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The Development of a Cross-Modal Sense of Body Ownership

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Abstract
In this study, we investigated the contribution of tactile and proprioceptive cues to the development of the sense of body ownership by testing the susceptibility of 4- to 5-year-old children, 8- to 9-year-old children, and adults to the somatic rubber-hand illusion (SRHI). We found that feelings of owning a rubber hand in the SHRI paradigm, as assessed by explicit reports (i.e., questionnaire), are already present by age 4 and do not change throughout development. In contrast, the effect of the illusion on the sense of hand position, as assessed by a pointing task, was present only in 8- to 9-year-old children and adults; the magnitude of such capture increased with age. Our findings reveal that tactile-proprioceptive interactions contributed differently to the two aspects characterizing the SRHI: Although the contribution of such interactions to an explicit sense of self was similar across age groups, their contribution to the more implicit recalibration of hand position is still developing by age 9.

Keywords
cognitive development, human body, perception

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The sense of body ownership is intrinsically linked to body self-awareness. Several studies have shown that the way people perceive their bodies arises from the efficient integration of bodily signals coming from different sensory modalities, among which touch, proprioception, and vision play a major role (Bolognini & Maravita, 2007; Ehrsson, 2012). A famous paradigm that has contributed to the notion of a multisensory sense of self is the rubber-hand illusion (RHI; Botvinick & Cohen, 1998), in which synchronous strokes performed on a participant's hidden hand and on a visible artificial rubber hand induce the participants to report that the rubber hand is their own hand. It is noteworthy that the feeling of owning a rubber hand is also induced without the contribution of vision (Ehrsson, Holmes, & Passingham, 2005; Nava, Steiger, & Röder, 2014). Indeed, in the somatic rubber-hand illusion (SRHI; Ehrsson et al., 2005; Nava et al., 2014; Petkova, Zetterberg, & Ehrsson, 2012), while blindfolded adult participants touch a rubber hand, one of their own hands is touched at the same time. This gives rise to the illusory feeling that participants are actually touching their own hands.

The RHI and SRHI are commonly measured through a questionnaire and a pointing task, which respectively assess two aspects of the illusion: an explicit, conscious feeling of having a rubber hand (i.e., self-evaluation in the questionnaire) and an implicit misinterpretation of the perceived location of one's own hand in the direction of the rubber hand (i.e., proprioceptive drift in the pointing task). Note that measures of these two aspects of the illusion do not always correlate (Nava et al., 2014; Rohde, Di Luca, & Ernst, 2011), which suggests that the explicit feelings of ownership and the recalibration of hand position reflect two separate mechanisms subserving body representation.

To date, the development of the sense of body ownership has received very little attention, notwithstanding its importance for the construction of a unitary and coherent

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representation of the body and for self-awareness. Two studies have directly investigated susceptibility to the RHI in children ages 4 to 9 (Cowie, Makin, & Bremner, 2013) and in children ages 10 to 13 (Cowie, Sterling, & Bremner, 2016). The first study showed a dissociation between reported feelings of ownership and recalibration of hand position toward the position of the rubber hand. Although both children and adults reported similar feelings of the rubber hand being their own (as indexed from responses to a questionnaire), children up to 9 years old showed larger proprioceptive drifts compared with adults. Cowie et al. (2013) proposed that these two components at the basis of the RHI may be supported by different mechanisms. In particular, although the similar scores provided in the questionnaire across age groups could indicate an early maturation of visuotactile integration processes linked to the explicit perception of ownership over one's own body, the larger proprioceptive drift could index a later-maturing, more implicit visuoproprioceptive process. It is noteworthy that Cowie et al. (2016) found that proprioceptive drifts reach adult levels by ages 10 to 11, suggesting that some aspects of multisensory body representation undergo a protracted period of development.

