Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes

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An illusory sensation of ownership over a surrogate limb or whole body can be induced through specific forms of multisensory stimulation, such as synchronous visuotactile tapping on the hidden real and visible rubber hand in the rubber hand illusion. Such methods have been used to induce ownership over a manikin and a virtual body that substitute the real body, as seen from first-person perspective, through a head-mounted display. However, the perceptual and behavioral consequences of such transformed body ownership have hardly been explored. In Exp. 1, immersive virtual reality was used to embody 30 adults as a 4-y-old child (condition C), and as an adult body scaled to the same height as the child (condition A), experienced from the first-person perspective, and with virtual and real body movements synchronized. The result was a strong body-ownership illusion equally for C and A. Moreover there was an overestimation of the sizes of objects compared with a nonembodied baseline, which was significantly greater for C compared with A. An implicit association test showed that C resulted in significantly faster reaction times for the classification of self with child-like compared with adult-like attributes. Exp. 2 with an additional 16 participants extinguished the ownership illusion by using visuomotor asynchrony, with all else equal. The size-estimation and implicit association test differences between C and A were also extinguished. We conclude that there are perceptual and probably behavioral correlates of body-ownership illusions that occur as a function of the type of body in which embodiment occurs.

body awareness | self consciousness | perceptual illusion

How would it be to have the body of a child again, and how would this change perception of the world and your attitudes toward yourself and others? In this article we address this question in the context of body-ownership illusions. The issue of how the brain represents the body has been approached extensively in philosophy (1, 2), cognitive neuroscience (3–5), robotics (6, 7), and virtual environments (8, 9). It has been demonstrated that it is straightforward to generate the illusion in people that their body has changed (1, 10–16). In particular, immersive virtual reality (IVR) has been used as a compelling way to manipulate and introduce illusions with respect to the body representation of people in terms of structure, size, and morphology. It has been shown that specific types of synchronous multisensory and sensorimotor stimulation can lead to illusory perceptions of body shape, size, and symmetry even when these are very different from the normal body form (17–23). In other words, there have been significant demonstrations that perceptual ownership of a body that may be quite different to your own is possible through particular types of multisensory stimulation.

Although previous work has focused on the phenomena of body ownership and explanations for it, here we show that the form of the body, in terms of the relative proportions of head size, trunk, and limbs, can impact size-perceptions of the external world and reaction-time behaviors in the selection of categories that compare the self with others. To achieve this end, we carried out two experiments. In the first, we embodied adults in the virtual body of a toddler (about 4-y-old) and as a control in a virtual body of the same size but representing a scaled-down adult body. The virtual body moved in real-time determined by the actual movements of the participant. The second experiment was carried out as a further control with the same child or scaled-down adult body, but where the virtual bodies moved asynchronously with respect to the real movements of the participants. This control was to examine what would happen when participants did not have the ownership illusion over their virtual body. The results of these experiments show the illusion of ownership over the child body has different perceptual and behavioral consequences than ownership over the scaled-down adult body form.

The effect of embodiment regarding perception of age and how that can influence subsequent behavior has not yet been extensively addressed in literature. Hershfield et al. (24) used IVR to expose participants to their future-aged selves to study the impact on attitudes toward monetary saving for the future. The results suggested that those interacting with their future selves later focused on long-term implications of choices and exhibited increased preferences for larger rewards later in life. Yee and Bailenson (25) found that negative stereotyping of the elderly was significantly reduced when participants were placed in avatars of old people compared with those participants placed in avatars of young people.

Moreover, behavioral changes via an altered self-representation have been partially addressed by researchers with respect to on-line 3D worlds and IVR. Yee and Bailenson (26) examined how one's self-representation can influence interaction with others, specifically by using more attractive or taller virtual characters. The authors refer to this as the "Proteus effect." Further studies have focused on avatar appearance and its effect on behavior and cognition (27).

What is the link, however, between an altered representation of oneself and the perception of the surrounding environment? It has been suggested that body size serves as a fundamental reference in visual perception of object size (28), but also that the combination of information from different visual and oculomotor cues also affects this perception (29). Previous studies have shown, for example, that hand size affects the perceived sizes of external objects (30, 31). Besides the size of specific body parts in the perception of the external world, the role of whole-body scaling has also been studied recently. Van der Hoort,

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Guterstam, and Ehrsson (22) studied the sense of body ownership and the effect on object sizes and distances where the seen body is a relative size cue. For this purpose, manikin bodies of different sizes were used, and participants experienced ownership of abnormally large and small bodies. The results demonstrated that the visual perception of distance and object sizes is affected by one's own multisensory body representation. Is size, however, the only factor influencing perception of the surrounding environment or do additional bottom-up and top-down influences play a role in spatial awareness?

