Abstract

The development of the ability to recognize the whole human body shape has long been investigated in infants, while less is known about their ability to recognize the shape of single body parts, and in particular their biomechanical constraints. The present study aimed to explore whether 9- and 12-month-old infants have knowledge of a hand grasping movement (i.e. pincer grip), being able to recognize violations of the hand's anatomical constraints during the observation of that movement. By using a preferential looking paradigm, we showed that 12-month-olds discriminate between biomechanically possible and impossible pincer grips, preferring the former over the latter (Experiment 1). This capacity begins to emerge by 9 months of age, modulated by infants' own sensorimotor experience with pincer grip (Experiment 2). Our findings indicate that the ability to visually discriminate between pincer grasps differing in their biomechanical properties develops between 9 and 12 months of age, and that experience with self-produced hand movements might help infants in building a representation of the hand that encompasses knowledge of the physical constraints of this body part.

Introduction

In our daily life, we constantly interpret social cues from body movements such as eye gaze shifts, facial expressions, manual gestures, and body postures to infer intentions and emotions of the people we interact with. Although bodies play a similar role to faces in conveying information about others' internal states (de Gelder, 2006; Slaughter, Stone, & Reed 2004), so far the development of infants' ability to process body parts other than faces has been less explored than face processing (e.g., Johnson, Senjua, & Tomalski, 2015).

A way to investigate human body perception in infancy is to study how the ability to detect violations in the human shape and its motion develops. Researchers have largely explored infants' recognition of the whole human body shape (Christie & Slaughter, 2009, 2010; Heron & Slaughter, 2010; Slaughter, Heron, & Sim, 2002; Slaughter & Heron, 2004; Slaughter, Heron-Delaney, & Christie, 2011; Zieber, Bhatt, Hayden, Kangas, Collins, & Bada, 2010), while less attention has been devoted to infants' ability to identify violations in the shape and postures of single body parts.

The ability to recognize the whole human shape develops gradually during the first year of life (Bhatt, Hock, White, Jubran, & Galati, 2016). Infants can detect biological motion in dynamic point-light-displays (PLDs) as early as few days from birth, showing a preference for biological over non-biological motion (Simion, Regolin, & Bulf, 2008). By the age of 3 months, infants discriminate between possible and impossible whole body configurations, presented as PLD or more realistic stimuli, such as videos, pictures, or drawings (Bertenthal, Proffitt, & Kramer, 1987; Christie & Slaughter, 2009; 2010). For instance, 3.5-month-olds discriminate between typical bodies and bodies with scrambled gross anatomy (e.g., switched

location of arms and legs) or with distorted proportions (Zieber, Kangas, Hock, & Bhatt, 2015).

Focused on infants' perception of the *whole* human body shape, these studies provide support to the hypothesis that humans possess a 'specialized structural description' of how the different parts of the body are arranged, specifying their relative positions and boundaries into an overall structure (Buxbaum & Coslett, 2001; Sirigu, Grafman, Bressler, & Sunderland, 1991). The ability to detect violations of the whole human body structure, as in the case of a scrambled body, requires a global, configural processing of the spatial relations among body parts, leading to the recognition of inappropriate anatomical connections between them (Reed, McGoldrick, Shackelford, & Fidopiastis, 2004; Reed, Stone, Grubb, & McGoldrick, 2006).

Unlike body structure knowledge, the ability to identify violations in the shape of single body parts *per se* has received far less attention. Being able to visually recognize violations of the biomechanical constraints of a joint or body part, such as the elbow or the hand, requires a representation of that single body part specifying its physical limits during the execution of specific movements. Identifying violations of these constraints involves local processing of body part details, rather than global processing of the entire body. In other words, such ability requires processing of featural information, defined as information regarding relatively local details, as compared to more global, spatial-relational properties of bodily stimuli.

