If I were a grown up: Children's response to the rubber hand illusion with different hand sizes

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Introduction

In the last two decades, research on body awareness showed that the integration of sensory signals is crucial for the construction of a sense of self as embodied beings (Tsakiris, 2017; Gallagher, 2005). These studies have unanimously provided support to the idea that our bodily self-consciousness is not fixed, but rather malleable and subject to continuous updates through incoming sensory information related to one's own body (Tsakiris, 2017; Longo, Azanon and Haggard, 2010; Serino and Haggard, 2010; Tsakiris, 2010). The Rubber Hand Illusion (RHI, Botvinick & Cohen, 1998) represents a well-established experimental paradigm to investigate the plasticity of bodily self-consciousness. In the classic scenario, participants watch a rubber hand placed in front of them being stroked with a brush at the same time as their own real unseen hand, which is placed out of view. In the RHI, the interplay between vision, touch and proprioception can lead participants to experience the rubber hand as part of their own body.

However, our bodies are not isolated entities in the environment. Thus, the way in which we mentally represent our physical body creates a framework that we use to act and interact with other human beings and objects in the world. Therefore, evidence of the malleability of our bodily self-consciousness paved the way to further investigation on the consequences that such multisensory changes can have for social cognition (Maister et al., 2015). Along this line, previous studies have used experimental paradigms such as the aforementioned RHI to extend the malleability of bodily self-consciousness to other races

(Banakou, Parasuram, and Slater; 2016; Farmer et al., 2014; Maister et al., 2013; Peck et al., 2013; Fini et al., 2013; Farmer et al., 2012), to different body sizes (Tajadura-Jimenez et al., 2018; Banakou et al., 2014; van der Hoort et al., 2011; Normand et al., 2011) and across ages (Tajadura-Jimenez et al., 2018; Banakou et al., 2013).

In particular, the perception of one's own body size provides a point of reference to the way we interact with objects in the external world, suggesting that experimental manipulations of bodily self-consciousness may result in concurrent changes in the perceptual awareness of the environment (van der Hoort et al., 2011; Banakou et al., 2014; Tajadura-Jimenez et al., 2018). From a developmental perspective, the link between changes in bodily self-consciousness and body size is of particular interest. Given the substantial and relatively rapid physical growth that we observe throughout development, it is still unclear the extent to which children are able to update their body representation to match the constant changing body form. Research studies using body illusion paradigms point to the gradual development of multisensory mechanisms for own-hand perception in children (Nava et al., 2017; Cowie et al., 2013; 2016; Greenfield et al., 2015; Cascio et al., 2012). Cowie and colleagues (2013; 2016) showed that children up to 10 years of age show significant mislocalization of their hand position towards the body midline after being exposed to synchronous visuotactile stimulation of the real and rubber hands during the RHI (Cowie et al., 2013). This error in identifying the position of their own hand is significantly higher than the one reported by adults and older children (Cowie et al., 2016), suggesting that body location in young children might be more influenced by visual information rather than proprioceptive signals (Cowie et al., 2016).

What is the link however between changes in body size and corresponding updates in bodily self-consciousness? The developmental literature seems to suggest that our perceptual interpretation of body size influences the perception of the surrounding environment. Indeed, several studies have provided evidence that children up to 3 years of age make systematical body representation errors when interacting with other objects (Ware et al., 2010; Rosengren et al., 2010; Casler, Eshleman, Greene and Terziyan, 2011; Moore et al., 2007; Brownell et al., 2007; DeLoache, Uttal and Rosengren, 2004). This might suggest the absence of a stable bodily self-consciusness and awareness of body competence in relation to the external world (Brownell et al., 2007). In a large investigation involving children and adolescents from 8 to15 years of age, Newport and colleagues (2015) examined the subjective perception of hand distortion using the illusion of finger stretching. Their results showed that the susceptibility to the illusion remains stable across the whole sample, regardless of age. These findings corroborate the plasticity of bodily self-consciousness across development; however, a more in-depth investigation of the interplay between changes (or stability) in body size representation and related perception of external objects in children, could provide a better understading of the relationship between body size representation and bodily self-consciousness.

A similar approach has already been applied in research with adults, by asking participants to complete perceptual tasks following the RHI (Kilteni et al 2012; Bruno & Bertamini 2010; Haggard and Jundi, 2009; Pavani & Zampini 2007), or its full body equivalent (full body illusion; Tajadura-Jimenez et al., 2018; Banakou et al., 2014; van der Hoort et al., 2011; Normand et al., 2011). Bruno and Bertamini (2010) found that, after exposure to the RHI using an enlarged or smaller fake hand (with respect to the size of the participants' own hand), participants reported objects to be larger or smaller, respectively. This effect was associated with the extent to which the fake hand differed from the participants' real hand in terms of size. In a similar RHI study, Haggard and Jundi (2009) used a weight-estimation task to quantify the impact of illusory changes in body size on perceptual awareness of the external environment. Specifically, participants were asked to estimate the weight of objects with constant size but different weight. They found that the illusory ownership of a larger hand modulated the perceived size of the grasped object, inducing a size-weight illusion (SWI, Cesari and Newell, 1999). Notably, Haggard and Jundi (2009) found that the SWI seemed to occur only when the seen fake hand was larger (compared to smaller) than the actual participant's hand, meaning that illusory ownership of a larger hand led to overestimation of perceived weight of the grasped objects. This finding seems to suggest that the perceptual awareness of the external environment changes as a function of the perception of our own body size. However, whether children are able to perform such dynamic update of bodily self-consciousness in relation to perceived variation in body size is still unclear.

Here, we aimed to investigate for the first time how changes in body size during childhood can lead to updates in bodily self-consciousness. Six-to-eight-year-old children experienced the RHI while watching a regular (child size) or larger (adult size) rubber hand being touched either synchronously or asynchronously with their own real hand. We focused on this age range because the effect of the RHI, in terms of both subjective ownership and self-location, seems to be rather stable between 6 and 9 years of age, with developmental changes occurring mainly before 5 and after 10 years of age (Cowie et al., 2016; Nava et al., 2017). We measured subjective changes in body ownership (i.e., ownership questions), recalibration of self-location (i.e. proprioceptive drift in the pointing task) and induced variation in the perceived body size (i.e. errors in the weight-estimation task) (see schematic illustration in Figure 1). Classic subjective reports used in body size research can be confounded by cognitive and linguistic developmental abilities, as well as desirability and motivational biases (Smolak, 2004). Therefore, we aimed to control for these potential confounding factors by using the validated and implicit size-weight illusion (SWI) following the RHI with different hand sizes as an indirect measure of body size representation (as in Haggard and Jundi, 2009; Crucianelli et al., 2019).

In line with previous developmental findings in the context of the RHI, we expected to find a significant difference in both subjective changes in body ownership and in self-location after visuotactile synchronous, compared to asynchronous, stimulation of the regular size rubber hand (Cowie et al., 2013). Additionally, based on the dynamic nature of bodily self-consciousness highlighted by previous developmental work (Newport et al., 2015; Cowie et al., 2016), we hypothesised that the manipulation of body size (i.e. synchronous multisensory stimulation of the RHI using a larger rubber hand) would lead to an update in bodily self-consciousness, as measured by means of subjective changes in body ownership and in self-location.

In terms of the interplay between perceived body size and perceptual awareness of objects in the external world, we had two different hypotheses. On the one hand, if children dynamically update their bodily self-consciousness in relation to body size changes (i.e. larger rubber hand), this would impact perceptual awareness of the external environment as shown in adults (Haggard and Jundi, 2009). Therefore, the size of the hand used to induce RHI would have a significant effect on weight estimation. That is, external objects grasped after embodiment of a larger hand would feel smaller in relation to the perceived size of one's own hand (Cesari and Newell 1999). In turn, changes in perceived object size would induce a change in perceived weight (i.e. objects will feel smaller following embodiment of a larger hand and therefore heavier), giving rise to a SWI (Haggard and Jundi, 2009). On the other hand, if, as suggested by scale-error developmental research studies, children are unable to optimally update their current body representations in relation to the external world (Dunphy-Lelii et al 2014; Brownell et al., 2007), we would expect that illusory changes in body size (i.e. larger rubber hand) would not significantly affect perceptual judgements about the size and weight of the grasped objects.