All of us can recall childhood memories and the environment in which they were set. We often find it surprising how objects that we found gigantic back then now seem considerably smaller, for example, when revisiting our childhood school. The experiment reported here addresses the question as to how embodiment of adults in a body of a child might influence size-perception of the environment and categorizations of self compared with others. We compare embodiment in a child (or "toddler" body) with embodiment in that of a scaled-down adult body of the same size. We consider three issues: First, whether there is evidence of an illusion of body ownership with respect to these two virtual bodies, and in particular whether the strength of the illusion differs between the two body types. Second, whether perception of size of the surrounding environment is influenced by the virtual body form. Third, whether there is a difference in reaction times in attributing child-like or adult-like attributes to the self.

Results

Exp. 1 had a single factor (body form) with two conditions. In condition C, participants were embodied in the body of a child (Fig. 1*A*). In condition A, they were embodied in a scaled-down adult body of the same height as that in C (Fig. 1*B*). The height (of 91.5 cm) represented a child of about 4 y old. Embodiment was through first-person viewpoint from the eyes of the virtual body that substituted the own body with synchronous visuomotor feedback, so that as the person moved their virtual body moved in real-time and synchronously (Movie S1). The eye heights were identical in both conditions.

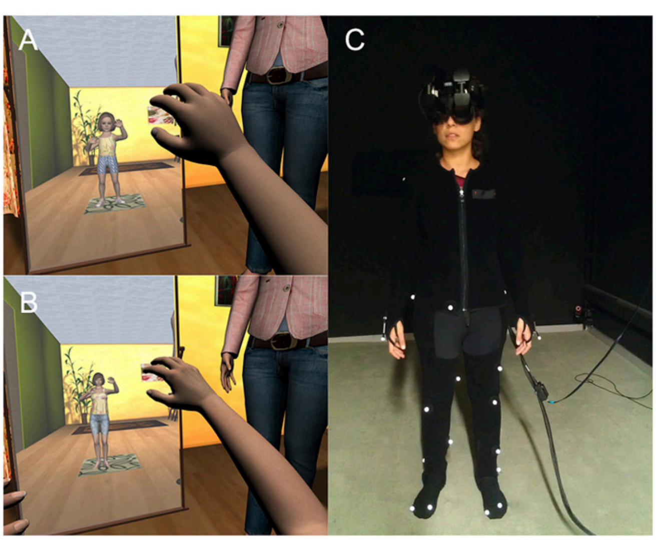

Fig. 1. Experimental setup. The body of the participant was substituted by a sex-matched virtual body, viewed from first-person perspective, onto which body and head movements were mapped in real time. The body could also be seen as reflected in a virtual mirror as shown. The body each participant viewed depended on the condition C (for child) or A (for adult) to which each one was assigned. (*A*) A female participant in a child's body. (*B*) A female participant in a scaled-down adult's body. (*C*) Participants' body movements were tracked by 34 Optitrack markers.

The experiment was conducted as a within-group counterbalanced design originally with 32 participants (n = 16 in each condition). Two participants were excluded from the analysis because of the lack of data during the second condition of the experiment (final, n = 15 in each condition). Participants were randomly allocated to one of the two groups, regarding whether they first experienced a child virtual body and then an adult body or an adult body first and then a child body. Their two trials were separated by 1 wk. The experimental design is shown in Table S1.

Body Representation Questionnaire. First, we examine the extent of body ownership with respect to the two virtual bodies of conditions C and A. Participants completed a questionnaire after each experimental condition (Table S2). The box plot (Fig. 2*A*) of questionnaire responses for the ownership illusion questions Q1 (VRBody) and Q2 (Mirror) shows that participants tended to affirm the illusion of ownership with respect to the child and the adult body, and that there was no significant difference between the two conditions. To test these hypotheses, we used the Friedman nonparametric test for two-way layouts, with the trial number as the blocking factor (for VRBody $\chi_1^2 = 0.05$, $P = 0.82$, for Mirror $\chi_1^2 = 0.16$, $P = 0.69$). The median scores for Q4 (TwoBodies) are each 0, with no difference between the conditions ($\chi_1^2 = 0.12$, $P = 0.73$). The median score for Q3 (Features) is significantly lower in the Child condition (median = −2) than the Adult condition (median = −1) ($\chi_1^2 = 5.32$, $P = 0.02$), which is consistent with participants recognizing the difference between the two bodies, although it should be noted that both scores are very low.

