' perception of goal-directed actions: Development through cue-based bootstrapping. Developmental Science, 10, 379–398. doi:10.1111/j.1467-7687.2006.00544.x

Christie, T., & Slaughter, V. (2010a). Movement contrib- utes to infants' recognition of the human form. Cogni- tion, 114, 329–337. doi:10.1016/j.cognition.2009.10.004

Cohen, L. B. (1972). Attention-getting and attention-hold- ing process of infant visual preferences. Child Develop- ment, 43, 869–879. doi:10.1111/1467-8624.ep12114579

Cohen, L. B. (1973). A two process model of infant visual attention. Merrill-Palmer Quarterly, 19, 157–180.

Craighero, L., Leo, I., Umilt□a, C., & Simion, F. (2011). Newborns' preference for goal-directed actions. Cogni- tion, 120, 26–32. doi:10.1016/j.cognition.2011.02.011

Del Giudice, M., Manera, V., & Keysers, C. (2009). Pro- grammed to learn? The ontogeny of mirror neurons. Developmental Science, 12, 350–363. doi:10.1111/j.1467- 7687.2008.00783.x

Farroni, T., Menon, E., Rigato, S., & Johnson, M. H. (2007). The perception of facial expressions in new- borns. European Journal of Developmental Psychology, 4, 2–13. doi:10.1080/17405620601046832

Fox, R., & Mc Daniels, C. (1982). The perception of bio- logical motion by human infants. Science, 218, 486–487. doi:10.1126/science.7123249

Hoehl, S., & Peykarjou, S. (2012). The early development of face-processing—What makes faces special? Neurosci- ence Bullettin, 28, 765–788. doi:10.1007/s12264-012- 1280-0

Hoehl, S., Reid, V. M., Parise, E., Handl, A., Palumbo, L., & Striano, T. (2009). Looking at eye gaze processing and its neural correlates in infancy—Implications for social development and autism spectrum disorder. Child Development, 80, 968–985. doi:10.1111/j.1467-8624. 2009.01311.x

Horowitz, F. D. (1975). Principles and procedures in the operation of an infant experimental research labora- tory. In F. D. Horowtz (Ed.), Visual attention, auditory stimulation, and language discriminiation in young infants. Monographs of the Society for Research in Child Development, 39(Serial No. 158). doi:10.1111/1540-5834. ep11787948

Jakobovits, A. A. (2009). Grasping activity in utero: A sig- nificant indicator of fetal behaviour. Journal of Perinatal Medicine, 37, 571–572. doi:10.1515/JPM.2009.094

Johnson, M. H. (2005). Subcortical face processing. Nature Reviews Neuroscience, 6, 766–774. doi:10.1038/nrn1766 Johnson, M. H. (2006). Biological motion: A perceptual

“life detector”? Current Biology, 16, R376–R377. doi:10. 1016/j.cub.2006.04.008

Johnson, M. H., Grossmann, T., & Cohen Kadosh, K. (2009). Mapping functional brain development: Build- ing a social brain through interactive specialization. Developmental Psychology, 45, 151–159. doi:10.1037/a0014548

Johnson, M. H., & Morton, J. (1991). Biology and cognitive development: The case of face recognition. Oxford, UK: Blackwell.

Kurjak, A., Stanojevic, M., Andonotopo, W., Salihagic-Kadic, A., Carrera, J. M., & Azumendi, G. (2004). Behavioural pattern continuity from prenatal to postnatal life—A study by four-dimensional (4D) ultrasonography. Journal of Perinatal Medicine, 32, 346–353. doi:10.1515/JPM.2004. 065

Kurjak, A., Stanojevic, M., Andonotopo, W., Scazzocchio- Duenas, E., Azumendi, G., & Carrera, J. M. (2005). Fetal behavior assessed in all three trimesters of normal pregnancy by four-dimensional (4D) ultrasonography. Croatian Medical Journal, 46, 772–780.

Macchi Cassia, V., Simion, F., & Umiltà, C. (2001). Face preference at birth: The role of an orienting mechanism. Developmental Science, 4, 101–108. doi:10.1111/1467- 7687.00154

Macchi Cassia, V., Turati, C., & Simion, F. (2004). Can a nonspecific bias toward top-heavy patterns explain newborns' face preference? Psychological Science, 15, 379–383. doi:10.1111/j.0956-7976.2004.00688.x

Marshall, P., & Shipley, T. F. (2009). Event-related potential to point-light displays of human actions in 5- month-old infants. Developmental Neuropsychology, 34, 368–377. doi:10.1080/87565640902801866

Meltzoff, A. N., & Moore, M. K. (1999). A new foundation for cognitive development in infancy: The birth of the representational infant. In E. K. Scholnick, K. Nelson, S. A Gelman, & P. H. Miller (Eds.), Conceptual development: Piaget's legacy. The Jean Piaget Symposioum Series (pp. 53–78). Mahwah, NJ: Erlbaum.