Despite there being a difference between synchronous and asynchronous conditions, Cowie and colleagues (2016) found that visuotactile stimulation *per se* does not seem to make a difference to perceived hand location until early adolescence, suggesting that vision of the rubber hand might be sufficient to elicit a change in self-location in children (see also Petrini et al., 2014; Nardini et al., 2013 for developmental studies on multisensory integration; Makin, Holmes and Ehrsson, 2008 for a review). However, to our knowledge, this hypothesis has not been tested directly. Therefore, here we introduced a pre-RHI test where participants were asked to watch the rubber hand in the absence of visuotactile stimulation (i.e. visual capture, Hohwy & Paton, 2010; as shown in Martinaud et al., 2017; Crucianelli et al., 2018). If the sight of a rubber hand seen from a 1st person perspective in an anatomical congruent position is sufficient to update self-location accordingly, then we should expect that the mere vision of a rubber hand with no tactile stimulation would lead to recalibration of hand position (i.e. proprioceptive drift). In contrast, if visuotactile stimulation significantly contributes to the illusion, then we should expect to observe the proprioceptive drift towards the rubber hand only after such multisensory stimulation.

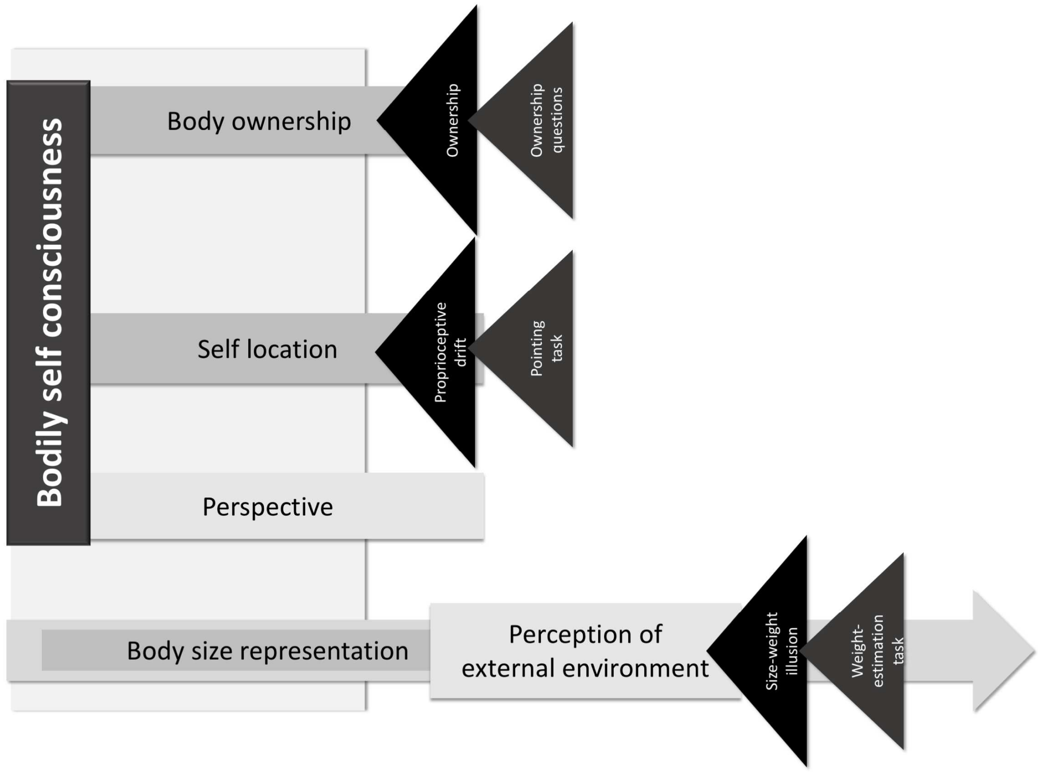

Figure 1 Schematic representation of the components of bodily self-consciousness, and the ones included in our RHI study, as well as the measures used to examine each component. Changes in body ownership were investigated using ownership questions as in previous developmental work (Cowie et al., 2013; Cowie et al., 2016). Changes in self-location were examined through the proprioceptive drift using the classic pointing response task. To investigate body size representation, we used the size-weight illusion (SWI) using a weight-estimation task adapted from the adult literature (e.g. Haggard & Jundi, 2009; Crucianelli et al., 2019). The SWI can be considered as an indirect measure of body size representation, by measuring the modulation of object weight perception (Haggard & Jundi, 2009; Crucianelli et al., 2019). The first-person perspective component of bodily self-consciousness was not manipulated in the current study.

Materials and methods

Participants

Children were recruited from local schools and tested individually in a room adjacent to their classroom. We based the effect size (d) of this study on previous finding of changes in body location and subjective body ownership measures in 90 children (30 4-5 year olds; 30 6-7 year olds; 30 8-9 year olds) during the RHI (Cowie et al., 2013). In their study, Cowie and colleagues used a between-subject design and therefore for half of each age group, the fake and real hands were stroked synchronously; for the other half, they were stroked asynchronously. Based on their effect size, we calculated that in order to obtain a power greater than 0.80, with alpha set at 0.05 and f at 0.45, a total sample size of 67 participants was required.

We tested sixty-eight 6-to-8-year-old children (regular hand size synchronous stroking: N = 17, mean age = 7.5 years, SD = 0.7 years; regular hand size asynchronous stroking: N = 17, mean age = 7.5 years, SD = 0.5 years; larger hand size synchronous stroking: N = 17, mean age = 7.8 years, SD =0.3 years; N = 17, larger hand asynchronous stroking: mean age = 7.7 years, SD = 0.5 years). As in previous RHI studies with children (Nava et al., 2017; Cowie et al., 2016; Cowie et al., 2013), we opted for a between-subject design to maximise data collection and reduce testing time for children, thus ensuring substained attention throughout the experiment. Two further participants (one from the larger hand size asynchronous group and one from the regular hand size synchronous group) were excluded from the final sample because they could not be brought to focus on the rubber hand and to stay still during the testing session. At the end of the session, children were thanked, given a sticker and badge, and taken back to class. Research was approved by the local research ethics committee (University of Essex).

Apparatus and Stimuli

Proprioceptive drift. We administered the *pointing response task* to measure proprioceptive drift following the same experimental procedure as in studies by Cowie and colleagues (2013; 2016). Therefore, on two training trials, the left hand was visible and rested on the table. Participants were trained to slide their right index finger following a ridge underneath the table, so that it ended up underneath their left index finger.

After training, participants underwent a baseline of the *pointing response task*. They were asked to point with their right index finger under the table to the left index finger of their own hand whilst keeping their eyes closed (Cowie et al. 2016; Cowie et al., 2013). This task was repeated twice and provided a baseline estimation error of hand position. Participants completed the *pointing response task* twice more; following the visual capture test and following the rubber hand illusion with either the regular size or larger hand, depending on which group they were randomly assigned to.

For baseline trials, we calculated the constant error as the difference between mean pointing response and actual hand position. Errors toward the body midline from actual hand position were scored as positive. Proprioceptive drift was calculated by subtracting, for each participant, the mean baseline pointing response from the mean test pointing response.

Ownership questions. After the visual capture test, participants were asked the question: Item 1 - "When you were watching the rubber hand, did it sometime feel like the rubber hand was your own hand or belonged to you?". To facilitate children's understanding of the scale and for consistency with other RHI research studies, we used the same 7-point answer scale and coding as described by Cowie and colleagues (2016; 2013): no, definitely not (0), no (1), no, not really (2), in between (3), yes, a little (4), yes, a lot (5), yes, lots and lots (6).