The contribution of visual and proprioceptive cues to the perception of bodily illusions in young children (i.e., 5- to 7-year-olds) has also been investigated by Bremner, Hill, Pratt, Rigato, and Spence (2013) using the mirror illusion (Holmes, Crozier, & Spence, 2004). In this cross-modal illusion, a mirror is placed between the participant's arms, facing one hand (e.g., the left) and covering the other hand (i.e., the right). The mirror presents an apparent visual location of the (right) hand, which is in conflict with its real position perceived through proprioception. In adults, reaching responses made with the unseen right arm are biased by the mirror reflection of the left hand. Overall, children were susceptible to the illusion (as indexed by the reaching bias), and the magnitude of this effect increased substantially up until 6 years of age.

Overall, current evidence indicates that, in particular, interactions among vision, touch, and proprioception for body representation undergo relevant changes during early childhood; note that Cowie et al. (2016) found that the development of body representation is protracted up to 11 years of age. However, it is still unknown whether and how tactile and proprioceptive modalities interact in the absence of vision and contribute to the development of the sense of body ownership and position.

Touch and proprioception alone, as well as their interactions, are foundational to self-perception from birth. Indeed, proprioceptive and somatosensory anatomy and functions are in place very early in prenatal development (along with chemosensation; see Turkewitz & Kenny, 1982). From birth, infants systematically explore themselves and the world primarily through touch and proprioception (e.g., moving their limbs, sucking reflex; Rochat & Striano, 2000). In particular, infants experience tactile-proprioceptive interactions when they bring their hands toward their mouths or other parts of their body, thus learning the contingency of this multisensory stimulation (Butterworth & Hopkins, 1988). This behavior may predict and shape a sense of body ownership that largely involves tactile-proprioceptive cues. Furthermore, infants can reach toward objects even if they cannot see their own hands, as shown in a study (Clifton, Muir, Ashmead, & Clarkson, 1993) in which infants successfully grasped an object both in light and in darkness; this results suggests that proprioceptive cues drive the development of reaching in early infancy.

In light of these considerations, the current study explored, for the first time, the role of proprioceptive and tactile cues in the development of the sense of bodily self (with no visual contribution) by testing the susceptibility to the SRHI of children ages 4 to 5 and 8 to 9. We had two competing hypotheses. First, because tactile and proprioceptive modalities develop very early in ontogeny and are integrated early, children could already present a susceptibility to the illusion similar to that in adults. Alternatively, because tactile information needs to be properly calibrated by vision (see Gori, Del Viva, Sandini, & Burr, 2008), children may show less susceptibility to the illusion than adults do, or even no susceptibility.

Experiment 1

Method

Participants. Informed by developmental studies on comparable topics (e.g., Cowie et al., 2013), we set our sample size at 18 per condition for the groups of children, all of whom were right-handed. Our final sample comprised 72 children—thirty-six 4- to 5-year-olds (20 girls; mean age = 5.0 years, *SD* = 0.5) and thirty-six 8- to 9-year-olds (19 girls; mean age = 5.1 years, *SD* = 0.6)—and 40 adults (25 women; mean age = 23.8 years, *SD* = 5.3). Four additional 4- to 5-year-old children were tested but excluded from the final sample because they had difficulty understanding the task. All age groups were further split into two groups; half were assigned to the synchronous condition, and half were assigned to the asynchronous condition. This between-subjects design was aimed at minimizing testing time; shorter test times made it more likely that the children would maintain focus. The children were tested after we obtained written informed consent from their parents. The study was approved by the ethics committee of the University of Milan-Bicocca.

Experimental procedure

Overview. Each participant was tested individually in a quiet room and was informed about the study and the material used (i.e., rubber hand, blindfold). Each participant was then blindfolded, and his or her left hand was placed palm down on the table. To familiarize the participant with the pointing task, the experimenter took the participant's right index finger and moved it toward the participant's left middle finger over the top of the cardboard box. Once the participant understood the task, the actual pointing task started, and the experimenter recorded the participant's pointing error on the three trials. After the pointing task, the experimenter placed the rubber hand next to the participant's left hand and started with the illusion induction. After the induction of the SRHI, the participant was retested on the pointing task, which consisted of three pointing trials. At the end of the task, the blindfold was removed, and the participant was presented with the questionnaire.