Morita, T., Slaughter, V., Katayama, N., Kitazaki, M., Kakigi, R., & Itakura, S. (2012). Infant and adult perceptions of possible and impossible body move- ments: An eye-tracking study. Journal of Experimental Child Psychology, 113, 401–414. doi:10.1016/j.jecp.2012. 07.003

Peelen, M., & Downing, P. E. (2007). The neural basis of visual body perception. Nature Reviews Neuroscience, 8, 636–648. doi:10.1038/nrn2195

Piontelli, A. (2010). Development of normal fetal move- ment: The first 25 weeks of gestation. New York, NY: Springer.

Pourtois, G., Peelen, M., Spinelli, L., Seeck, M., & Vuilleu- mier, P. (2007). Direct intracranial recording of body-selective responses in human extrastriate visual cortex. Neuropsychologia, 45, 2621–2625. doi:10.1016/j.neuro- psychologia.2007.04.005

Regolin, L., Tommasi, L., & Vallortigara, G. (2000). Visual perception of biological motion in newly hatched chicks as revealed by an imprinting procedure. Animal Cognition, 3, 53–60. doi:10.1007/s100710050050

Reid, V., Belsky, J., & Johnson, M. H. (2005). Infant perception of human action: Toward a developmental cognitive neuroscience of individual differences. Cognition, Brain, Behaviour, 11, 35–52.

Reid, V. M., Hoehl, S., Landt, J., & Striano, T. (2008). Human infants dissociate structural and dynamic infor- mation in biological motion: Evidence from neural systems. Social, Cognitive and Affective Neuroscience, 3, 161–167. doi:10.1093/scan/nsn008

Saxe, R., Tzelnic, T., & Carey, S. (2007). Knowing who dunnit: Infants identify the causal agent in an unseen causal interaction. Developmental Psychology, 43, 149– 158. doi:10.1037/0012-1649.43.1.149

Simion, F., Regolin, L., & Bulf, H. (2008). A predisposition for biological motion in the newborn baby. Proceedings of the National Academy of Sciences of the United States of America, 105, 809–813. doi:10. 1073_pnas.0707021105

Slaughter, V., & Heron, M. (2004). Origins and early development of human body knowledge. Monographs of the Society for Research in Child Development, 69 (2, Serial No. 276). doi:10.1111/j.1540-5834.2004.00286.x

Slaughter, V., Heron, M., & Sim, S. (2002). Development of preferences for the human body shape in infancy. Cogni- tion, 85, B71–B81. doi:10.1016/S0010-0277(02)00111-7

Slaughter, V., Stone, V. E., & Reed, C. (2004). Perception of faces and bodies—Similar or different? Current Directions in Psychological Science, 13, 219–223. doi:10.1111/j. 0963-7214.2004.00312.x

Sparling, J. W., Van Tol, J., & Chescheir, N. A. (1999). Fetal and neonatal hand movement. Physical Therapy, 79, 24–39. Retrieved from http://ptjournal.apta.org/ content/79/1/24

Turati, C., Macchi Cassia, V., Simion, F., & Leo, I. (2006). Newborns' face recognition: The role of inner and outer facial features. Child Development, 77, 297–311. doi:10. 1111/j.1467-8624.2006.00871.x

Van der Meer, A. L. H. (1997). Keeping the arm in the limelight: Advanced visual control of arm movements in neonates. European Journal of Paediatric Neurology, 1, 103–108. doi:10.1016/S1090-3798(97)80040-2

Van der Meer, A. L. H., van der Weel, F. R., & Lee, D. N. (1995). The functional significance of arm movements in neonates. Science, 267, 693–695. doi:10.1126/science. 7839147

von Hofsten, C. (2004). An action perspective on motor development. Trends in Cognitive Science, 8, 266–272. doi:10.1016/j.tics.2004.04.002

Vinter, A. (1986). The role of movement in eliciting early imitations. Child Development, 57, 66–71. doi:10.2307/ 1130638

White, B., Castle, P., & Held, R. (1964). Observations on the development of visually-directed reaching. Child Development, 35, 349–364. doi:10.2307/1126701

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. Cognition, 69, 1–34. doi:10.1016/S0010-0277(98)00058-4

Zoia, S., Blason, L., D'Ottavio, G., Bulgheroni, M., Pezzetta, E., Scabar, A., & Castiello, U. (2007). Evidence of early development of action planning in the human foetus: A kinematic study. Experimental Brain Research, 17, 217–226. doi:10.1007/s00221-006-0607-3