Effect of Body Form on Size Estimation. A major issue of the study was to investigate the relationship between body form and the perceived sizes of objects in the environment. Our expectation was that condition C would result in greater overestimation of sizes compared with condition A, although based on previous literature, we expected overestimation in both conditions. Participants were trained to hold their hands apart with the distance between the two hands representing the estimated sizes of objects. The locations of the two hands were tracked and the distance between them recorded (Fig. S1*A*). Participants were required to carry out these estimations twice, for three differently sized cubes (15 cm, 30 cm, 45 cm); they had previously had training on this method of size estimation (*Materials and Methods*). The first estimates were obtained after they had entered the virtual environment but before embodiment in a virtual body, where they made three estimates for each object. Then, after some experience of being in the virtual body, the participants were required to make the estimations again. The full procedure for training and measurement is described in *SI Materials and Methods*. We took the mean of nine estimates as their final estimate for each size estimation, as each object was measured three times in random order at three different locations, all at the same distance from the participant (0.6 cm) and with the same orientation (Fig. S1 *B–D*). The differences between the mean size estimates during the embodiment phase and the preembodiment mean estimates are denoted by *dmean15*, *dmean30*, and *dmean45*. One extreme outlier was detected, which was removed from all analyses involving these means (Fig. S2 and Dataset S1).

The results (Fig. 2*C*) show that there is a significantly greater overestimation of size in condition C compared with condition A. This finding is confirmed by a within-groups ANOVA: *dmean15*: $F(1, 28) = 11.37$, $P = 0.002$; *dmean30*: $F(1, 28) = 16.43$, $P = 0.0004$; *dmean45*: $F(1, 28) = 8.92$, $P = 0.006$. The Shapiro–Wilk test shows compatibility of the residual errors of the fit with normality for *dmean15* and *dmean30* (both $P > 0.89$) but not so for *dmean45* ($P = 0.03$, although the distribution of residual errors is clearly symmetric about 0 and bell-shaped). It should be noted that in the adult condition the differences are significantly greater than 0, consistent with earlier results (22) that the scaled-down body does result in object size overestimation (t tests all $P < 0.00005$).