Induction of the SRHI. A life-sized rubber left hand served as the stimulus to induce the SRHI. The rubber hand was placed between the participant's hands, with 15 cm between the participant's left index finger and the rubber hand's index finger. The stimulation consisted of having the experimenter move the index finger of the participant's right hand along the rubber hand. At the same time, the experimenter stroked the same part of the participant's left hand. In the synchronous condition, the stroking of the two hands was synchronized as closely as possible; in the asynchronous condition, the stroking was sequential (i.e., one stroke to the rubber hand and then one stroke to the participant's hand). The participant's hand was stroked in a proximal-distal direction, randomly across all fingers, knuckles, and parts of the hand, at a rate of approximately one stroke every 0.5 to 1.5 s. The stroking velocity was also randomly changed. As researchers have done in other studies (e.g., see Rohde et al., 2011), we conducted a pilot study with adults. The results showed that randomly changing spatial and temporal pattern during tactile stimulation increased a sense of ownership of the rubber hand.

Each stimulation (i.e., each trial) lasted about 60 s. There were three trials (i.e., 180 s of stimulation overall). Short breaks between trials (about 10 or 15 s) allowed the experimenter to ask the participants (particularly the children) if everything was all right.

Measurement of performance on the pointing task. We examined whether participants' sense of the location of their left hand in space changed after the stroking session. To that end, we had the participants perform a pointing task with the right-hand index finger, toward the middle finger of the left hand, which was placed under a cardboard box (60 × 30 × 40 cm) designed to resemble a small table. Participants made the pointing movement over the cardboard table, along which an open measuring tape was placed. After each trial, the experimenter typed into the computer the horizontal distance (in centimeters) between the tip of the right index finger and the actual location of the left middle finger (i.e., the pointing error). The exact position of the tip of the middle finger corresponded to 0, and the error toward the right or left side of the middle finger was coded as + or –, respectively.

Measurement of the sense of body ownership through a questionnaire. At the end of the experiment, participants were asked to rate two statements. The first one was designed to reflect the strength of the embodiment of the rubber hand: "I felt as if I were touching my own hand." The other statement was unrelated to the illusion and served as a control statement for suggestibility: "I felt as if I had three hands."[1]

All participants were asked to rate each single statement on a continuous rating scale by pointing to the appropriate position on a continuous line (adults were asked to mark the rating scale with a pencil). The extreme left of the line indicated *I strongly disagree* (−5), whereas the extreme right of the line indicated *I strongly agree* (5). A mark in the middle of the line indicated *I neither agree nor disagree* (0).

For children, the statements were repeated and rephrased until the experimenter thought the children fully understood. In addition, the scale was adapted for children to be more easily understood, so that +5 corresponded to *yes, a lot*, −5 to *not at all*, and 0 to *in between*.

Results

Pointing. Our analyses were aimed at answering two main questions: (a) Do children and adults recalibrate their hand positions after the SRHI induction? (b) Is there a change in susceptibility to the SRHI across development?

To answer the first question, we entered the average pointing error into a repeated measures analysis of variance (ANOVA), with session (pre-SRHI or post-SRHI) as a within-subjects factor and age (4- to 5-year-olds, 8- to 9-year-olds, or adults) and condition (synchronous stroking or asynchronous stroking) as between-subjects factors. The analysis revealed main effects of age, $F(2, 106) = 3.35$, $p = .04$; condition, $F(1, 106) = 17.01$, $p < .001$; and session, $F(1, 106) = 51.34$, $p < .001$. We also found the following significant interactions: Session × Age, $F(2, 106) = 14.43$, $p < .001$; Session × Condition, $F(1, 106) = 43.73$,

