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The second me: Seeing the real body during humanoid robot embodiment produces an illusion of bi-location

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ABSTRACT

Whole-body embodiment studies have shown that synchronized multi-sensory cues can trick a healthy human mind to perceive self-location outside the bodily borders, producing an illusion that resembles an out-of-body experience (OBE). But can a healthy mind also perceive the sense of self in more than one body at the same time? To answer this question, we created a novel artificial reduplication of one's body using a humanoid robot embodiment system. We first enabled individuals to embody the humanoid robot by providing them with audio-visual feedback and control of the robot head movements and walk, and then explored the self-location and self-identification perceived by them when they observed themselves through the embodied robot. Our results reveal that, when individuals are exposed to the humanoid body reduplication, they experience an illusion that strongly resembles heautoscopy, suggesting that a healthy human mind is able to bi-locate in two different bodies simultaneously.

1. Introduction

Perceptual illusions of body-ownership transfer have been previously used to demonstrate that multisensory correlations, together with a manipulated visual perspective, are enough to feel the sense of self located in a different body than one's own, or displaced towards it (Ehrsson, 2007; Guterstam & Ehrsson, 2012; Lenggenhager, Tadi, Metzinger, & Blanke, 2007). It has been reported that, during these illusions, healthy participants experience an illusion which strongly resembles an out-of-body (OBE) experience (Ehrsson, 2007; Guterstam & Ehrsson, 2012), in the sense that the self is perceived outside the borders of the physical body and the own body is perceived from the perspective of another person (Ehrsson, 2007).

OBE is one of the manifestations of the mental illusory visual experiences known as *autoscopic phenomena* (Anzellotti et al., 2011), in which patients experience an illusory reduplication of their own body (i.e. they see a second own body) in extracorporeal space (Blanke & Metzinger, 2009; Brugger, Regard, & Landis, 1997). In addition to OBE, autoscopic phenomena can also be classified as either *autoscopic hallucination*, or *heautoscopy* (Blanke & Metzinger, 2009; Blanke & Mohr, 2005; Brugger, 2002).

During an OBE, patients experience disembodiment (i.e. they feel located outside of the physical body) and see their real body from outside, generally, from and elevated visuo-spatial perspective (Blanke & Metzinger, 2009; Blanke & Mohr, 2005). In autoscopic hallucination, patients see the world from their habitual visuo-spatial perspective and experience their sense of self to be located within the real body (Blanke & Metzinger, 2009; Blanke & Mohr, 2005). However, they see an illusory

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double of themselves in extrapersonal space. Finally, in heautoscopy as well, patients see a double of themselves in extrapersonal space, but their sense of self-location and self-identification may alternate between the real and the illusory body or be simultaneously in both. Also in heautosocopy, patients sometimes report a sensation of "being split in two selves" (Blanke & Metzinger, 2009; Blanke & Mohr, 2005). Fig. 1 schematically represents the three forms of the phenomena.

Understanding autoscopic phenomena is important as it tells us how our brain defines the physiological and spatial characteristics of the self. Although the origin of autoscopic phenomena is not clear, it has been suggested that these phenomena occur due to a failure to integrate multisensory signals in the temporo-parietal junction, resulting in a breakdown of the spatial unity between the self and the body (Anzellotti et al., 2011). Specifically, Blanke and Mohr (2005) suggest that pathological activity in the right temporo-parietal junction (TPJ) are related to OBE (right TPJ) and heautoscopy (left TPJ), while they suggest that autoscopic hallucination relates to pathological activity distinct from the TPJ. However, proving the multisensory integration failure hypothesis is difficult with brain imaging studies that can highlight brain regions involved in the illusion, but cannot strongly support any one underlying mechanism. Therefore, the replications of these illusions using "unnatural" multi-sensory stimulations in healthy humans (Ehrsson, 2007; Lenggenhager et al., 2007) are critical, as they provide support to the idea that it is the multi-sensory integration mechanisms that are affected in patients who experience autoscopic phenomena.