Evidence that infants attend to featural information when observing bodily stimuli comes from studies investigating action and gesture understanding. From an early age infants rely on the actor's hand shape to assess the goal-directedness of the observed hand actions, and to recognize communicative gestures (Ambrosini, Reddy,

de Looper, Costantini, Lopez, & Sinigaglia, 2013; Daum & Gredebäck, 2011; Daum,

Vuori, Prinz, & Aschersleben, 2009; Loucks & Sommerville, 2012a; 2012b). By 6-to-

8 months of age, infants anticipate the goal of a reach-to-grasp action by performing

proactive gaze to the action target when the hand is shaped in a whole-hand grasp or

in a pincer grip, but not when the hand performs a non-functional closed fist reach

(Ambrosini et al., 2013). **Around the same age or soon after,** they are able to predict

the directionality of grasping actions and communicative gestures, such as pointing

and give-me gestures in social interactions (e.g., Daum & Gredebäck, 2011; 2013;

Elsner, Bakker, Rohlfing, & Gredebäck, 2014).

These studies show that infants process fine details related to the surface

properties of the hand to infer the intentions of the agent. However, to build a

complete representation of the body and its parts, infants need to gain knowledge

about how the body and its parts can and cannot move, in accordance with their

biomechanical constraints. To investigate infants' knowledge of the human body

parts' physical limits, some studies have assessed infants' expectations about

biomechanical constraints of the arms. While 6- to 8-months-olds either fail to detect

or disregard information about the biomechanical properties of the elbow during

grasping actions (Southgate, Johnson, & Csibra, 2008), infants from the age of 8-12

months discriminate between arm movements that respect or violate the

biomechanical constraints of the elbow (Morita, Slaughter, Katayama, Kitazaki,

Kakigi, & Itakura, 2012; Reid, Belsky, & Johnson, 2005). When presented with

grasping actions in which the violation of the biomechanical constraints involves the

hand, 6-months-old infants are able to distinguish between possible and impossible

actions (Geangu, Senna, Croci, & Turati, 2015). Even 2-day-old newborns are able to

detect violations of the hand's constraints when presented with hand movements they

had already experienced during prenatal life (i.e., whole hand closure; Longhi, Senna, Bolognini, Bulf, Tagliabue, Macchi Cassia, & Turati, 2015).

It is likely that the early ability to discriminate between anatomically plausible and implausible hand movements is rooted in the relevance of the hand to the human species. Since birth, infants pay special attention to their own and others' hands, compared to other body parts (Van der Meer, 1997; von Hofsten, 2004), especially during hand-object interactions (Yoshida & Smith, 2008). Interestingly, infants' understanding of manual actions seems to be influenced by infants' own sensory-motor experience with the observed action (e.g., Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2011; Gerson & Woodward, 2014; Kanagogi & Itakura, 2011; Natale, Senna, Bolognini, Quadrelli, Addabbo, Macchi Cassia, Turati, 2014; Sommerville, Woodward, & Needham, 2005). Sensorimotor experience might affect action perception by helping infants learning the sensory counterpart of the actions they are able to perform. Similarly, it has been suggested that the ability to perform sophisticated goal-directed actions involving specific body parts can help infants to learn the biomechanical properties of those body parts, and thus to detect violations of their physical constraints while observing similar actions (Geangu et al., 2015; Reid et al., 2005).

In light of this evidence, the present study aimed to investigate whether infants are able to recognize violations of the biomechanical properties of the fingers during the observation of a single hand movement (i.e. pincer grip) when such movement is not embedded in a goal-directed action. Indeed, while infants might be able to recognize a familiar grasp as such, the violation of the hand's anatomy might be unnoticed. To this end, in Experiment 1 we assessed whether 12-month-old infants are able to visually discriminate between an anatomically plausible pincer grip, and a

similar movement violating the fingers' constraints. Such ability was assessed by means of an infant-controlled visual preference paradigm (Fantz, 1958), which consists in presenting two stimuli (here the possible and impossible hand configurations) bilaterally on the screen, and recording the length of time the infant looks at each stimulus. Stimulus discrimination is inferred by longer looking time to one stimulus than the other. Therefore, if infants are able to discriminate between the possible and the impossible pincer grip, they will spend significantly more time looking at one grip over the other.

The same procedure was used in Experiment 2 to further investigate in 9-month-old infants whether the discrimination between possible and impossible pincer grips might be influenced by infants' capability to perform this particular hand movement. Pincer grip requires the ability to move fingers individually, in order to grasp an object between the thumb and the index finger. Although rudimentary precursors of pincer grip appear in the first months of life (Wallace & Wishaw, 2003), it is only from the age of 9 months that the ability to execute efficient precision grips emerges (Butterworth, Verweij, & Hopkins, 1997). Therefore, Experiment 2 aims at uncovering the role of sensorimotor experience in infants' detection of anatomical constraints' violations during hand movements by exploring visual recognition of possible pincer grip in relation to infants' ability to perform pincer grips.