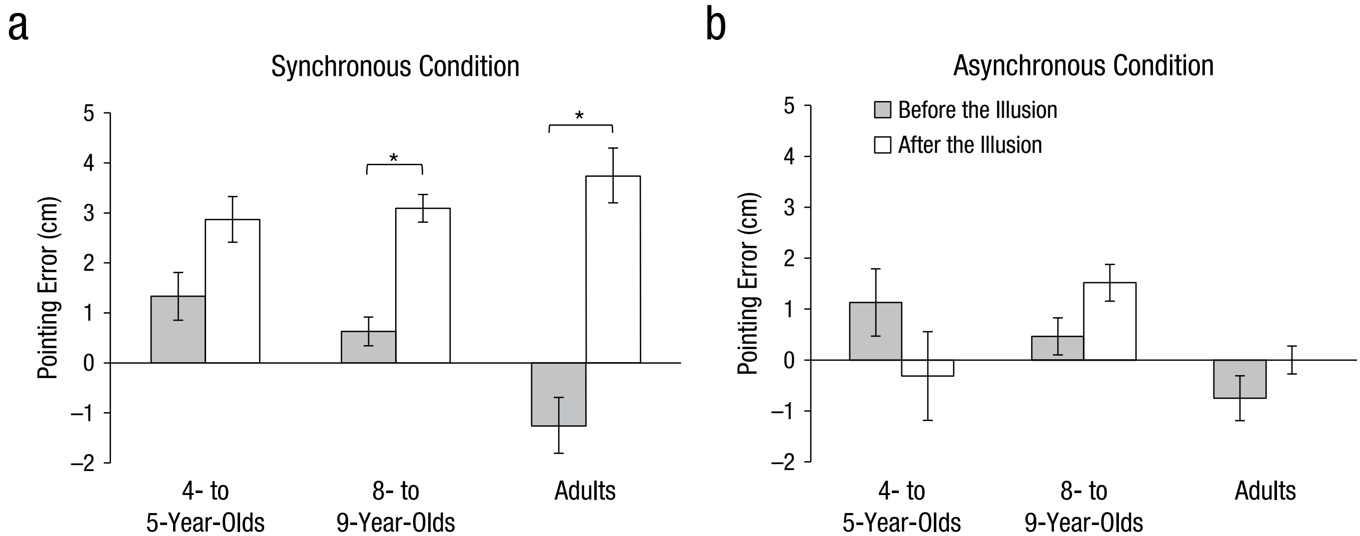

Fig. 1. Results from Experiment 1: mean pointing error before and after the illusion for each age group in the (a) synchronous condition and the (b) asynchronous condition. The asterisks indicate significant differences between pointing error before and after the illusion ($p < .05$). Error bars represent ±1 *SEM*.

$p < .001$; and, most important, Session × Condition × Age, $F(2, 106) = 3.62$, $p = .03$. To further explore the triple interaction, and specifically to document whether all groups experienced the illusion, we conducted two additional repeated measures ANOVAs, one for each of the two stroking conditions, given that the SRHI is reliably induced by synchronous stroking (Botvinick & Cohen, 1998; Ehrsson, Spence, & Passingham, 2004). That is, we expected to observe group differences in the synchronous condition but not in the asynchronous condition.

The 2 (session: pre-SRHI or post-SRHI) × 3 (age: 4- to 5-year-olds, 8- to 9-year-olds, or adults) repeated measures ANOVA for the synchronous condition revealed a main effect of session, $F(1, 53) = 97.77$, $p < .001$, and a significant interaction between age and session, $F(2, 53) = 12.00$, $p < .001$. Post hoc Bonferroni-corrected comparisons showed that only the 8- to 9-year-olds and adults had significant differences between pre-SRHI and post-SRHI scores (ps < .001); in contrast, there was no such difference for the 4- to 5-year-olds ($p = .09$). That is, only the older children and adults proved to be sensitive to the SRHI, as indexed by recalibration of their hand positions toward the rubber hand (see Fig. 1a). In the asynchronous condition, the same repeated measures ANOVA model showed a significant Age × Session interaction, $F(2, 53) = 621$, $p = .003$. However, post hoc comparisons revealed no difference between preillusion and postillusion scores in any group (all ps > .20; see Fig. 1b).