After each RHI trial, participants were asked two questions (Cowie et al., 2016; 2013), which we assessed using the same 7-point answer scale as in the 'visual capture' test: Item 2 - ''When I was stroking with the paintbrush, did you sometimes feel like the fake hand was your hand or belonged to you?" and Item 3 - ''When I was stroking with the paintbrush, did it sometimes seem as if you could feel the touch of the brush where the fake hand was?".

Weight-estimation. This task was based on the procedures described by Haggard and Jundi (2009). Before the main experimental task, participants were trained in weight estimation. Children were familiarised with two objects (i.e. two cylinders containing a small sugar bag) identical in any aspect (i.e. shape, size and colour), but with different mass (either 200g or 300g). They were told that the heavier object (300g) weighed 10 and the lighter objected (200g) weighed 0. Participants were then asked to use their left hand (which was out of view) to lift and estimate the weight of the two objects, presented in pseudorandomised order (ABBABA, with the order of the first object counterbalanced across conditions and participants) and were asked the question: "Does this object weigh 0 or 10?". After each estimation, children received a feedback about their performance (i.e. if they were right or wrong). By the end of the training session, all participants successfully learnt to distinguish between cylinders weighing 200g and 300g (i.e. the cut off was 4 out of 6 correct trials in a row – none of the children were excluded from the final sample according to this criterion). This training was done to make sure participants could reliably discriminate the light from the heavy object, and therefore completed the main experiment with the same weight reference points (see also Haggard and Jundi, 2009; Crucianelli et al., 2019).

Next, participants underwent a baseline of the *weight-estimation task*. They were asked to lift three objects of the same shape and size (the same cylinders described above), but different in weight (225g, 250g, and 275g, their order randomised across conditions and participants). The experimenter placed the object between the participants' left index finger and thumb. Participants were asked to gently lift the cylinder and estimate its weight, on a scale ranging from 0 to 10 ("How much does this object weigh between 0 and 10?"). The use of a 10-point scale was more user-friendly for children compared to providing estimates in grams, and allowed us to transform each weight into its respective number on the scale (i.e. 250g = 2.5 out of 10; 250g = 5 out of 10; 275g = 7.5 out of 10). Instructions included the information that the weight could be anything between 0 and 10, but no feedback about the estimation was given at this stage. For each object, the weight-estimation was repeated twice; therefore this task comprised 6 trials.

Similarly to the *pointing response task*, participants completed the *weight-estimation task* twice more; following a visual capture test where children were asked to simply watch a prosthetic rubber hand for a few seconds, and following the RHI with either the regular or larger size hand, depending on the group randomly assigned to them.

For each trial, the separate estimations were then averaged across weight to compute a total estimated weight measure. The difference between the estimated and actual weight was the measure of the SWI, quantified as weight-estimation error.

Procedure

The procedure consisted of training, baseline, visual capture test, and test trials. Participating children were welcomed in the testing room and familiarised with the experimental material. Following training of weight-estimation and pointing response, the main experiment began (i.e. baseline; visual capture; test trials).

First, participants underwent the baseline *pointing response task*, followed by the baseline *weight-estimation task* as detailed in the Apparatus and Stimuli section above. Next, a prosthetic rubber hand (Ottobock SE & Co., see Figure 2) was placed on the table, at the midline, the real left hand to the left of the body midline. The distance between the real left hand and the rubber hand was 15 cm. A black hairdresser cape was placed around the child to cover both the real hand and part of the prosthetic arm. In the regular size hand condition, the rubber hand was approximately sized to this age group (middle finger to wrist = 14cm in length; little finger to index finger = 6cm in width), whereas for the larger size hand condition we used the standard adult sized rubber hand (middle finger to wrist = 18cm in length; little finger to index finger = 8cm in width). After hands were positioned, the participant was asked to watch the rubber hand for 30 seconds, trying to keep their focus and without looking away. In this visual capture test, neither the rubber hand nor the real hand were stroked. Next, participants were asked to close their eyes and point with their right index finger under the table to their left index finger of their own hand (*pointing response task* as in baseline trials). Then, eyes were opened, participants performed again the *weight-estimation task* and were asked to estimate the weight of the same three objects as in baseline trials. Participants were asked one question about their subjective experience of ownership (Item 1). After the visual capture test, participants were asked to take a short break and move their hands.

Finally, participants performed the test trials. The rubber hand and real hand were repositioned and children were asked again to watch the rubber hand without looking away. The experimenter stroked the rubber hand and the participants' real hand either synchronously or asynchronously for 1 minute. Next, the rubber hand was covered up and participants performed again the *pointing response task* (one trial) and *weight-estimation task* (three trials) as detailed above. Then the right and left hands were repositioned and stroking was repeated for 20 seconds (top-up), after which participants were asked to close their eyes and point again (pointing response trial), and then repeat the remaining three trials of the *weight-estimation task*. In total, each participant performed the *pointing response* and *weight-estimation task* 3 times (i.e. once after baseline, once after visual capture and once after the RHI). Finally, participants were asked the two questions about their subjective experience of ownership (Item 2 and Item 3).

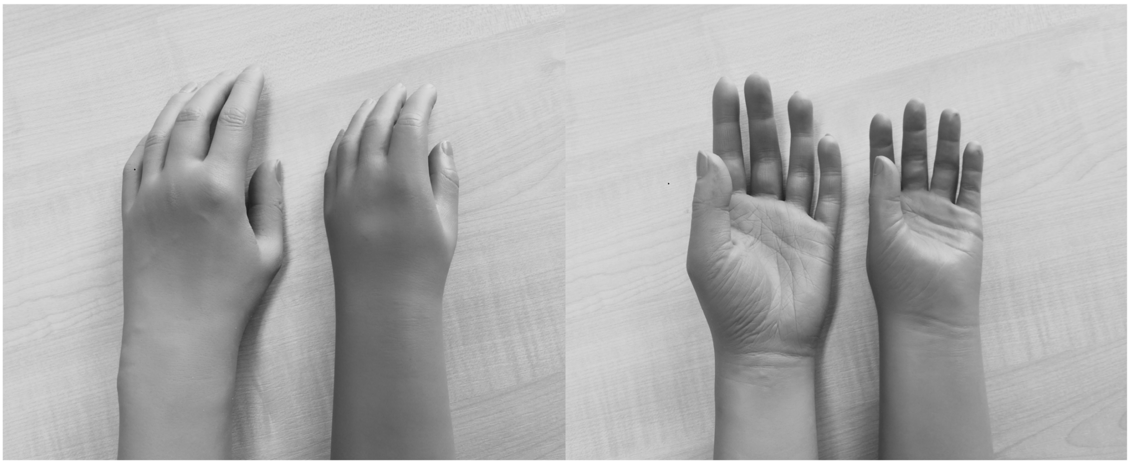

Figure 2 The larger- and regular-sized prosthetic hands (Ottobock SE & Co.) used in our study. In the regular size hand condition, the rubber hand was approximately sized to this age group, whereas for the larger size hand condition we used the standard adult sized rubber hand.

Results

Proprioceptive drift. Because the effect of visual capture in the absence of visuotactile stimulation has not previously been reported in children, one-sample t-tests were conducted for baseline-corrected proprioceptive drift in the regular vs. larger size hand conditions after the visual capture test. The presence of the illusion was indexed by drifts that were significantly different from zero. To account for multiple comparisons, we applied a Bonferroni correction to the reported p values (i.e. $p_{corr} = p_{uncorr}$ / number of tests comparing differences against zero). These tests showed that only proprioceptive drift after watching the regular hand was significantly different from zero; regular rubber hand: t(33) = 3.06, *p* = 0.004, *d* = 0.53; larger rubber hand: t(33) = 1.72, *p* = 0.09, *d* = 0.29 (Figure 3a).