Experiment 1

Twelve-month-old infants' ability to visually discriminate between possible and impossible pincer grips was tested using an infant-controlled preferential looking paradigm. Infants were simultaneously presented with two videos, one showing a biomechanically possible grip, and the other displaying a biomechanically impossible

version of the same movement. A preferential looking paradigm was used to establish whether infants can discriminate between the stimuli based on knowledge of the biomechanical constraints of the hand that they bring to the experimental setting. Indeed, this technique rules out the possibility that infants discriminate between the stimuli based on short-term learning of the stimulus features that they develop during the experimental session, as it might happen in habituation tasks (see Christie & Slaughter, 2010). A spontaneous preference for either the possible or impossible hand configuration would allow us to conclude that infants have access to a representation of the hand that specifies how the hand should move, according to the biomechanical constraints of the fingers. A preference for the possible grip would be in line with earlier demonstrations of infants' preference for familiar motion patterns, such as human biological motion (Bertenthal, Proffitt, & Cutting, 1984; Bertenthal et al., 1987; Simion et al., 2008), biologically possible versus impossible whole-body movements (Christie & Slaughter, 2010), and movements that are already part of infants' motor repertoire (Sanefuji, Ohgami, & Hashiya, 2008). Conversely, a preference for the impossible grip would suggest that the movement is perceived as an unfamiliar, unexpected event as compared to the overly familiar possible movement, and would be in accord with earlier demonstrations of longer looking times to unfamiliar body shapes and movements (Christie & Slaughter, 2010; Geangu et al., 2015; Longhi et al., 2015; Morita et al., 2012; Reid et al., 2005; Slaughter et al., 2002).

Materials and Methods

Participants.

Fourteen 12-month-old infants (9 females, Mean age, M = 12 months and 7

days, Standard Deviation, SD = 9 days) took part in the study. Four additional infants were tested, but discarded from the final sample because they became fussy during the testing session (N = 2), watched only one out of two trials (N = 1), or manifested a position bias, looking towards one direction for over 85% of their total looking time across the two trials (N = 1). Participants were all able to perform pincer grips, as stated by their parents and confirmed by a brief motor task administered at the end of the experimental session (see below). The protocol was carried out in accordance with the ethical standards of the Declaration of Helsinki (BMJ 1991; 302: 1194), and approved by the ethics committee of the University of X. Parents provided their written informed consent before the beginning of the experimental session.

Stimuli.

Two videos showing a hand moving against a black background were simultaneously presented side by side on a PC monitor. The videos showed an index finger and a thumb closing either in a biomechanically possible or impossible pincer grip. To create the stimulus depicting the possible grip, 7 frames were extracted from a video that recorded a female right hand performing a precision grip. The video presenting the impossible gesture was obtained by modifying the single frames with Photoshop software (Adobe Systems, San Jose, CA). The first two frames were identical in both stimuli: the first frame depicted the right hand with the palm facing the observer and the fingers straight up; the second frame showed the hand rotated by 90° with respect to its vertical axis (i.e., seen from a sideway view), with the thumb facing the viewer and the other fingers aligned and oriented upward. In the following 5 frames, the thumb and the index finger could either close gradually until a precision grip was completed (possible grip) or bend unnaturally towards the back of the hand,

violating the biomechanical properties of the phalangeal joints, until the nails of the two fingers got in contact (impossible grip) (Figure 1a). The angles of the phalanxes' displacement were matched frame by frame between the possible and impossible stimuli. Luminance, contrast, hue, and saturation were kept constant across all frames in the two videos. Each video lasted 4 s. The mean grayscale value, calculated across the frames of each stimulus, did not differ between the possible (M = 48.4, SD = 0.66) and impossible (M = 48.1, SD = 0.31) grips (Mann-Whitney test, U = 0, Z = 0, p = 1). Moreover, the two videos were comparable in smoothness, as confirmed by a frame-by-frame cross-correlation calculated across successive frames in each condition (possible grip: M = 1.98, SD = 0.1; impossible grip: M = 1.93, SD = 0.1; Mann-Whitney test, U = 0, Z = 0, p = 1). The size of the hand, at a distance of 60 cm, subtended a visual angle of 14.8°-15° in height and 5.3°-10.3° in width. In each frame, the palm of the hand was 12.7° from the centre of the screen.