To determine whether the magnitude of the illusion changed with age, we compared the drift (i.e., the difference between postillusion and preillusion scores) in the three age groups in two separate one-way ANOVAs. In the synchronous condition, we found a main effect of age, $F(2, 53) = 12.00$, $p < .001$, explained by larger proprioceptive drifts in the adults compared with both the 4- to 5-year-olds ($p < .001$, Bonferroni post hoc comparisons) and the 8- to 9-year-olds ($p = .003$). We also found no difference between the two groups of children ($p = .68$).

There was a main effect of age in the asynchronous condition too, $F(2, 53) = 6.21$, $p = .004$; however, this effect was caused by the fact that the 4- to 5-year-olds had a different directional pointing drift than either the 8- to 9-year-olds ($p = .006$) or the adults ($p = .02$). Indeed, the younger children showed a proprioceptive drift in the direction opposite that of the rubber hand; hence, they did not show the typical directional bias found with the SRHI. No difference emerged between the 8- to 9-year-olds and the adults ($p = .99$).

Questionnaire. Because the scores for the illusion and control questions were not normally distributed, they were analyzed with nonparametric tests to observe differences between groups (Kruskal-Wallis test) and within groups (Wilcoxon signed-rank test).

Following the rationale of the analysis performed on the pointing data, we first explored whether children and adults perceived the illusion at all by comparing responses to the illusion question and to the control question separately by group. Higher scores in response to the illusion question (than to the control question) after synchronous stroking would indicate sensitivity to the illusion. This analysis indeed revealed a general sensitivity to the illusion in all age groups in the synchronous condition, in that all participants rated the illusion question more positively than they did the control question (all ps < .03; see