To analyse proprioceptive drift data as a result of the RHI, we performed a factorial 2x2 ANCOVA, with hand size (regular vs. larger) and stroking mode (synchronous vs. asynchronous) as between-subject variables, and age (in days) as covariate. We decided to include age as continuous rather than categorial variable in order to gain insights into the developmental changes occurring between 6 and 8 years of age. After visuotactile stimulation, baseline-corrected proprioceptive drift showed no significant effect of hand size, $F(1, 63) = 3.42$, $p = 0.07$, $\eta^2 = 0.05$, or stroking mode, $F(1, 63) = 0.13$, $p = 0.72$, $\eta^2 = 0.002$ (Figure 3b). We did not find any interaction, $F(1, 63) = 0.76$, $p = 0.39$, $\eta^2 = 0.012$.

Ownership questions. Questionnaire items were coded on a 7-point scale in response to questions about feeling a sense of ownership over the fake hand (after just watching the rubber hand, Item 1; after watching the rubber hand being touched, Item 2; and feeling touch on the fake hand, Item 3). As data were not normally distributed, we performed non-parametric analyses. Table 1 shows mean and standard error of ratings for each item. After the visual capture test, participants tended to disagree with questionnaire Item 1 (i.e. score below 3). Mann-Whitney U test revealed no significant differences between regular and larger hand size on Item 1 (ownership), $U(68) = 1066$, $Z = -1.15$, $p = 0.25$, suggesting that

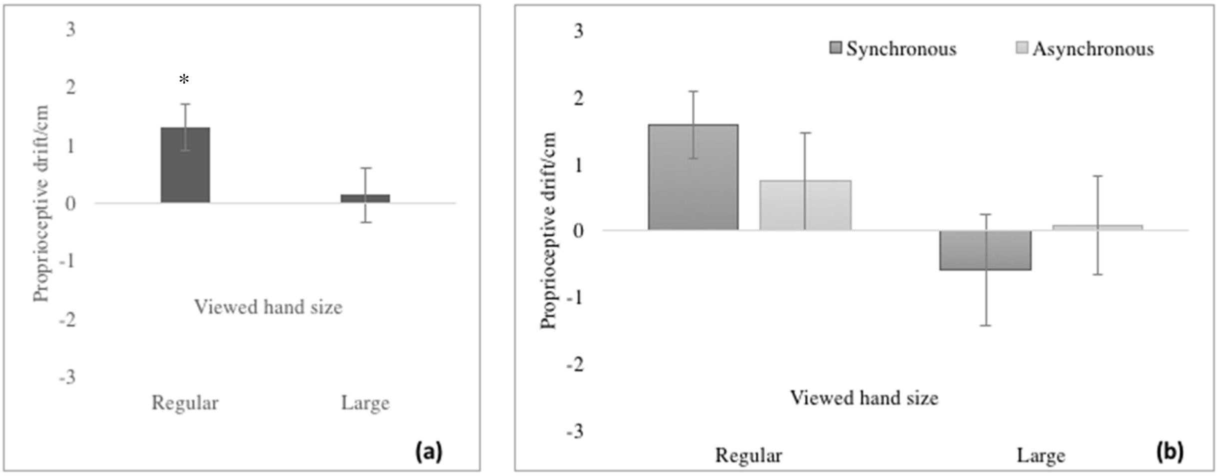

*Figure 3. Mean baseline-corrected proprioceptive drift in cm of pointing responses toward the body midline as a function of hand size after the visual capture test (a), and as a function of hand size and stroking mode postinduction (b). * p <0.05; Error bars indicate standard errors.*

solely watching the fake hand did not elicit any subjective change in body ownership.

After visuotactile stimulation, participants in the synchronous condition tended to positively agree with questionnaire items 2 and 3 (i.e. scores above 3), whereas participants in the asynchronous condition tended to disagree with these items. Interestingly, this was true irrespective of hand size, suggesting that children might have embodied a regular and larger size hand to a similar extent. Mann-Whitney U test revealed significant differences between synchronous and asynchronous condition on Item 2 (ownership), $U(68) = 936.5$, $Z = -2.96$, $p = 0.003$ and Item 3 (touch referral), $U(68) = 921$, $Z = -3.15$, $p = 0.002$ (see Table 1). The same non-parametric test revealed no significant differences between regular and larger hand size on Item 2 (ownership), $U(68) = 1086.50$, $Z = -1.08$, $p = 0.28$ or Item 3 (touch referral), U(68) = 1196.59, $Z = 0.29$, $p = 0.77$. The difference between regular hand synchronous and regular hand asynchronous was significant only for Item 2 (ownership): $U(34) = 85.500$, Z = -2.102, $p = 0.041$, [Item 3 (touch referral), $U(34) = 108.500$, Z = -1.264, $p = 0.206$]. The difference between large hand synchronous and large hand asynchronous approached significance for Item 2 (ownership): $U(34) = 91.000$, Z = -1.879, $p = 0.067$ and was significant for Item 3 (touch referral), $U(34) = 50.000$, Z = -3.315, $p = 0.001$

As with the proprioceptive drift data, to investigate the effect of age in our questionnaire measures, we computed an ANCOVAs with hand size and stroking mode as factors and age (in days) as covariate. This analysis showed that there were main effects of stroking mode for both items – Item 2: F(1, 63) = 9.83, $p = 0.003$, $\eta^2 = 0.14$; Item 3: F(1,63) = 9.90, $p = 0.003$, $\eta^2 = 0.14$. There were no effects of hand size – Item 2: F(1, 63) = 1.83, $p = 0.18$, $\eta^2 = 0.03$; Item 3: F(1,63) = 0.14, $p = 0.71$, $\eta^2 = 0.02$ – and no interactions between hand size and stroking mode – Item 2: F(1, 63) = 0.02, $p = 0.88$, $\eta^2 = 0.00$; Item 3: F(1,63) = 1.63, $p = 0.21$, $\eta^2 = 0.03$. In sum, ownership questions data after the RHI show that children reported a change in their sense of body ownership after synchronous but not asynchronous stroking of the rubber hand, regardless of its size.

Table 1. Mean ratings on items concerning the visual capture test and 'rubber hand illusion' in the two groups (synchronous and asynchronous). Standard errors are given in parentheses. Please note that while mean ratings in the synchronous and asynchronous groups are shown separately for Item 1, participants in the visual capture test were not exposed to visuotactile stimulation.

	Item 1: ownership 'visual capture'		**Item 2: ownership 'rubber hand illusion'**		**Item 3: touch referral 'rubber hand illusion'**	
	Synchronous group	Asynchronous group	Synchronous group	Asynchronous group	Synchronous group	Asynchronous group
Regular hand	3.06 (0.55)	3.12 (0.62)	4.71 (0.42)	3.24 (0.49)	3.82 (0.55)	2.88 (0.54)
Larger hand	2.38 (0.50)	2.00 (0.39)	4.24 (0.45)	2.53 (0.59)	4.76 (0.42)	2.47 (0.48)

Weight estimation. Weight-estimation error was defined as the difference between estimated and actual weight (Haggard and Jundi, 2009; Crucianelli et al., 2019). First, we analysed weight-estimation at baseline using a factorial 2x2 ANOVA. This analysis showed no significant main effects nor interactions, suggesting that there were no differences between groups in our baseline weight-estimation measure (hand size, $F(1, 64) = 3.39$, $p = 0.07$, $\eta^2 = 0.050$; stroking mode, $F(1, 64) = 0.17$, $p = 0.69$, $\eta^2 = 0.003$; hand size x stroking mode, $F(1, 64) = 0.04$, $p = 0.85$, $\eta^2 = 0.001$).