In order to ascertain that the stimuli were actually perceived as either biologically possible or impossible movements, 15 adults (7 female, mean age = 26.4, SD = 2.92) were asked to rate the anatomical plausibility of the stimuli on a 5-point Likert scale, where -2 and +2 indicated minimum and maximum plausibility, respectively. Results showed that the impossible grip was perceived as impossible to perform (M = -1.93, SD = 0.25), while the possible grip was judged as being plausible (M = 1.93, SD = 0.25, Wilcoxon test, p < 0.001).

Procedure.

Participants sat in an infant seat at a distance of about 60 cm from a 24" monitor (1920 x 1200 pixel resolution, refresh rate of 60 Hz) in a dimly lit room. A video-camera was placed just above the monitor and recorded the infants' face. The

video-camera sent live image of the participant to a second computer screen, allowing an experimenter to code infants' gaze direction online. The experimenter could see only the infants' face and was blind to the position of the stimuli on the screen. Stimulus presentation and online coding were controlled with E-prime 2 (Psychology Software Tools). An infant-controlled preferential looking paradigm was used. To catch infants' attention at the beginning of the experimental session, the experimenter presented a red circle (1.6°) flickering at a frequency of 300 ms at the centre of the screen against a black background. As soon as the infant looked at it, the experimenter turned off the circle and started the video presentation. Each participant was presented with two trials. In each trial the possible and impossible grips were shown simultaneously, one on the left and the other on the right side of the screen, then their position was switched in the following trial. The initial position of the stimuli was counterbalanced across participants. Stimuli were shown continuously, in a loop, and each trial ended when the infant watched each stimulus at least once for a minimum of 5 s, and looked away for more than 10 s. At the end of the first trial, the fixation point (i.e. the red circle) was presented again to catch infant's attention before presenting the second trial.

Looking time. The experimenter, who was blind to the left/right position of the stimuli on the screen, coded the duration of infant's looking times by pressing either the left or right button of the mouse according to which side of the screen the infant was looking at. When the infant stopped looking, the button was released. Video-recordings of eye movements were coded offline for half of the infants by a second observer, blind to the hypotheses of the study and to the stimuli shown. Inter-rater agreement (Pearson correlation), as computed on total looking times on the two trials, was $r = 0.99$.

Grasping skills. Infants' ability to perform a pincer grip was assessed at the end of the experimental session. Infants' mothers were asked about their child's ability to perform the grip, and then infants were engaged in a brief motor task. They sat on their mother's lap in front of a table, and one experimenter presented them with a small ring-shaped cereal. The object was placed on the table, on infants' body midline, and within a comfortable reaching distance. The experimenter attracted the infant's attention toward the object by tapping next to it or moving it. If infants did not grasp the cereal at the first attempt, the task was repeated for a maximum of 5 times. Grasping ability was scored with '1' or '0', depending on whether the infant was able or unable, respectively, to grasp the cereal with a pincer grip. The grip was considered as pincer if the infant grasped the object by opposing the index finger against the thumb, either with a tip-to-tip or a pad-to-pad pinch. Moreover, if the infant's grasping was ambiguous (e.g., the infant fumbled with the cereal before successively grasping it), the presentation of the object was repeated. Infants' performance was scored on-line by two experimenters, who were both blind to the results of the preferential looking task. There was a complete inter-rater agreement between the two experimenters. All participants were able to perform pincer grip, as reported by their mothers, and measured in the motor task.