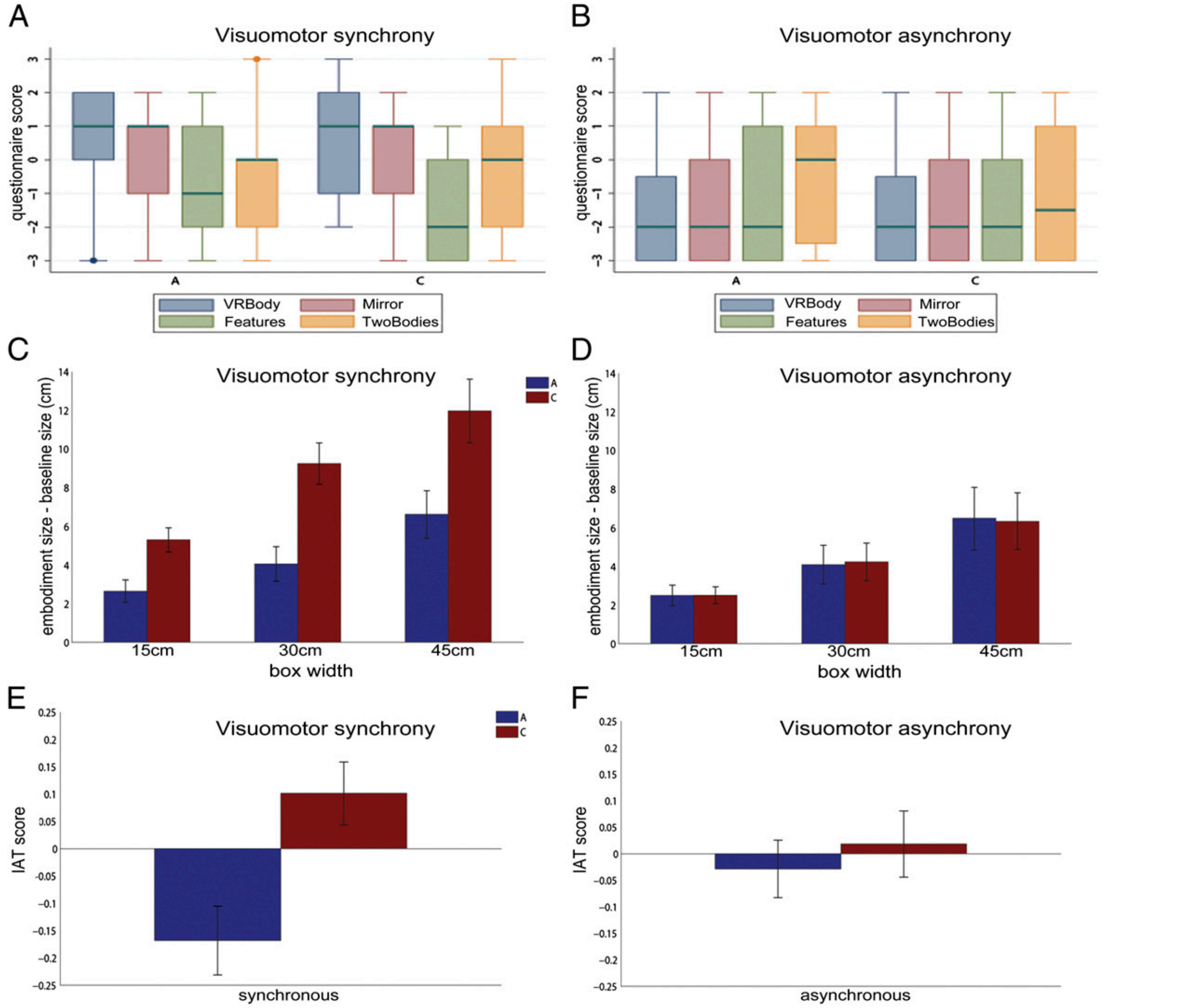

Fig. 2. Box and bar plots of questionnaire, size estimations, and IAT results by the Adult and Child conditions for Exps. 1 and 2. (*A* and *B*) Box plots for questionnaire results on body ownership (see Table S2) for Exps. 1 and 2, respectively. The thicker horizontal lines are the medians and the boxes the interquartile ranges. (*C* and *D*) Bar chart size-estimation results for Exps. 1 and 2. The heights are means and the bars SEMs. The variable *dmean15*, *dmean30*, and *dmean45* are the differences between the postembodiment size estimations and preembodiment (baseline) size estimations, for the boxes of the three different sizes. (*E* and *F*) Bar charts for the IAT results for Exps. 1 and 2. A higher IAT score represents faster response times for self compared with child categories. Significance levels are given in the text.

Implicit Association Test Scores. Participants completed an Implicit Association Test (IAT) (32) at the end of both conditions and while still in the virtual environment. This IAT paired child or adult with self and other categories. The results show that participants in the child condition C responded faster when the self was paired with child images (Me-C) than when the self was paired with adult images (Me-A). On the other hand, participants in the adult condition A had faster response times for Me-A pairs than for Me-C pairs. In the interpretation of the IAT scores, positive scores reflect stronger associations for Me-C relatively to Me-A. Fig. 2*E* shows that the IAT C scores are greater than the A scores. The within-groups ANOVA shows that the difference in means between the conditions is significant [$F(1, 29) = 22.12$, $P = 0.0001$, and Shapiro–Wilk test for normality $P = 0.49$].

Exp. 2: The Influence of Body Ownership. The analysis above shows that there is a significant effect of the type of body; that is, the child body leads to higher IAT scores and overestimation of object sizes compared with the adult body. However, we are interested in whether it was the illusion of body ownership that contributed to these effects. To this end, Exp. 2 was designed to diminish the degree of body ownership by using visuomotor incongruence. Another 16 people were recruited from the same population as Exp. 1. These participants completed the full experiment in the same session, with counterbalanced order (either child embodiment first or adult embodiment first). However, whereas in Exp. 1 there was real-time synchrony between the movements of the participant and the movements of the virtual body, in this case the virtual body moved asynchronously with respect to the movements of the participant, although seen from exactly the same perspective condition as in Exp. 1 (Movie S1). In other words, in Exp. 2 participants saw the virtual body from a first-person perspective and in the mirror as before, but its movements were not those of the participant. Based on previous research (17, 20, 33–35), we expected this aspect to reduce the degree of body ownership (*SI Text*, Table S3).