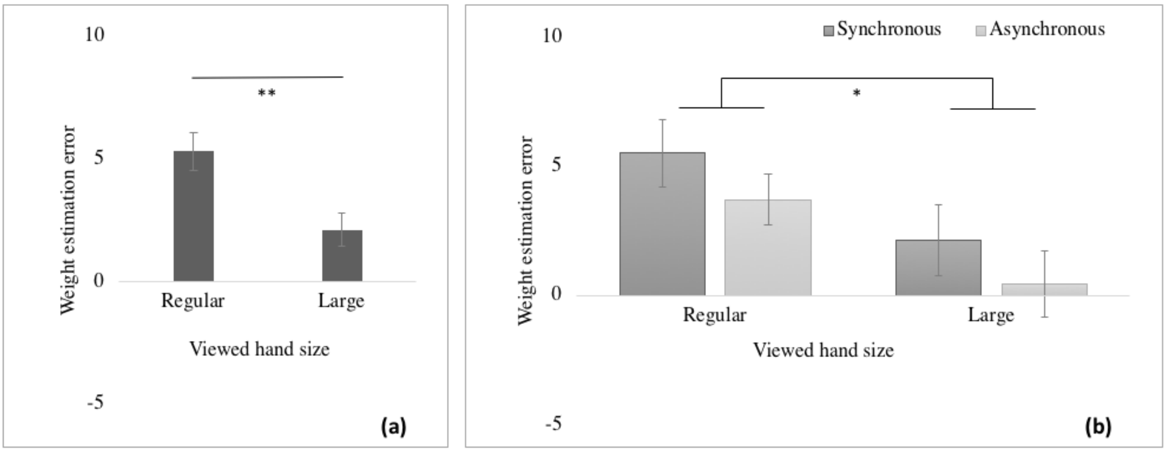

Figure 4. Mean weight-estimation error after the visual capture test (a) and postinduction (b). Asterisks indicate significant effects of hand size (p <0.05; ** p < 0.01). Error bars indicate standard errors.*

Next, weight-estimation after the visual capture test was analysed using independent samples t-tests, to investigate differences between hand sizes. We found that viewing the regular hand led to overestimation of weight relative to the larger hand, $t(66) = 3.17$, $p = 0.002$ (Figure 4a).

Weight estimation after visuotactile stimulation was analysed with a factorial 2x2 ANCOVA, with hand size and stroking mode as between-subject variables and age (in days) as covariate. We found a significant effect of hand size after controlling for age, $F(1, 63) = 10.52$, $p = 0.002$, $\eta^2 = 0.14$, but no effect of stroking mode, $F(1, 63) = 1.57$, $p = 0.21$, $\eta^2 = 0.02$, or interaction between these two factors, $F(1, 64) = 0.001$, $p = 0.97$, $\eta^2 = 0.00$ (Figure 4b), suggesting again that viewing the regular hand led to overestimate the weight of the objects compared to the larger hand. The covariate, age in days, was significantly related to weight estimation, $F(1, 63) = 6.51$, $p = 0.01$, $\eta^2 = 0.09$ (Figure 5).

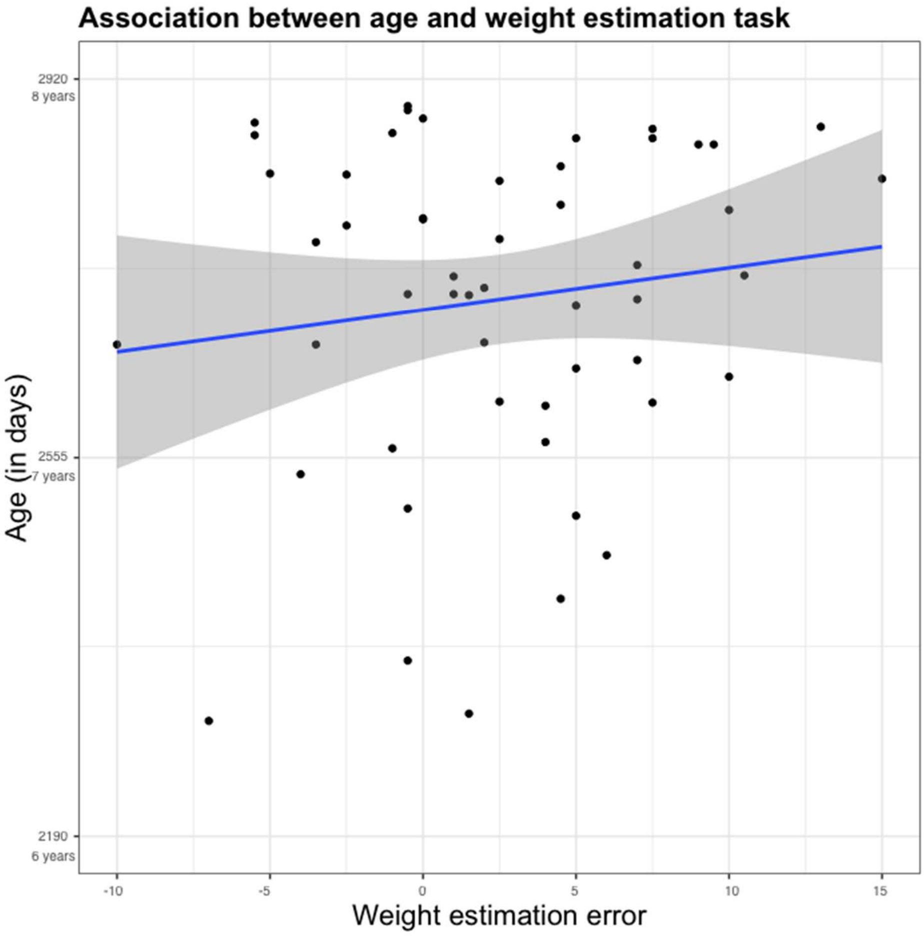

Figure 5. Scatterplot of children's weight estimation error as a function of age in days.

Correlations. To explore the association between our dependent measures, we conducted correlation analyses after visual capture and after the RHI. We only found a small positive correlation between size weight illusion and proprioceptive drift after the RHI, $r = 0.26$, $p = 0.032$, and a large positive correlation between Item 2 (ownership) and Item 3 (touch referral) of our ownership questions, r = 0.662, $p < 0.001$ (Table 2).

Table 2 Correlation analyses of the dependent measures after visual capture (Post visual capture test -top of the table) and after the induction of the RHI (Post RHI – bottom of the table).

Post visual capture test

	1	*2*
1. SWI		
2. Proprioceptive drift	0.211	
3. Item 1 (visual capture)	0.001	0.162

Post RHI

	1	*2*	*3*
1. SWI			
2. Proprioceptive drift	*.261**		
3. Item 2 (ownership)	0.108	-0.001	
4. Item 3 (touch referral)	0.072	-0.218	*.662***

**. Correlation is significant at the 0.05 level (2-tailed).*
***. Correlation is significant at the 0.001 level (2-tailed).*

Discussion

The present rubber hand illusion study used a regular and larger size rubber hand to assess whether changes in body size would in turn update bodily self-consciousness in 6-to-8-year old children. We measured two key components of bodily self-consciousness (Figure 1), namely self-location by means of proprioceptive drift measure, and subjective changes in body-ownership by means of ownership questions. In addition, to quantify body size representation, we used the size-weight illusion (SWI) via a weight-estimation task adapted from the adult literature (Haggard & Jundi, 2009; Crucianelli et al., 2019). Children reported owning the rubber hand after synchronous but not asynchronous stroking between the real and the fake hand, regardless of the size of the viewed hand. This finding confirmed the successful induction of the illusion in this age group. We also found that children showed no reliable recalibration of hand position towards the rubber hand (proprioceptive drift) after the

RHI regardless of stroking and hand size condition (as suggested by the results of our ANCOVA). However, proprioceptive drift significantly differed from zero after watching the regular rubber hand suggesting the presence of visual capture. Finally, children overestimated the weight of the grasped objects after being exposed to the regular rubber hand, and regardless of the stroking condition. Indeed, the data showed a significant weight overestimation after merely watching the regular rubber hand. We discuss these findings in relation to previous adult and children studies on bodily self-consciousness below.

Ownership

Developmental studies investigating directly the sense of body ownership in children suggest that the ability to identify a rubber hand as one's own is already present by 5 years of age and does not undergo significant changes across childhood (Nava et al., 2017; Cowie et al., 2013, 2016). In line with this work, we expected to find a significant difference between synchronous and asynchronous visuotactile stroking in our ownership questions. In addition, we predicted that this effect would be present after RHI with both the regular and large hand. The 6-to-8-year old children in our sample reported hand-ownership after synchronous visuotactile stroking, irrespective of hand size. Therefore, our subjective ownership data replicate previous findings and further demonstrate that the sense of body ownership in children arises dynamically and promptly, regardless of perceived variations in body size.