Results and discussion

Given that the data were not normally distributed, as assessed by a Kolmogorov–Smirnov test ($p < .05$), total fixation times on the two stimuli for each of the two trial presentations were log-transformed to normalize their distribution. Data were then analyzed via an Analysis of Variance (ANOVA) with grip type (possible, impossible) and trial presentation (first, second) as within-subjects factors. The

analysis showed a significant main effect of grip type, $F_{1,13} = 6.25$, $p = .027$, $\eta_p^2 = .22$, with longer looking times for the possible (M = 43.41 s; SD = 23.25), compared to the impossible grip (M = 35.35 s; SD = 15.21) (Figure 1b). The main effect of trial presentation, $F_{1,13} = 7.73$, $p = .016$, $\eta_p^2 = .7$, indicated that participants looked longer at the second (M = 43.22; SD = 16.66) than at the first trial (M = 35.53; SD = 25.36). The Grip type by Trial presentation interaction did not reach significance, $F_{1,13} = .027$, $p = .87$.

The significant preference for the possible grip was further confirmed by examination of the data for individual infants, showing that 12 out of the 14 infants in the sample looked longer at the possible stimulus than at the impossible one (binomial test, $p = .006$).

The present findings indicate that 12-month-old infants are able to distinguish between biomechanically possible and impossible pincer grips. Since participants were all familiar with the possible pincer grip movement, and able to perform it, one could claim that their motor ability to perform the observed hand movement may have affected their visual discrimination of the two observed grips. To test for this hypothesis, in Experiment 2 we investigated whether the attention imbalance towards the possible grip is present also at 9 months of age, when the ability to properly perform pincer grips is still developing.

Experiment 2

Experiment 2 used the same methods and stimuli used in Experiment 1 to explore whether the capability to perform pincer grip movements might affect infants' ability to visually distinguish between pincer grips either respecting or violating the biomechanical constraints of the fingers. To this end, 9-month-old infants were

involved in the study, as 8-to-9 months is the critical time in the development of grasping abilities when pincer grasp typically emerges, mainly in the form of an 'inferior pincer grip', involving a pad-to-pad, instead of a more mature tip-to-tip pinch (Butterworth et al., 1997). We tested whether the preference for the possible grip exhibited by older infants in Experiment 1 generalizes to 9-month-olds. Moreover, we hypothesized that, if sensorimotor experience with a specific movement–here the pincer grip–plays a role in the ability to visually detect the violation of physical constraints of the body part involved in such movement, 9-month-olds may show individual differences in their ability to visually discriminate between possible and impossible pincer grips as a function of their ability to perform such grasping movement. To this end, infants' ability to perform precision grip was assessed during a brief motor task at the end of the experimental session.

Materials and Methods

Participants.

Fourteen healthy full-term 9-month-old infants (5 females, M age = 9 months and 6 days, SD = 13 days) took part in the study. Six additional infants were tested, but discarded from the final sample because they became fussy during the testing session (N = 4), watched only one out of two trials (N = 1), or manifested a position bias (N = 1).

Procedure. Procedure and behavioural measures were the same as in Experiment 1. There was a complete inter-rater agreement between the two experimenters assessing the motor performance. With respect to grasping skills, 7 out of the 14 (i.e., 50%) 9-month-old infants were able to perform a pincer grip. Therefore, subsequent analyses were conducted separating infants in two groups, namely able vs. unable to perform

pincer grip. Infants able to perform pincer grip did not significantly differ in age from those who could not perform the grip, t = 1.395, p = .19. For 12 out of 14 infants there was agreement between the mother's report and the infant's performance in the motor task. In the two remaining cases, the infants grasped the small cereal with a pincer grip, while their mothers have reported them being unable to perform such a grip. The two infants were scored as 1, according to the motor task's result.

Results and discussion

Because the data were not normally distributed, as assessed by a Kolmogorov-Smirnov test (p < .05), total fixation times were log-transformed.

Data were then analyzed via an ANOVA, with grip type (possible, impossible) and trial presentation (first, second) as within-subjects factors, and grip skill (able, unable to perform pincer grip) as between-subjects factor. The analysis revealed a significant Grip type by Grip skill interaction, $F_{1,12} = 5.02$, p = 0.04, $\eta_p^2 = .38$. Post-hoc comparisons (Newman–Keuls) showed that infants who were able to perform the pincer grip looked longer at the possible grip (M = 50.86 s; SD = 19.28) than at the impossible one (M = 31.67; SD = 17.71, p = .044). Conversely, infants who were unable to perform the pincer grip looked equally long at the possible (M = 39.54; SD = 21.67) and impossible grips (M = 40.03; SD = 24.58), p = 0.9 (Figure 1c). The main effect of grip type was close to significance, $F_{1,12} = 4.29$, p = .06, $\eta_p^2 = .32$, with an overall trend for longer looking times to the possible (M = 45.2 s; SD = 20.56 s) than to the impossible grip (M = 35.85 s; SD = 20.99 s). No other main effects or interactions were significant (all *p*s > .12) (Figure 1c**, left panel**).