Indeed, this result is what happened, as can be seen in Fig. 2*B*. For example, for Q1 (VRBody) and Q2 (Mirror), the medians are both −2 in all asynchronous conditions, compared with 1 in all synchronous conditions. (Using the Wilcoxon rank-sum test comparing VRBody between synchronous and asynchronous conditions $P < 0.00005$, and for Mirror $P = 0.0001$. There are no significant differences for Features or TwoBodies).

Fig. 2*D* shows the bar charts for *dmean15*, *dmean30*, and *dmean45* in the asynchronous condition. It is evident that there are no differences between the child and adult conditions. The within-group ANOVAs have all $P > 0.80$ for the difference between C and A in this asynchronous setup (and all satisfy normality using the Shapiro–Wilk test all $P > 0.68$). Similarly, Fig. 2*F* shows the IAT results, with no difference between C and A (within-groups ANOVA $P = 0.65$, Shapiro–Wilk $P = 0.10$).

Taking both experiments together, "synchronous" is a between-group factor and condition (A or C) is a within-group factor. As can be seen from Fig. 2 *C* and *D*, for *dmean15* the within-groups main effect difference between A and C is significant [$F(1,43) = 5.67$, $P = 0.02$], with a significant interaction between condition and synchronous [$F(1,43) = 5.50$, $P = 0.02$]. The residual errors satisfy normality (Shapiro–Wilk $P = 0.26$). The findings are similar for *dmean30*: the within-groups condition main effect $F(1,43) = 8.73$, $P = 0.005$, interaction $F(1,43) = 7.68$, $P = 0.008$, Shapiro–Wilk $P = 0.97$. For *dmean45*: the within-groups main effect is $P = 0.05$, and interaction effect $P = 0.04$. This time normality is not satisfied (Shapiro–Wilk $P = 0.001$) but the residual error distribution is highly symmetric. As before, each of *dmean15*, *dmean30*, and *dmean45* are significantly greater than 0 (*t* tests, all $P < 0.0001$), showing that there was an overestimation of size.

For IAT (Fig. 2 *E* and *F*), the within-groups main effect for condition has $F(1,44) = 9.01$, $P = 0.004$, with interaction effect $F(1,44) = 4.72$, $P = 0.035$ (Shapiro–Wilk $P = 0.86$). The significant interaction effects are all critical in demonstrating that the relationship between responses in the adult and child conditions were different, depending on whether there was asynchronous or synchronous visuomotor feedback. The former is associated with a low level of body ownership and the latter with a high level.

Discussion

Our first result is that it is possible to generate a subjective illusion of ownership with respect to a virtual body that represents a child and a scaled-down adult of the same size when there is real-time synchronous movement between the real and virtual body. The illusion is extinguished when the virtual body moves asynchronously compared with the real body. It was found that there were no significant differences with respect to body ownership between the child and adult condition. This result is not surprising and is in line with earlier results that it is possible to generate such illusions with different body forms (15, 19, 21, 23), including very small or large bodies (22). This result serves mainly as a reference point, to show that there is no difference in the extent of the illusion of ownership over the adult and child body forms in Exp. 1 that could account for the other findings.

Our second result concerned object size estimation in the different body forms. It has been argued that body size serves a reference for the external world, and earlier studies using IVR have examined how the perception of one's body size influences the perception of spatial layouts (22). Other studies (e.g. refs. 33 and 34), show that scaling one's body size up or down proportionally results in perceiving the world as smaller or larger respectively. The results of our study go one step beyond this. We have shown that although there was an overestimation by the A group, as would be expected, there was an even greater overestimation by the C group compared with the A group (Fig. 2*C*). Hence, as well as body size influencing the estimation of the sizes of objects in the environment, there must be an additional underlying mechanism relating to perception of the form of the own body. The findings support the notion that higher-level cognitive processes (i.e., the implications of the form of the body in terms of how it represents age) can influence our perceptual interpretation of sizes of objects in the external world other than body size alone.