On the other hand, previous results are contradictory regarding the possibility of mental bi-location in healthy individuals. In particular, in an artificial out-of-body illusion experiment, Guterstam and Ehrsson (2012) pointed out that participants had a strong sense of their perceived self being located at either the veridical or the illusory location, but never at both or at neither, and concluded that mental bi-location in two different bodies at a time is not possible in healthy subjects. In contrast, Furlanetto, Bertone, and Becchio (2013) suggest that mental bi-location occurs "more frequently than commonly thought" in healthy people. Finally, in Wissmath, Weibel, Schmutz, and Mast (2011), participants were exposed to a virtual rollercoaster displayed on a LCD large-screen television and had to rate to what extent they felt present in the real and in the mediated environment. It was observed that participants distributed their self-localization to both environments (Wissmath et al., 2011). Overall, it is still unclear whether healthy individuals can experience the sense of self located at more than one body at a time.

Another unresolved question during body-ownership transfer illusions is whether the sense of self or, more specifically, self-location (i.e. where "I" feel located in space; Blanke, 2012) and self-identification (i.e. the sense that a body belongs to "me"; Blanke, 2012) can be displaced towards a non-human looking body, such as the body of a humanoid robot. All the previous works in this regard have been done with highly-human looking avatars in virtual reality, or using mannequins. On the other hand, while artifical avatars (or just limbs) have been often used in robotic teleoperations (Kheddar, 2001; Kheddar, Chellali, & Coiffet, 2014), technological research in robotic teleoperation and telepresence have been generally more concerned with the high fidelity of the sensory feedback display at the "master" station, the performance of the tasks, and the motions of the robot in the remote locations rather than issues related to self-consciousness.

To investigate the above two issues, we embodied participants in the body of a non-human looking humanoid robot, by providing them with first person perspective (1PP) -i.e. the visual display of space centered around the own body and sense of body-ownership (by providing control of the robot head and walk), and explored the perceived sense of self-location and self-identification during illusory induced reduplication of one's own body. In virtual reality, avatars and doppelgangers can be modeled to look similar to the real physical appearance (Aymerich-Franch, Karutz, & Bailenson, 2012; Aymerich-Franch, Kizilcec, & Bailenson, 2014; Bailenson, 2012). However, the resulting product is a digital character resembling the self, but not the physical self. The key advantage of our set-up compared to other embodiment technologies, such as avatar

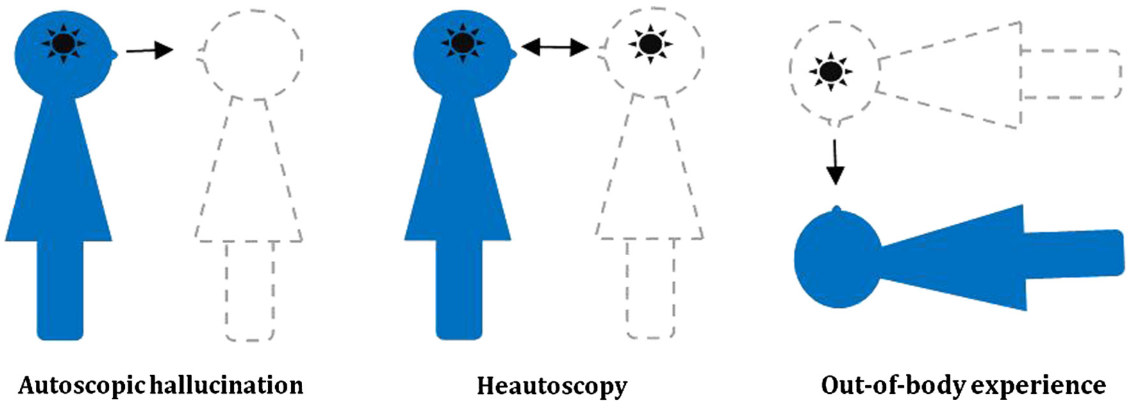

Fig. 1. Self-location and self-identification in autoscopic phenomena: the blue figure represents the real body and the white figure represents the illusory body. The black star represents self-location and self-identification with that body. The arrow indicates the perspective from which the person perceives the surroundings. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) *Source:* Adapted from Blanke and Metzinger (2009).