Interestingly, solely viewing the rubber hand in either hand size conditions (visual capture test) did not elicit a change in hand-ownership as measured by our question (Item 1), implying that multisensory signals might be necessary for modulating the experience of ownership over one's own body in our age group. Current models of body ownership in children (Cowie et al., 2013, 2016) and adults (Botvinick and Cohen, 1998; Makin, Holmes and Ehrsson, 2008; Tsakiris, 2010; 2017) suggest that visuotactile processes underlying body ownership are at the core of body identification (but see Carey et al., 2019 for visual capture effects in the full body illusion). The present results extend this converging evidence by showing that multisensory signals also play a key role in updating bodily self-consciousness in relation to concurrent changes in body size (i.e. the newly embodied larger rubber hand) in children. However, because the current study did not include a smaller hand manipulation nor different degrees of hand sizes, we are unable to conclude whether we can expect the same results in these conditions. Future studies should investigate whether a smaller rubber hand is embodied similarly as a larger one and to what extent size discrepancies between real and rubber hand can be incorporated within the own-body.

Proprioceptive drift

One of the aims of this study was to disentangle the respective role of vision of the rubber hand and visuotactile integration for changes in hand location in children. Results from the pointing response task show larger drifts (significantly different from zero) after watching the regular hand compared to the larger size hand. To our knowledge this is the first study to show that 6-to-8-year-old children exhibit a significant drift in hand position in the absence of visuotactile stimulation (i.e. visual capture). In line with Cowie and colleagues (2013; 2016), as well as developmental research on multisensory integration (e.g. Nardini et al., 2013; Gori et al., 2008), these results suggest that vision of an appropriately oriented hand is a sufficient cue to hand re-localization at this age. Furthermore, hand size might provide important top-down information regarding the more behavioural aspect of our bodily self-consciousness, that is self-location as measured by means of proprioceptive drift.

In line with the body ownership questions, we expected to find a significant difference between synchronous and asynchronous visuotactile stroking in proprioceptive drift and irrespective of hand size. Our analysis however, did not show any reliable effect of recalibration of hand position towards the rubber hand in neither stroking condition (synchronous vs. asynchronus) nor hand size condition (regular vs. larger). While we could not replicate previous findings with similar age range (Nava et al, 2017; Cowie et al., 2013, 2016; Greenfield et al., 2015; Cascio et al., 2012), these results are in line with recent evidence suggesting a dissociation between the subjective (i.e. questionnare) and behavioural (i.e. proprioceptive drift) measures of the RHI (e.g. Abdulkarim and Ehrsson, 2016; Holmes, Snjiders and Spence, 2006; Holmes, Crozier and Spence, 2004; Rohde, Di Luca, & Ernst, 2011). Importantly, these two measures tackle two independent components within bodily self-consciousness (Serino et al., 2013), thus raising the question of the developmental trajectories of these constructs (Cowie et al., 2016). Future studies are needed to experimentally manipulate these two measures in children and to establish whether such differences apply to other ages.

Weight-estimation

To our knowledge this study is the first to investigate body size representation using the SWI. Thus, we had two different predictions. On the one hand, as shown in the adult literature, participants would acquire ownership of a larger hand and perceive the grasped objects as smaller in size and therefore heavier in weight. On the other hand, as suggested by scale-error developmental research studies with younger children, participants would not update their estimation of object weight as a result of a change in bodily self-consciousness. Our results show that children estimated the weight of the grasped objects as heavier after viewing the regular rubber hand compared to the larger size hand. This was true irrespective of multisensory stroking and was associated with age, meaning that merely watching the regular rubber hand induced an overestimation in object weight, and such overestimation increased with the age of the child. Previous SWI work with children (Pick and Pick, 1967) suggested that when participants are able to perceive the volume of the object through haptic touch (as in our experiment), the strength of the illusion increases from 6 years of age to adulthood. In line with this result, here we show that the magnitude of the SWI in our sample increases with age. In addition, our results suggest that the mere vision of the rubber hand is sufficient to induce a change in the perceptual awareness of objects. This finding is in line with our proprioceptive drift results. The SWI is strongly modulated by visual appearance (Case, Wilson and Ramachandran, 2012; Buckingham and Goodale, 2010) and our results might indicate that optimal visual and proprioceptive integration is still undergoing significant development at this age. However, as we did not include an adult comparison in our investigation, it is important for future studies to examine the specific developmental trajectories of these mechanisms.

Contrary to our prediction, children did not overestimatimate the weight of the object after RHI with the larger hand; however, our SWI data shows that children might be unable to use their updated bodily self-consciousness as a reference for perceptual judgements about the grasped objects (as evidenced by scale-error studies with toddlers – for a review see DeLoache and Uttal, 2011). This, however, does not explain why children in our study overestimated the weight of objects only after being exposed to the regular rubber hand. One possibility is that children fail to make accurate judgments in this condition because their perceptual experience of objects is influenced by both bottom-up (the seen size of the hand) as well as top-down mechanisms (the stored knowledge of their body shape) (Banakou et al., 2013). The adult literature provides some support to this hypothesis. For example, evidence suggests a causal relationship between representations of body space and external space, in the sense that our own body size affects how we perceive the world (Van Der Hoort et al., 2011). Van Der Hoort and colleagues (2011) conducted a full body illusion study, where participants were induced to embody a different sized artificial body. This resulted in a change in the perception of sizes and distances in the external world. Similarly, Banakou and colleagues (2013) experimentally triggered adults to embody virtual child-like body or adult-like body but of the same size of a child. They found that, although adults tend to overestimate the size of objects when embodying a scaled-down adult body, illusory ownership of a child body lead to a significantly higher overestimation of object size. Importantly, this result has been more recently replicated (Tajadura-Jimenez et al., 2018). Banakou and colleagues (2013) suggested that higher-level cognitive processes (i.e., age-related implications on body size) affect our perceptual interpretation of sizes of external objects. It could be that children in our study interpreted both regular and larger hand in terms of the age associated to them (i.e. the regular hand as a child hand and the larger hand as an adult hand). That is, objects in the environment are generally heavier for younger people compare to adults who, on the other hand, live in a world that is better 'scaled' for them (see DeLoache and Uttal, 2011 for a similar observation and Buckingham, 2014 for review on top-down mechanisms of the SWI). Indeed, the developmental literature points towards a higher susceptibility to body illusions in children (Cowie et al., 2016; Newport et al., 2015), suggesting greater plasticity of bodily self-consciousness across development.Therefore, it is possible that without necessarily inducing a significant change in bodily self-consciousness, our regular size hand condition might have strengthened one's own bodily self-consciousness and hence judgments about objects and their physical properties as they usually appear to children; whereas, the larger rubber hand condition might have led to perceptual adjustment of the grasped object with respect to the bodies of adults. However, this interpretation remains tentative, serving as hypothesis for future studies. Buckingham and MacDonald

(2016) have recently suggested that variations in object identity are sufficient to induce a weight illusion. An experimental condition where age-related changes in body form are manipulated – for example using an older-adult hand vs. a younger-adult hand, could help to disentangle this issue. If children's representation of their own body and its relative influence to the perception of the external environment are affected by top-down mechanisms, then illusory ownership of an 'elderly' rubber hand would lead to overestimation of object weight (i.e. the assumption that elderly people have less strength compared to younger adults). Future studies should perhaps investigate this possibility in a systematic and experimental manner.