Our third result shows an impact of body form on self- and other-categorization (measured by reaction times) with respect to classification of the self as a child or as an adult, where those in the C body responded significantly faster to self-categorization with child-like attributes compared with those in the A body. In the late 1980s, Jaron Lanier was the first to realize that IVR could be used for body transformation (discussed in ref. 35) and previous research has focused on demonstrating how an avatar's visual appearance can influence participants. Yee and Bailenson (26) examined how manipulating the online self-representation can cause changes in the behavior of people embodied in avatars (their notion of the Proteus effect). However, this earlier work does not provide evidence that body ownership can affect attitudes and behavior intrapersonally. First, there was no notion of or attempt to measure the degree of body ownership; and second, their theoretical framework describes how an external perceiver can possibly influence the user of an avatar through interpersonal communication behavior (i.e., when interacting or communicating with others). As Yee and Bailenson (26) have pointed out, behaviors can be influenced by assumptions about how one would believe others would expect them to behave. As they state, "the false self-concept (i.e. self-stereotyping) may override behavioral confirmation" (26), discussing the possibility of a feedback effect playing a role in their findings. The concept of the feedback loop, as described in Walther's (36) hyperpersonal model, suggests that behavior can be influenced in online interactive conversations by behavioral expectations of the conversation partner, which in turn can also influence the behavior of this partner. Another study has also focused on how an avatar's appearance can affect the behavior and cognition of the participant (27) by making the user more or less confident, friendly, aggressive, negative, or intimate. In that study however, the hypothesis was based on how the manipulation of outer appearance and clothing contribute to the argued effect. Therefore, no direct manipulation of the bodily self-representation and type of body was engaged.

In our study we concentrated on manipulating solely the bodily self-representation and on the consequences of this in subsequent perception and attitudes. No external factors, such as social interaction, were present, and participants were alone rather than in social settings. Furthermore, this study is innovative in the way that takes into account the virtual representation in a body of a different age—a child—and on the consequences of such a transformation on behavior and attitudes. To our knowledge, no previous studies have examined the effect of owning a body of a child in an experimental setup. The results of the present study support the hypothesis that not only did participants feel ownership of the child body, but that this body transformation also affected their identification by modifying their IAT responses.

Our fourth finding is that the size estimation and IAT results were influenced by the extent of the illusion of body ownership. Importantly, the size estimation and IAT responses compared between high (synchronous) and low (asynchronous) ownership-illusion conditions show that the difference in responses between the C and A conditions only occur for the group with the higher level of body-ownership illusion. This finding suggests that a correlate of a body-ownership illusion is that the type of body carries with it a set of temporary changes in perception and behaviors that are appropriate to that type of body. Here it relates to age, and everyone will have experiences of being 4 y old, possibly with first-hand memories that may be triggered by being embodied in and having strong agency over an apparent 4-y-old body. As noted by Vogeley and Fink (37) in their review of the neural correlates of first-person perspective: "'emotional traces' of past experiences trigger our actual decisions based upon experiences similar to the actual experience." The authors also argue that our core self is reconstituted on a moment-to-moment basis in the relationship between ourselves and the external world, and that this is a "necessary component for the so-called autobiographical self, that integrates particular states of the core self over one's personal life history" (37). In our experiment we radically changed not only the relationship of the self to the external world through the manipulation of size but

PSYCHOLOGICAL AND COGNITIVE SCIENCES

also with respect to body type representing a profoundly different age. Therefore, we would predict a triggering of past first-person perspective experiences associated with being that younger age that then influenced present-day perceptual and attitudinal processing.

However, if the body type was not one that had been coded in memory through previous experience, participants might be influenced by socially and culturally derived expectations of what it would be like to have a specific type of body. The recently introduced framework of a cortical "body matrix" might explain this. The body matrix is a multisensory representation of peripersonal space and the space immediately around the body, in a body-centered reference frame (38). According to this, and a further interpretation in ref. 39, when multisensory data generates an illusion of change in the body structure, then the body matrix maintains the homeostatic and psychological integrity of the body to conform with the changed body. Our current results suggest the intriguing possibility that this even extends to perceptual processing and implicit attitudes and behaviors (40). There is further evidence for this in recent experiments where light-skinned people were induced to experience the illusion of ownership over a black rubber arm (41) and over a dark-skinned virtual body (42). In both cases, there was a reduction in implicit racial bias associated only with the illusion of ownership of a dark-skinned body. These experiments provide evidence supporting the idea that it is not only prior experience of a body type that influences the extent of perceptual, attitudinal, and behavioral correlates of the body ownership illusion. However, more work is required in this regard, including brain-imaging studies, to help to understand the extent of cortical reorganization under body illusions that result in such changes.