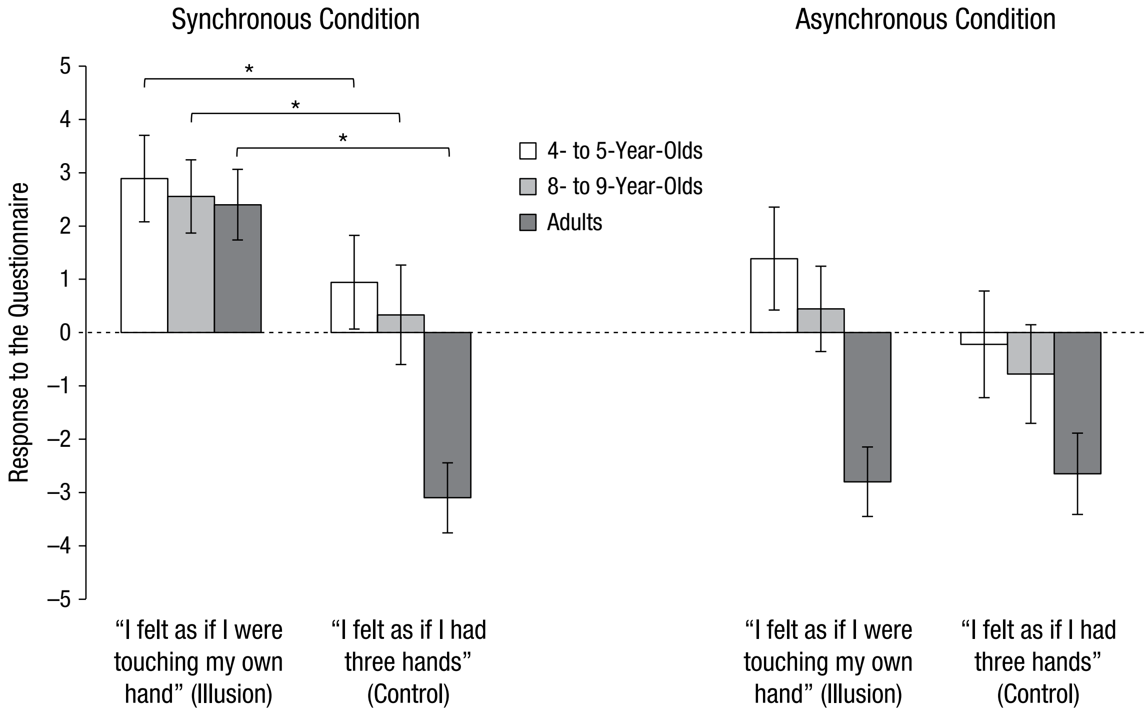

Fig. 2. Results from Experiment 1: mean responses to the illusion and control questions for each age group, presented separately for the synchronous and asynchronous conditions. Participants responded on a scale from −5 (*I strongly disagree*) to 5 (*I strongly agree*); a rating of 0 indicated *I neither agree nor disagree*. Asterisks indicate significant differences between responses to the illusion question and to the control question ($p < .05$). The dashed line indicates a rating of 0. Error bars represent ±1 *SEM*.

Fig. 2). In contrast, no difference emerged between responses to the illusion question and to the control question across all age groups in the asynchronous condition (all ps > .20).

Having established that all participants in the synchronous condition subjectively experienced the illusion, we explored the developmental changes in the magnitude of the perceived illusion in the synchronous and asynchronous conditions. A Kruskal-Wallis test revealed no difference across age groups in the synchronous condition, $H(2, 56) = 1.29$, $p = .52$. In contrast, there was a difference across age groups in the asynchronous condition, $H(2, 56) = 12.29$, $p = .002$. Post hoc comparisons showed that this difference was caused by stronger negative responses to the illusion question from adults than from children. No difference was found between the two groups of children ($p = .99$). Overall, these findings indicate that there was no developmental change in the subjective report of the illusion.

Inspection of Figure 2 suggests that the difference observed between the younger children and adults in the magnitude of the self-reported illusion may have been the result of the younger children having difficulty understanding the questions rather than the younger children not genuinely experiencing the SRHI.

Experiment 2

To rule this possibility out, and to assess whether younger children are genuinely sensitive to the illusion, we ran a new experiment with a new sample of younger children ($n = 33$). Four questions (two illusion and two control questions) were presented before and after the induction of the illusion. We reasoned that if the children genuinely experienced the illusion, the responses before and after would differ for the illusion questions but not the control questions.

Furthermore, we also changed the way of recording children's responses: Instead of indicating their responses on the scale used in Experiment 1, children were asked to rate their experiences on a different 7-point scale. The pointing task was performed as in Experiment 1 so that we also had the opportunity to test the replicability of our findings on the proprioceptive drift.

Method

Eighteen new 4- to 5-year-olds (8 girls; mean age = 5.0, *SD* = 0.60) were tested on the SRHI in the synchronous condition, and fifteen 4- to 5-year-olds (5 girls; mean age = 4.8, *SD* = 0.60) were tested in the asynchronous condition. The stimuli and the procedure mimicked Experiment 1, with the following differences: The questionnaire consisted of four questions. Two items referred to the illusion, and two items were used as control questions. That is, we added one illusion question and one control question to those used in the previous experiment (Experiment 1), and we also presented them in a different form. The two illusion questions were "While you were touching the rubber hand, did you feel as if you were touching your own hand?" (as in Experiment 1) and "While you were touching the rubber hand, did you feel as if the rubber hand were your own hand?" The two control questions were "While you were touching the rubber hand, did you feel as if you had three hands?" (as in Experiment 1) and "While you were touching the rubber hand, did you feel as if your own hand had disappeared?"

In this new experiment, instead of pointing on the response line from Experiment 1, the children were asked to rate the perception on a 7-point scale (0 = *absolutely no*, 6 = *absolutely yes*) similar to that used by Cowie et al. (2013). The child gave a verbal response that the experimenter typed into the computer, unlike the procedure in Experiment 1. By simply adding two new questions to the ones used in Experiment 1 (and not changing them all), we aimed to verify whether possible differences between Experiments 1 and 2 would arise from the difficulty of the questions (i.e., children did not understand them overall) or from the way in which children were instructed to answer the questions.