Infants' preference to the possible stimulus were also analyzed by computing a preference score for each participant by dividing the looking time

to the possible stimulus by the sum of the looking time to the possible and impossible stimuli. One sample t-tests (vs. 50%) indicated that preference scores were significantly above the chance level for the group of infants who were able to perform pincer grips (M = 63%; SD = 13), t(6) = 2.61, p = 0.04, but not for those unable to perform the grips (M = 49%, SD = 10), t(6) = 0.2, p = 0.82. Overall, 6 out of 7 infants who were able to perform pincer grips **preferred (i.e., showed a preference score larger than 50%)** the possible **stimulus** (binomial test, p = .055**), showing a mean preferences score of 66% (SD = 10). In contrast,** only **3** out of **the** 7 infants **who were** unable to perform **pincer grips looked longer toward the possible stimulus** (binomial test, p = .27**), showing a mean preference score of 59% (SD = 3) (Figure 1c, right panel).**

On average, each trial lasted 40.52 s (SD = 17.68). Average trial duration did not differ between infants who preferred the possible grip (M =39.2; SD = 11.86) and those who preferred the impossible one (M = 42.8; SD = 25.9), t_{12} = 0.36, p = 0.72 (2-tailed).

–Insert Figure 1 about here–

The present findings suggest that the ability to perform pincer grips might play a role in the visual discrimination of pincer grips either respecting or violating the fingers' biomechanical properties. In fact, the preference for the possible grip observed in Experiment 1 **was evident in Experiment 2 only in the group of 9-**month-old infants who were able themselves to perform the pincer grip. **W**e cannot exclude that these infants differed from those **un**able to perform pincer grips for other variables, in addition to their grasping abilities; **nonetheless** they did not differ in

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their chronological age. **Furthermore, despite the small** sample size, the **finding** that 6 out of the 7 infants in the grasping group**, but only 3 out of the 7 in the no-grasping group,** showed **a** preference for the possible pincer grip indicates that the observed group difference is reliable.

General Discussion

This study investigated whether 9- and 12-month-old infants are able to detect violations of the biomechanical properties of the fingers during the observation of pincer grips, and whether such ability might be influenced by infants' own motor experience with the observed grip. Results indicated that 12-month-old infants were able to discriminate between a biomechanically possible and an impossible pincer grip, showing a preference for the possible stimulus. Among the 9-month-old **infants,** those who were able to perform precision grips**, as a group,** looked longer at the possible grip than at the impossible one. **In contrast, the group of** infants who lagged behind in their grasping abilities did not show a preference for either of the two visual stimuli.

In an action context, infants discriminate between possible and impossible (i.e., violating the constraints of the fingers) grasping actions at about 6 months (Geangu et al., 2015). Of note, when exposed to possible and impossible whole-hand grasps, even 2-day-old newborns discriminate between the two (Longhi et al., 2015). Given that whole-hand grasps are part of newborns' motor repertoire, these findings suggested that sensitivity to violations of hand's physical constraints during the observation of whole-hand gestures at birth would be modulated by newborns' own sensorimotor experience with that specific grip.

The current study extends this previous evidence, showing that infants' motor

skills with pincer grips affect sensitivity to violations of fingers' constraints **in observed pincer grip gestures**. Indeed, the ability to visually detect such violations is present at 12 months, when pincer grip is already part of infants' motor repertoire. Among 9-month-olds, infants who were able to perform pincer grips **proved to be more sensitive to violations of fingers' constraints than those who were unable to perform this type of grasps**. **This finding is** in line with previous evidence highlighting a link between sensorimotor experience and action or gesture recognition. Sensorimotor experience with the observed hand movement might facilitate infants' visual discrimination between different hand shapes. For instance, infants who are able to perform pincer grips show **more** anticipatory gaze**s** to a precision grasp (Ambrosini et al., 2013), and understand its functional consequences **better than those unable to perform such grips** (Loucks & Sommerville, 2012a). Similarly, sensorimotor experience with self-produced actions seems to play a role in the development of the ability to detect violations of the human anatomy during goal-directed actions: infants with good grasping skills (Geangu et al., 2015), or with overall relative high motor skills (Reid et, 2005) discriminate better than less skilled infants between possible and impossible reaching and grasping actions. Along this line, our findings suggest that infants' motor experience with pincer grips plays a role in their ability to recognize violations in the fingers' anatomical constraints, even during the execution of intransitive movements.