The experiments presented in this report confirm that altered bodily self-representation can have a spontaneous and significant influence on aspects of perception and behavior. It has been shown that IVR supports global scaling of sizes, where the brain automatically adjusts for the overall size of one's avatar, which is in line with past studies (22). Most importantly, our system can reproduce the experience of the world "as a child experiences it," and not only as a simple linear transformation of size. Furthermore, a demonstration that avatars can change perception of our selves has great potential in various applications and for the interaction between participants. Finally, and importantly, it is worth pointing out that as we choose our self-representations in virtual reality settings, our behaviors may be shaped accordingly (26); it is therefore not only the influence that users exert on avatars, but essentially the impact of avatars on their users and how they can shape their attitudes.

Materials and Methods

Exp. 1 was conducted as a within-groups counterbalanced design with a single binary factor, referred to as "Body Form." The first factor level represented the body of a visually realistic 4-y-old child (condition C) and the second level (condition A) (Fig. 1) represented the body as an adult but with the same height as the child body (91.5 cm) by scaling down the adult body to match the height of the child body. Both virtual bodies were dressed in a similar way. The size of the virtual environment and proportions of the content were equivalent to reality and identical in both conditions.

Participants were randomly allocated to one of the two designed groups, regarding whether they first experienced a child virtual body and then an adult body (C) or an adult body first and then a child body (A). The experimental design can be seen in Table S1. Further details of experimental procedures are provided in *SI Materials and Methods*.

Procedures. Participants attended the experiment at prearranged times. Upon arriving, they were given an information sheet to read, and after they agreed to continue with the experiment, they were given a consent form to sign. Before the experiment started, participants were fitted with the head-mounted display (HMD) and the body-tracking suit. The view seen through the HMD was calibrated for each one of them.

The position of all participants was controlled through Velcro strips on the floor, which were used to mark where they should stand during the experiment. These positions corresponded to the center of the physical and virtual room. Participants were instructed to turn and move their heads and bodies but not walk away from that area unless requested otherwise by the experimenter. That area was represented in the virtual environment by a virtual carpet, on which participants were asked to stand.

During the first part of the experiment, participants entered a virtual outdoor scene where they trained their object-size estimation capability, thereby also familiarizing themselves with the task of estimating sizes of objects in virtual reality. In this setup they had no virtual body. During this task the participants were presented in random order with six virtual red color cubes of different sizes (15, 25, 30, 45, 60, and 75 cm) in front of them over a period of 5 min. All cubes were shown in the same position and at 0.6 m with the same orientation. The position from which participants looked at the objects was from a height of about 90 cm, equal to the height of the child and scaled adult avatars. The participants were instructed to indicate the width of each cube by raising their hands and hold them straight in front of them, as if they would like to grasp it, and the size was measured as the distance between the palms. The distance was calculated using the tracking devices on their hands and was automatically recorded for each object separately. An offset corresponding to the distance between the tracking device and the participant's palms individually was also taken into account when estimating the final results (the average among all participants was 8 cm) (Fig. S1*A*). After each size estimation, participants were given visual feedback in the form of words on the screen regarding their measurements that categorized their estimations as "Too Big," "Too Small," or "Correct." In cases where measurements were other than "Correct," participants were instructed to relax their arms and try again, until they achieved a "Correct" feedback. Only then was the next virtual object presented to them. Each measurement was classified with a $\pm$4-cm tolerance (e.g., for 15-cm virtual objects, "Correct" estimation varied from 11 to 19 cm).

Next, participants removed the HMD and were asked to complete a personal traits questionnaire, the information from which was used later during the IAT test. For example, participants had to provide their age, sex, profession, and other such individual information. Immediately after completing the questionnaire they put on the HMD again, and the second and main part of the experiment started. Participants entered the same training virtual scene, still with no virtual body; they were asked to repeat the object-size estimation task. Red-colored cubes of 15 cm, 30 cm, and 45 cm were each presented three times in random order. Each virtual object remained visible in front of participants at a constant distance (of 0.6 cm) for 5 s. After each cube disappeared, they were asked to indicate their estimate by the distance between their hands, and the measurements were recorded with the same procedure as described before, but without any feedback as to the correctness of the size estimations. This process provided the baseline size estimations.