Conclusions

In conclusion, this study provides further support to the presence of separate mechanisms for own bodily self-consciousness and body size representation, which uniquely contribute to the development of body awareness during childhood. In line with previous studies (Nava et al., 2017; Cowie et al, 2013; 2016; Greenfield et al., 2015; Cascio et al., 2012), we show that visuotactile processes underlying the ability to identify a rubber hand as being part of one's own body are already established in young children, and further provide evidence of dynamic update of one's sense of body ownership in relation to changes in body size. The current data delineate the protracted development of optimal fine tuning of visual and proprioceptive signals of the own body in children between 6 and 8 years of age (Nava et al., 2017; Cowie et al, 2013; 2016), and further demonstrate that embodied recalibration of the external environment undergoes a similar extended development, perhaps more sophisticated than initially hypothesised.

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References:

1. Abdulkarim, Z., & Ehrsson, H. H. (2016). No causal link between changes in hand position sense and feeling of limb ownership in the rubber hand illusion. *Attention, Perception, & Psychophysics*, *78*(2), 707-720. https://doi/ 10.3758/s13414-015-1016-0.
2. Banakou, D., Groten, R., & Slater, M. (2013). Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proceedings of the National Academy of Sciences*, *110*(31), 12846-12851. https://doi/10.1073/pnas.1306779110
3. Banakou, D., Parasuram, D. H. & Slater, M. Virtual Embodiment of White People in a Black Virtual Body Leads to a Sustained Reduction in their Implicit Racial Bias. *Front. Hum. Neurosci.* 10, 601 (2016). https://doi.org/10.3389/fnhum.2016.00601
4. Botvinick, M., & Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. *Nature*, *391*(6669), 756.
5. Brownell, C. A., Zerwas, S., & Ramani, G. B. (2007). "So Big": The Development of Body Self-Awareness in Toddlers. *Child development*, *78*(5), 1426-1440. https://doi.org/10.1111/j.1467-8624.2007.01075.x
6. Bruno, N., & Bertamini, M. (2010). Haptic perception after a change in hand size.

Neuropsychologia,48(6),1853-1856.
https://doi.org/10.1016/j.neuropsychologia.2010.01.006

7. Buckingham, G., & Goodale, M. A. (2010). Lifting without seeing: The role of vision in perceiving and acting upon the size weight illusion. PLoS one, 5(3), e9709. https://doi.org/10.1371/journal.pone.0009709
8. Buckingham, G. (2014). Getting a grip on heaviness perception: a review of weight illusions and their probable causes. *Experimental Brain Research*, 232(6), 1623-1629.
9. Buckingham & MacDonald (2016) The weight of expectation: Implicit, rather than explicit, prior expectations drive the size–weight illusion, *The Quarterly Journal of Experimental Psychology*, 69:9, 1831-1841, https://doi.org/10.1080/17470218.2015.1100642
10. Carey, M. A., Crucianelli, L., Preston, C. E. J., & Fotopoulou, A. (in press). The Effect of Visual Capture Towards Subjective Embodiment Within the Full Body Illusion. *Scientific Reports*.
11. Cascio, C. J., Foss-Feig, J. H., Burnette, C. P., Heacock, J. L., & Cosby, A. A. (2012). The rubber hand illusion in children with autism spectrum disorders: delayed influence of combined tactile and visual input on proprioception. *Autism*, 16(4), 406-419. https://doi.org/10.1177/1362361311430404
12. Case, L. K., Wilson, R. C., & Ramachandran, V. S. (2012). Diminished size–weight illusion in anorexia nervosa: evidence for visuo-proprioceptive integration deficit. *Experimental brain research*, *217*(1), 79-87. https://doi.org/10.1007/s00221-011-2974-7
13. Casler, K., Eshleman, A., Greene, K., & Terziyan, T. (2011). Children's scale errors with tools. *Developmental psychology*, *47*(3), 857. https:// 10.1037/a0021174.
14. Cesari, P., & Newell, K. M. (1999). The scaling of human grip

configurations. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(4), 927.

15. Cowie, D., Makin, T. R., & Bremner, A. J. (2013). Children's responses to the rubber-hand illusion reveal dissociable pathways in body representation. *Psychological Science*, *24*(5), 762-769. doi: 10.1177/0956797612462902
16. Cowie, D., Sterling, S., & Bremner, A. J. (2016). The development of multisensory body representation and awareness continues to 10 years of age: evidence from the rubber hand illusion. *Journal of experimental child psychology*, *142*, 230-238. doi: 10.1016/j.jecp.2015.10.003.
17. Crucianelli, L., Paloyelis, Y., Ricciardi, L., Jenkinson, P., & Fotopoulou, A. (in press). Embodied precision: Intranasal oxytocin modulates multisensory integration. *Journal of Cognitive Neuroscience*.
18. Crucianelli, L., Krahé, C., Jenkinson, P. M., & Fotopoulou, A. K. (2018). Interoceptive ingredients of body ownership: Affective touch and cardiac awareness in the rubber hand illusion. *Cortex*, 104, 180-192.
19. DeLoache, J. S., & Uttal, D. H. (2011). Gulliver, Goliath and Goldilocks: young children and scale errors. *Early Development of Body Representations*, *13*, 59-67.
20. DeLoache, J. S., Uttal, D. H., & Rosengren, K. S. (2004). Scale errors offer evidence for a perception-action dissociation early in life. *Science*, *304*(5673), 1027-1029. DOI:10.1126/science.1093567
21. Dunphy-Lelii, S., Hooley, M., McGivern, L., Skouteris, H., & Cox, R. (2014). Can I Reach That Sticker? Preschoolers' Practical Judgments About Their Own and Others' Body Size. *Journal of Cognition and Development*, *15*(4), 584-598. https://doi.org/10.1080/15248372.2013.797905
22. Farmer, H, Tajadura-Jiménez A, and Tsakiris M. "Beyond the colour of my skin: How

skin colour affects the sense of body-ownership." *Consciousness and cognition* 21, no. 3 (2012): 1242-1256. https://doi.org/10.1016/j.concog.2012.04.011

23. Farmer, H., Maister, L., & Tsakiris, M. (2014). Change my body, change my mind: the effects of illusory ownership of an outgroup hand on implicit attitudes toward that outgroup. *Frontiers in psychology*, *4*, 1016. https://doi.org/10.3389/fpsyg.2013.01016
24. Fini, C., Cardini, F., Tajadura-Jiménez, A., Serino, A., & Tsakiris, M. (2013). Embodying an outgroup: the role of racial bias and the effect of multisensory processing in somatosensory remapping. *Frontiers in behavioral neuroscience*, *7*, 165. https://doi.org/10.3389/fnbeh.2013.0016
25. Gallagher, S. (2005). Dynamic models of body schematic processes. *Advances in consciousness research*, 62, 233.
26. Gordon, A. M., Forssberg, H., Johansson, R. S., Eliasson, A. C., & Westling, G. (1992). Development of human precision grip. *Experimental Brain Research*, 90(2), 399-403.
27. Gori, M., Del Viva, M., Sandini, G., & Burr, D. C. (2008). Young children do not integrate visual and haptic form information. *Current Biology*, 18(9), 694-698. https://doi.org/10.1016/j.cub.2008.04.036
28. Greenfield, K., Ropar, D., Smith, A. D., Carey, M., & Newport, R. (2015). Visuo-tactile integration in autism: atypical temporal binding may underlie greater reliance on proprioceptive information. *Molecular autism*, 6(1), 51. https://doi.org/10.1186/s13229-015-0045-9
29. Haggard, P., & Jundi, S. (2009). Rubber hand illusions and size–weight illusions: self-representation modulates representation of external objects. *Perception*, *38*(12), 1796-1803. https://doi.org/10.1068/p6399
30. Hohwy, J., & Paton, B. (2010). Explaining away the body: Experiences of

supernaturally caused touch and touch on non-hand objects within the rubber hand illusion. *PloS one*, *5*(2), e9416. https://doi.org/10.1371/journal.pone.0009416