embodiment in virtual reality, is that both the artificial (humanoid robot) and the real body are in the same "reality" or space. This enabled us to create a condition in which users met their *real* physical selves in real-time while they were embodied in another body. A feature that we hypothesized was crucial to study the possibility of simultaneous self-location in two different bodies. Specifically, this study created an artificially induced illusion of body reduplication to answer *in what body (real or artificial) individuals perceive self-location and with what body self-identification prevails during humanoid embodiment* (RQ_1), as well as to establish parallelisms with the different manifestations of the autoscopic phenomena.

For the general validity of our experimental design, we measured embodiment before and during the experience. We expected that *participants would feel significantly more embodied in the robot's body during the embodiment process than before starting the experience* (H_{1a}). Also, we expected that *participants would feel significantly more embodied in the robot's body during the illusion of body reduplication than before starting the experience* (H_{1b}).

Finally, given the importance attributed to agency in embodiment (Aymerich-Franch & Ganesh, 2016) and self-consciousness (David, Newen, & Vogeley, 2008), we assessed the effect of agency as an independent variable during the body reduplication. In our experiment, we tried to 'displace' the subjects' sense of self by embodying them in the robot and then moving the robot. In this scenario, agency (other than its known role in embodiment) might play an additional role in the sense of displacement, that is, it might be possible that the subjects felt the displacements more strongly when they moved the robot themselves. Thus, we specifically examined whether *having agency influences the perceived sense of self-location and self-identification during robot embodiment and artificial body reduplication compared to the case when there is no agency* (RQ_2).

2. Methods

2.1. Participants

We conducted a within-subject experimental study with 13 participants from different nationalities (seven females and six males), aged 21–43 ($M = 27.38$, $SD = 7.7$). On a 7-point scale, the median score of the sample for videogame playing habits was 3, the median for familiarity with robots was 2 and the median for likeability of humanoid robots was 5 (see *Measures*). Participants received 1500 Japanese yens to participate and were naïve to the purpose of the experiment. They were recruited through a call for volunteers in the website of the experiment, which was posted on social networks. Working in the Robotics or Neuroscience field was used as exclusion criteria. Previous to the main study, a pretest was carried out with five volunteers (two females, three males), aged 23–36 ($M = 28$, $SD = 5.43$). The study was conducted with ethical approval of the National Institute of Advanced Industrial Science and Technology (AIST) in Tsukuba, Japan.

2.2. Material

A bipedal humanoid-looking robot (HRP-2), 154 cm tall and 58 kg, with 32 degrees of freedom, was used for the experiment. In order to induce a sense of embodiment, participants were provided with 1PP of the humanoid field-of-view (from cameras mounted on the humanoid's head) using an *Oculus Rift Development Kit 2* head-mounted display (HMD). The *Oculus* was also used to synchronize the robot's head movements to that of the user. In addition, the user wore stereo headsets with active noise cancellation, which provided sound recorded by the robot embedded microphones and prevented subjects from hearing any external sounds. For the control, we provided users with a joystick controller that allowed them to start and stop the robot's motion, go forward (walk), and turn left and right.

Two large mirrors, which reflected the full body of the robot, were used in the experimental set-up (Figs. 2 and 3, left) to facilitate identification with the robot's body. The first mirror was 150 cm high × 30 cm wide and the second mirror was 175 cm high × 90 cm wide.