While participants wore the HMD they were asked to close their eyes, during which time a new scene was loaded. This scene portrayed a virtual living room decorated with everyday furniture, including a virtual mirror. The body of the participant was substituted by a sex-matched virtual body, seen from a first-person perspective. The participant's head and body movements were mapped in real time to the virtual body; they could see this body both by looking toward directly toward their real body and also in the virtual mirror. The body seen by each participant depended on the condition A or C. A series of tasks were then assigned to the participants. First, they were asked to perform a simple set of stretching exercises that had previously been demonstrated to them by the experimenter, in order that they should explore the capabilities and real-time motion of the virtual body, including movements of their arms, legs, and feet. Participants were asked to continue performing these exercises by themselves and also look around the virtual room in all directions. During this visual exploration, participants were asked to state and describe what they saw, to be sure that they were paying attention. After the exploration period (5 min), the participants were asked to repeat the size-estimation task, with no virtual body present. Each object was measured three times in random order at three different locations, all at the same distance from the participant equal to that of the control measurements and with the same orientation (Fig. S1 *B–D*). The heights at which each object was placed were always the same, and were the same as in the control condition.

Then participants were instructed to locate two virtual doors in the room and face toward these. One door was to a room that looked like a child's playroom, and the second more like an adult sitting room (Fig. S3). We asked participants to choose between these two virtual doors. The location of the rooms in the environment was randomized across participants to avoid choice based on adaptation. Participants were told that they would be given only 4 s to make their choice before the doors closed. They were told that any delay could result in failing the experiment.

Finally, the participants completed the IAT (from within the HMD) and after removing the HMD they were asked to complete the postexperimental questionnaire. Next, the participants were paid and debriefed. The whole procedure lasted between 45 and 60 min. The experimental operator (female) was present throughout the whole experiment. All participants attended the second trial of the experiment 1 wk after the first phase and the procedures were identical to the ones presented above, except that the avatar body used was the other one.

Exp. 2 was identical to Exp. 1, except that the virtual body moved independently of the movements of the participant and the second trial was carried out on completion of the first (*SI Text*).

IAT Procedure. As described by Schnabel, Asendorpf, and Greenwald (32), the "IAT measures are designed to assess automatic associations between a contrasted pair of target… and attribute… concepts through a series of discrimination tasks that require fast responding." The target category in the IAT design adapted for the current study refers to "Children versus Adults" images; the attribute category to "Me versus Others" has personal attributes in the form of words or short sentences.

The IAT was applied immediately after the exposure in the virtual environment and while participants were still wearing the HMD through which the test was displayed. A virtual reality wand was used by the participants to make their selections by putting their left and right thumbs on the left and right buttons, respectively (Fig. S4*B*). During the first IAT block, the participant was asked to categorize visual stimuli into the two target categories, namely "Children" and "Adults" (Table S4). The stimuli were pictures of adult and child faces appearing in the middle of the screen for the participant to sort into the appropriate category. In the second block, the participant was trained to press one button for "Me" attributes and the other button for "Others" attributes. These attributes were presented as written words. The attributes were personalized for each participant and corresponded to preferences and personal data, such as their names, ages, occupation, food/music, or other likes, life status, and so on. These personal data and preferences had been obtained for each individual from the questionnaire administered before they started the experiment. The third and fourth blocks combined the target and the attribute discrimination that were subdivided into two blocks of 40 trials each. The subsequent fifth block reversed the target discrimination and the sixth and seventh blocks combined again the attribute and the previously reversed target discrimination. As has been shown, mean IAT scores tend to show slightly stronger associations corresponding to the pairings of the combined block that is completed first (43). To control for this effect, the order of combined blocks was counterbalanced between participants as proposed by Nosek, Greenwald, and Banaji (44).

Statistical Note. All ANOVAs were within-group (or within-group for condition and between-group when comparing results of Exps. 1 and 2), and all allowed for sphericity computing both Greenhouse–Geisser and Huynh–Feld ε, which were equal to 1 in every case. The statistical software used was Matlab for the nonparametric statistics and Stata 12 for the ANOVAs.

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