31. Holmes, N. P., Crozier, G., & Spence, C. (2004). When mirrors lie:"Visual capture" of arm position impairs reaching performance. *Cognitive, Affective, & Behavioral Neuroscience*, *4*(2), 193-200. https://doi.org/10.3758/CABN.4.2.193
32. Holmes, N. P., Snijders, H. J., & Spence, C. (2006). Reaching with alien limbs: Visual exposure to prosthetic hands in a mirror biases proprioception without accompanying illusions of ownership. *Perception & Psychophysics*, *68*(4), 685-701. https://doi.org/10.3758/BF03208768
33. Kilteni, K., Normand, J. M., Sanchez-Vives, M. V., & Slater, M. (2012). Extending body space in immersive virtual reality: a very long arm illusion. *PloS one*, 7(7), e40867. https://doi.org/10.1371/journal.pone.0040867
34. Kloos, H., & Amazeen, E. L. (2002). Perceiving heaviness by dynamic touch: An investigation of the size-weight illusion in preschoolers. *British journal of developmental psychology*, *20*(2), 171-183. https://doi.org/10.1348/026151002166398
35. Lenggenhager, B. et al. (2007) Video ergo sum: manipulating bodily self-consciousness. Science 317, 1096–1099.httpps//doi.org/ 10.1126/science.1143439
36. Longo, M. R., Azañón, E., & Haggard, P. (2010). More than skin deep: body representation beyond primary somatosensory cortex. *Neuropsychologia*, *48*(3), 655-668. https://doi.org/10.1016/j.neuropsychologia.2009.08.022
37. Maister, L., Sebanz, N., Knoblich, G., & Tsakiris, M. (2013) Experiencing ownership over a dark-skinned body reduces implicit racial bias. *Cognition* 128, 170–178. https://doi.org/10.1016/j.cognition.2013.04.002
38. Maister, L., Slater, M., Sanchez-Vives, M. V., & Tsakiris, M. (2015). Changing bodies changes minds: owning another body affects social cognition. *Trends in*

cognitive sciences, *19*(1), 6-12. https://doi.org/10.1016/j.tics.2014.11.001

39. Makin, T. R., Holmes, N. P., & Ehrsson, H. H. (2008). On the other hand: dummy hands and peripersonal space. *Behavioural brain research*, *191*(1), 1-10. doi: 10.1016/j.bbr.2008.02.041
40. Martinaud, O., Besharati, S., Jenkinson, P. M., & Fotopoulou, A. (2017). Ownership illusions in patients with body delusions: Different neural profiles of visual capture and disownership. *Cortex*, 87, 174-185. doi: 10.1016/j.cortex.2016.09.025.
41. Maselli, A. & Slater, M. (2013). The building blocks of the full body ownership illusion. *Front. Hum. Neurosci.* **7**, 83. DOI:10.3389/fnhum.2013.00083
42. Nardini, M., Begus, K., & Mareschal, D. (2013). Multisensory uncertainty reduction for hand localization in children and adults. *Journal of Experimental Psychology: Human Perception and Performance*, 39, 773–787. https://doi.org/10.1037/a0030719
43. Nava, E., Bolognini, N., & Turati, C. (2017). The development of a cross-modal sense of body ownership. *Psychological science*, *28*(3), 330-337. doi:10.1177/0956797616682464
44. Normand, J. M., Giannopoulos, E., Spanlang, B., & Slater, M. (2011). Multisensory stimulation can induce an illusion of larger belly size in immersive virtual reality. *PloS one*, *6*(1), e16128. https://doi.org/10.1371/journal.pone.0016128
45. Pavani, F., & Zampini, M. (2007). The role of hand size in the fake-hand illusion paradigm. *Perception*, 36(10), 1547-1554.
46. Peck, T.C. et al. (2013) Putting yourself in the skin of a black avatar reduces implicit racial bias. *Conscious. Cogn.* 22, 779–787 https://doi.org/10.1016/j.concog.2013.04.016
47. Petkova, V. I. & Ehrsson, H. H. (2008). If I were you: perceptual illusion of body swapping. *PLoS One* 3, e3832 https://doi.org/10.1371/journal.pone.0003832

48. Petrini, K., Remark, A., Smith, L., & Nardini, M. (2014). When vision is not an option: children's integration of auditory and haptic information is suboptimal. *Developmental science*, 17(3), 376-387. DOI: 10.1111/desc.12127
49. Pick Jr, H. L., & Pick, A. D. (1967). A developmental and analytic study of the size-weight illusion. *Journal of Experimental Child Psychology*, *5*(3), 362-371.
50. Preston, C. and Ehrsson, H.H. (2014) Illusory changes in body size modulate body satisfaction in a way that is related to non-clinical eating disorder psychopathology. *PloS one* 9, e85773. https://doi.org/10.1371/journal.pone.0085773
51. Robinson, H. B. (1964). An experimental examination of the size-weight illusion in young children. *Child Development*, 91-107.
52. Rohde, M., Di Luca, M., & Ernst, M. O. (2011). The rubber hand illusion: feeling of ownership and proprioceptive drift do not go hand in hand. *PloS one*, *6*(6), e21659.
53. Rosengren, K. S., Schein, S. S., & Gutiérrez, I. T. (2010). Individual differences in children's production of scale errors. *Infant Behavior and Development*, *33*(3), 309-313. https://doi.org/10.1016/j.infbeh.2010.03.011
54. Serino, A., & Haggard, P. (2010). Touch and the body. *Neuroscience & Biobehavioral Reviews*, *34*(2), 224-236. https//doi.org/10.1016/j.neubiorev.2009.04.004
55. Serino, A., Alsmith, A., Costantini, M., Mandrigin, A., Tajadura-Jimenez, A., & Lopez, C. (2013). Bodily ownership and self-location: components of bodily self-consciousness. *Consciousness and Cognition*, 22(4), 1239-1252.
56. Sforza, A., Bufalari, I., Haggard, P. & Aglioti, S. M. (2010). My face in yours: Visuo-tactile facial stimulation in uences sense of identity. *Soc. Neurosci.* 5, 148–62 doi: 10.1080/17470910903205503
57. Slater, M. et al. (2010) First person experience of body transfer in virtual reality. *PloS*

One 5, e10564 https://doi.org/10.1371/journal.pone.0010564

58. Smolak, L. (2004). Body image in children and adolescents: where do we go from here? *Body image*, *1*(1), 15-28. DOI:10.1016/S1740-1445(03)00008-1
59. Tajadura-Jiménez, A., Banakou, D., Bianchi-Berthouze, N., & Slater, M. (2017). Embodiment in a Child-Like Talking Virtual Body Influences Object Size Perception, Self-Identification, and Subsequent Real Speaking. *Scientific reports*, *7*(1), 9637. doi: 10.1038/s41598-017-09497-3.
60. Tajadura-Jiménez, A., Grehl, S. & Tsakiris, M. (2012). The other in me: interpersonal multisensory stimulation changes the mental representation of the self. *PLoS One* 7, e40682. https://doi.org/10.1371/journal.pone.0040682
61. Tsakiris, M. (2008). Looking for myself: current multisensory input alters self-face recognition. *PLoS One* 3, e4040 https://doi.org/10.1371/journal.pone.0004040
62. Tsakiris, M. (2010). My body in the brain: a neurocognitive model of body-ownership. *Neuropsychologia*, *48*(3), 703-712. https://doi.org/10.1016/j.neuropsychologia.2009.09.034
63. Tsakiris, M. (2017). The multisensory basis of the self: from body to identity to others. *The Quarterly Journal of Experimental Psychology*, *70*(4), 597-609. doi: 10.1080/17470218.2016.1181768
64. van der Hoort, B., Guterstam, and Ehrsson (2011) Being Barbie: the size of one's own body determines the perceived size of the world. PLoS ONE 6, e20195 https://doi.org/10.1371/journal.pone.0020195
65. Ware, E. A., Uttal, D. H., & DeLoache, J. S. (2010). Everyday scale errors. *Developmental science*, *13*(1), 28-36. doi: 10.1111/j.1467-7687.2009.00853.x.
66. Ware, E. A., Uttal, D. H., Wetter, E. K., & DeLoache, J. S. (2006). Young children make scale errors when playing with dolls. *Developmental Science*, 9(1), 40-45.

doi:10.1111/j.1467-7687.2005.00461.