It might be argued that infants' ability to discriminate between hand movements differing in their biomechanical properties may reflect some unspecific maturational processes affecting both the emergence of a new motor skill (here the ability to perform pincer grip) and changes in the way in which that movement is visually processed. However, previous evidence showing that motor training

influences the interpretation of actions in infants (Libertus and Needam, 2010; 2011; Sommerville et al., 2005; Sommerville, Hildebrand, & Crane 2008) indicates that the opportunity to experience new actions or movements affects action perception, over and above unspecific maturational processes. Our results suggest that sensorimotor experience might exert a key role also in shaping infants' visual ability to discriminate between possible and impossible hand movements.

The present study highlights for the first time the influence of sensorimotor experience with pincer grips on infants' ability to visually detect violations of fingers' constraints during pincer grips. Future studies are necessary to further characterize the role of grasping skills in such visual discrimination ability, going beyond the simple dichotomous scoring system (able/unable) adopted here to measure infants' pincer grasp abilities. For instance, featuring the level of maturity of the pincer grip (i.e., differentiating between inferior pad-to-pad, or superior tip-to-tip types of pincer grasps), or considering the number of attempts made by the infant before making a successful grasp might allow a better understanding of the relationship between grasping abilities and looking preferences. In the present study, 3 out of the 7 infants who were unable to perform pincer grip showed a preference for the possible grip. With our dichotomous score we cannot exclude that those 3 infants differ from the others included in the non-grasping group in some subtle motor skills that our scoring system did not capture. A more sensitive scoring system, together with a greater sample size, might provide a deeper understanding of the link between grasping skills and the ability to visually detect violations of the fingers' constraints.

Which aspects of infants' previous sensorimotor experience are likely related

to their understanding of the biomechanical constraints of the hand? The fact that even newborns are able to visually discriminate between a grip they have already experienced and one violating hand's constraints (Longhi et al., 2015) might indicate that active experience with intentional actions is not necessary in order to drive such ability. Importantly, this suggests that proprioceptive and tactile counterparts of movements might have played the pivotal role. Indeed, while newborns have gained extensive tactile- and proprioceptive-motor experience in utero, they don't have a comparable visual experience. Later on, infants' predisposition to pay attention to and visually explore their hands from the very first days of life (Van der Meer, 1997; von Hofsten, 2004) likely contributes to the active learning of the association between the motor and visual components of self-generated movements; this ability, in turn, might guide the development of a more complex and complete body representation.

Unlike previous studies, we used an intransitive movement, consisting in a hand presented alone, detached from the whole body and in the absence of any object (thus avoiding object affordances) or communicative context. The ability to discriminate between biomechanically possible and impossible pincer grips requires not only knowledge of the hand gesture, but also knowledge of the biomechanical constraints of the body part performing the movement. In our daily life, we constantly interpret others' manual gestures, even when they are not directed to a specific target: to do so, we recognize hand configurations and attribute a meaning to them. The spontaneous preference for a possible, familiar hand movement found in our study implies the knowledge of that movement: in order to be able to recognize violations in the hand's shape during a precision grip, infants must have access to a representation of how the hand can move during the execution of such a grip. Therefore, our results indicate that the ability to recognize violations in the biomechanical constraints of the

fingers during the observation of pincer grips emerges between 9 and 12 months of age. They also suggest that the ability to discriminate between possible and impossible hand gestures might be supported by the sensorimotor representation of infants' own hand movements, likely derived by infants' own motor experience. Experience with self-produced hand movements might provide infants with a unique insight into the biomechanical properties of that body part, helping them to develop knowledge about how body parts can or cannot move.

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