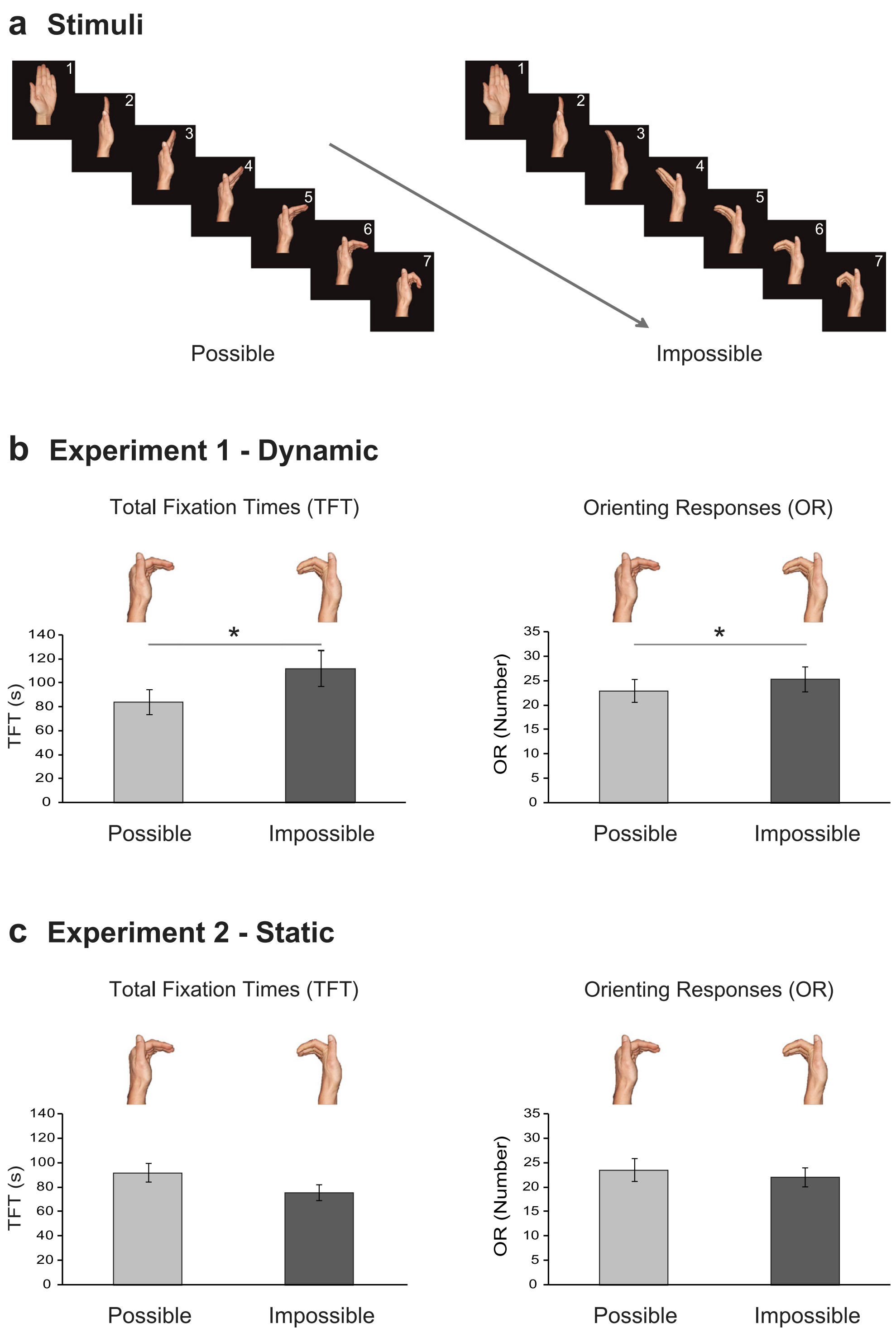

Figure 1. Stimuli and results from the two experiments. (a) Frames used to create possible and impossible whole-hand closure stimuli are shown. In particular, Frames 1–7 Possible and 1–7 Impossible were implemented in Experiment 1 (dynamic stimuli). Frame 6 Possible and Frame 6 Impossible were used in Experiment 2 (static stimuli). (b) Total fixation time and orienting responses to the possible and impossible dynamic whole-hand closure in Experiment 1. (c) Total fixation time and orienting responses to the possible and impossible static hand posture in Experiment 2 (see also the online Supporting Information). Error bars represent standard errors of the mean. *$p < .05$