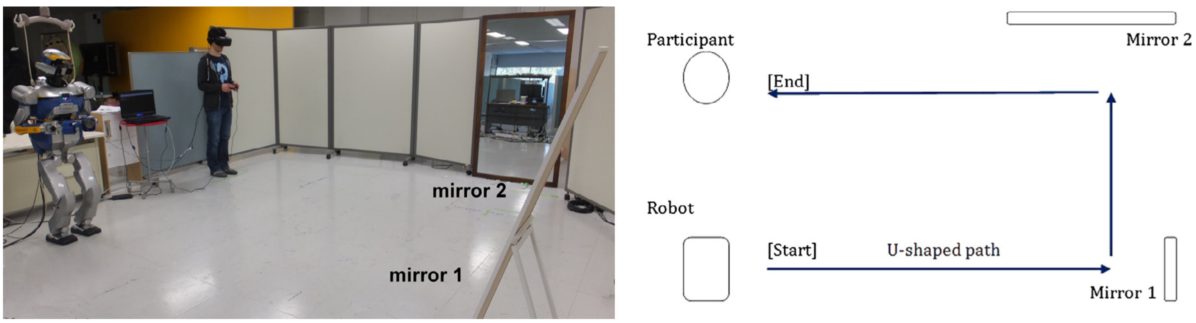

Fig. 2. Experimental set-up: A participant wears an HMD which provides 1PP from the robot's eyes, a headset, which provides stereo sound feedback from the robot's ears (microphone), and holds a joystick to control the robot movement. The robot is strategically located next to the participant at the beginning of the experiment to avoid the participant being in the field-of-view of the robot. Mirrors are placed along the path in order for the participant to have a complete view of the humanoid robot body (left panel). U-shaped path that participants followed during the experiment with start and end positions and location of the main elements involved in the set-up are shown in the sketch (not to scale, right panel).

Fig. 3. On the left, the participant completes the *induction* stage and sees her/himself in front of the second mirror from the robot's perspective (left image). On the right, the participant establishes visual contact with her/his human body while s/he is embodied in the robot's body (right image) during the *reduplication* stage.

2.3. Experimental design

The experiment included an initial training, followed by two main stages: (1) *induction:* induction of the illusion of embodiment in the robot's body, that concluded with the experimental subjects seeing themselves in front of a mirror from the robot's perspective (Fig. 3, left) and, (2) *reduplication:* artificially induced reduplication of one's own body during which participants established visual contact (and approached) their real human body while they were embodied in the robot's body (Fig. 3, right).

Participants experienced the full process (stages 1 and 2) in two experimental conditions: *controlled-robot* (*CR*), in which they controlled the body movement (head and walk) of the robot, and *non-controlled-robot* (*NCR*), in which they did not control the body movement (head and walk) of the robot (the robot walk and head movements were controlled by an experimenter). The order of the two experimental conditions (*CR* and *NCR*) was counterbalanced across participants.

2.4. Procedure

2.4.1. Initialization

After providing written consent, participants completed an initial survey (see *Measures*). Next, they wore an *Oculus Rift* visor which provided real-time visual feedback from the robot's cameras on its "eyes". A headset was used to provide sound feedback from a microphone placed in the robot's head (see *Material*). The participants held a joystick in their hands that they could use to start, stop and modulate the direction of the robot's walk. The humanoid and the participant were located in the same room, at a distance of 2.3 m one from the other and facing the same direction, such that the participant was out of the robot's field-of-view (Fig. 2, left). In order to emulate the participant's position and the sense of being in touch with the joystick, the robot hands also held a fake joystick such that if the participants looked down, they were able to see the robot's hands holding a joystick. During the experiment, any instructions by the experimenter were given to the participants through the robot intermediary, i.e. they heard them only through the earphones. The participant's physical body remained at the same place throughout the experiment.

2.4.2. Initial Embodiment measure

Once the participants wore the visor and the headset, an experimenter displayed the three questions from the embodiment questionnaire (see *Measures*), one at a time in front of the robot's eyes, for which the participants gave a verbal rating to each question.