To determine whether the younger children really understood the questions and could discriminate between illusion and control questions, we posed them both before and after the illusion induction with the rubber hand. We reasoned that if the children were unable to distinguish between the illusion and control statements, they would provide the same answer to each of them regardless of the induction of the illusion. In a baseline test, each child was blindfolded and the experimenter stroked the child's finger over the rubber hand. (That is, there was no illusion induction, only the experience of touching the rubber hand alone.) At this point, the questions were posed for the first time. The experiment then proceeded exactly as Experiment 1 did, including the measurement of the proprioceptive drift.

Results

Pointing. Results from this control experiment confirmed the absence of the illusion in the pointing task in the new sample of 4- to 5-year-old children. A repeated measures ANOVA, with session (pre-SRHI or post-SRHI) as a within-subjects factor and condition (synchrony or asynchrony) as a between-subjects factor, confirmed the absence of the illusion in the pointing task, *p*s > .27.

Questionnaire. As in Experiment 1, responses to the questions were analyzed using nonparametric tests. Experiment 2 served specifically to test whether 4- to 5-year-olds understood the questions related to the illusion; because the questions were presented in a different fashion in Experiment 2, we analyzed responses to them without making further comparisons with Experiment 1. First, we compared responses to all four questions in the synchronous and the asynchronous conditions before induction of the illusion (i.e., baseline) but found no difference, in that the children rejected the idea that they experienced the illusion (i.e., responded with 0 to the illusion questions; all *p*s > .73). In contrast, we did find a difference between conditions in responses to the illusion questions after the SRHI induction: The children gave higher ratings to the two illusion questions after synchronous stroking (Question 1: M = 4.72, SD = 1.18; Question 2: M = 3.89, SD = 2.11) than after asynchronous stroking (Question 1: M = 0.80, SD = 1.52; Mann-Whitney U = 18.00, $p < .001$; Question 2: M = 0.33, SD = 1.29; Mann-Whitney U = 39.00, $p < .001$). Furthermore, there was no difference in responses to the control questions between the synchronous and asynchronous conditions after the induction (both *p*s > .44). A significant difference was observed between responses to the illusion and the control questions after synchronous stroking (both *p*s < .001) but not after asynchronous stroking (both *p*s > .10), which means that the children experienced the illusion.

Discussion

In this study, we investigated for the first time the contribution of tactile and proprioceptive cues in the development of the sense of body ownership brought about by the SRHI. Results showed that the subjective feeling of having a rubber hand, as assessed by means of explicit reports (i.e., questionnaire), is already present by age 4 and does not change throughout development. This evidence is in line with results from previous studies conducted in both adults (Ehrsson et al., 2005; Nava et al., 2014) and children (Cowie et al., 2013, 2016) and suggests that the conscious perception of the body does not rely on constant visual feedback. This evidence is also in line with the perspective that the responses to the questionnaire reflect a sort of "default" representation of the body image: This internal body representation controls, in a top-down fashion, new sensory input that comes from different modalities, monitoring their inclusion in the body image (Costantini & Haggard, 2007). In other words, children and adults are aware that they possess a certain number of body parts that have specific characteristics; the incoming multisensory cues induced by the SRHI are processed to be consistent with this explicit knowledge, and the rubber hand is thereby included in the body image.

By contrast, results from the pointing task show a reliable effect of the illusion on the sense of hand position by the SRHI, which is a more unconscious bottom-up measure, with respect to the questionnaire, was present only in the 8- to 9-year-olds and the adults. Indeed, whereas older children and adults showed a difference in preillusion and postillusion pointing only in the synchronous condition, 4- to 5-year-olds did not show the recalibration of hand position toward the rubber hand in either stroking condition. Furthermore, the changes in the magnitude of the drift in the synchronous condition (i.e., larger drifts in adults compared with both the 4- to 5-year-olds and the 8- to 9-year-olds) further confirm that although the integration of tactile and proprioceptive cues necessary to experience the SRHI is in place by age 8 or 9, such a multisensory process is not yet like that in adults.

The absence of an effect of the illusion on the sense of hand position by 4- to 5-year-olds could have two, non–mutually exclusive reasons. First, some studies have suggested that tactile spatial abilities appear late in development. For example, Begum Ali, Cowie, and Bremner (2014) showed that 4-year-old children were worse than 6-year-old children at localizing tactile stimuli applied to their hands. This disadvantage was observed when the 4-year-olds could see the position of their hands and disappeared when they were unable to see their hands. This means that vision strongly conflicts with proprioception at this age. Given this perspective, it could be claimed that the children "took advantage" of being blindfolded to fully rely on the tactile cue (i.e., on the hand being stroked).

Another possibility is that younger children have yet not developed optimal integration abilities, on which both the SRHI and the RHI strongly rely (see Ehrsson et al., 2005, 2004). If children do not integrate tactile and proprioceptive cues, the tactile effect of the illusion on the sense of hand position is prevented. Indeed, cross-modal illusion in general, and the SHRI in particular, arises when the brain is capable of fusing together multisensory inputs (i.e., the real self-touch of the rubber hand and the position of the participant's hand being stroked in the SHRI) on the basis of their temporal correlations. At the neural level, the emergence and maturation of multisensory integration critically depend on cross-modal experience (Stein, Stanford, & Rowland, 2014). Thus, along the same lines, it could be claimed that the experience made with tactile-proprioceptive cues, necessary for optimally integrating them, is still not sufficient by age 8 or 9.

Because Cowie et al. (2013) tested 4- to 9-year-old children on the visual RHI, it is important to compare their results with our own. First, both Cowie et al. (2013) and we revealed that the subjective feeling of owning the rubber hand is already similar to that in adults by age 4. This suggests that an explicit, conscious experience of owning a rubber hand is not modulated by the types of sensory modalities involved: Both visuotactile and tactile-proprioceptive cues contribute to the explicit sense of body ownership and, ultimately, to a sense of self. However, the proprioceptive drift is dramatically different between the two illusions. Indeed, in contrast to our findings with the SRHI, Cowie et al. (2013) found that all children experienced the visual RHI and that the magnitude of the illusion decreased with age. The most evident difference between our paradigm and that of Cowie et al. (2013) concerns vision—children in Cowie et al. (2013) were able to see their hands in that RHI but our participants were unable to do so in our SRHI. The different performance of younger children suggests a special role for vision in shaping the multisensory representation of the body in space during development. Among the other senses, vision is predominant and probably guides multisensory experiences that constantly update the brain about current postures of the body and its parts.

Finally, the developmental differences we found between explicit and implicit body representations is reminiscent of the difference between the body image and the body schema put forward in the neuropsychological literature regarding brain-damaged patients (Berlucchi & Aglioti, 1997; Head & Holmes, 1911; Paillard, 1999). Although the body image represents the knowledge of possessing different body parts in their actual layout and occurs at a conscious level, the body schema registers one's body parts in space and updates them—unconsciously—while the body moves. From this perspective, it could be speculated that although the body image develops early in life, the body schema adjusts as the body rapidly changes in size through development.

In conclusion, our findings show that tactile-proprioceptive interactions contribute differently to emerging aspects of body representation during development. Although these interactions underlie an earlier development of a subjective sense of self, they still need to be fine tuned in determining the position of the body parts.

Action Editor

Jamin Halberstadt served as action editor for this article.

Author Contributions

E. Nava and C. Turati developed the study concept. E. Nava performed the testing and data collection. E. Nava and N. Bolognini performed the data analysis and interpretation under the supervision of C. Turati. E. Nava drafted the manuscript, and C. Turati and N. Bolognini provided critical revisions. All the authors approved the final version of the manuscript for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Note

1. We included only a single illusion statement because in a pilot study with ten 4- to 5-year-old children (who were different from the sample included in the final analysis), we found that other classical questions (adapted from Botvinik & Cohen, 1998; e.g., "It seemed as if I were feeling the touch on my hand in the location where I was touching the rubber hand") were too difficult for this particular age group to reliably understand.

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