2.4.3. Training

Following the rating, participants engaged in an initial training in which they learnt how to control the robot. The training allowed participants to familiarize with the functioning of the set-up.

Subjects were first instructed on the use of the joystick to control the robot. In the first trial of the training, participants experienced the robot walking an L-shaped path while they held an unplugged joystick in their hands. In this trial, they did not control the robot movement. In the second trial of the training, participants were given the real joystick that controlled the robot and asked to make the robot walk along the same "L" path. This time, they controlled the robot's walk.

2.4.4. Induction stage

After the training, the researchers uncovered the two mirrors and the participants completed the *CR* and *NCR* conditions. In the *CR* condition, the robot head movements were synchronized with those of the participant's, and they were able to control the robot's walk with the joystick. Participants were instructed to first turn their head left and right and look around, then walk (i.e. make the robot walk) straight towards the first mirror, stop the walk for few seconds, and observe themselves *in* the robot's body. Next, participants were required to turn left (i.e. make the robot's body turn left) to the second mirror and walk towards it. After reaching the second mirror, participants were again asked to stop the walk for few seconds and observe the robot's body on the mirror. Following this, they completely stopped the robot's motion and the experimenter displayed the embodiment questionnaire in front of the robot's eyes (Fig. 4). The participants read the questions by themselves through the HMD and verbally reported the answer.

The NCR condition was similar and the same the robot followed the same path, but all the actions (head movement, start-stop walk and motion, and left turns) in the NCR condition were controlled by the researcher.

2.4.5. Reduplication stage

Following the *induction* stage, the participants in the CR condition reactivated the robot motion using the joystick and turned the robot to the left. In doing so, they saw their real human body through the robot's cameras on its eyes. They walked towards their real body and stopped the walk and the motion in front of themselves (Fig. 3, right). The researcher again displayed the questionnaire in front of the robot's eyes and the participants verbally reported the answers.

Again in the NCR condition, the robot path and questionnaires remained same, while the robot movements were controlled by the experimenter (and not the subject).

Before starting, participants were explained the path they had to follow and the specific actions they had to do in order to complete each stage (i.e. start-stop the walk and the motion, left-turns, read and respond the questionnaire). Markers with the word "stop" were placed on the floor in front of each mirror and in front of the participant to ensure safety. Participants were instructed to stop before the markers.

Completing the full path once took about 5 min. After finishing one condition, participants completed a pc-based questionnaire. They, then continued on to the next condition. After finishing the experiment, they were thanked for their participation and paid.

2.5. Measures

2.5.1. Embodiment

A short-form *embodiment questionnaire* (Appendix A) was designed based on previous works (Kilteni, Groten, & Slater, 2012; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008). The sense of embodiment is understood in the context of the study as the feeling of owning a body in which one perceives to be located (de Vignemont, 2011; Kilteni et al., 2012). The questionnaire contained three questions, one for each of the three sub-dimensions of embodiment identified in (Kilteni et al., 2012). Each question was rated on a 7-point scale that ranged from (1) *not at all* to (7) *very strongly*. Following previous studies (Aymerich-Franch et al., 2014), the questionnaire was specifically designed to be responded *in situ* in order to minimize the effect of recall bias (Sackett, 1979), attending the needs of the experiment.

In total, the questionnaire was assessed three times: (i) before starting the experience (pre-test), (ii) after seeing the robot's body in front of the second mirror (*induction stage*), and (iii) after seeing the real human body through the "eyes" of the robot (illusory reduplication of one's own body). Brief versions of self-rated questionnaires such as the Mini-Social Phobia Inventory (Connor, Kobak, Churchill, Katzelnick, & Davidson, 2001), consisting of only three items, demonstrate that shortened versions of assessment instruments are as efficient (Connor et al., 2001), and demonstrate reliability and validity

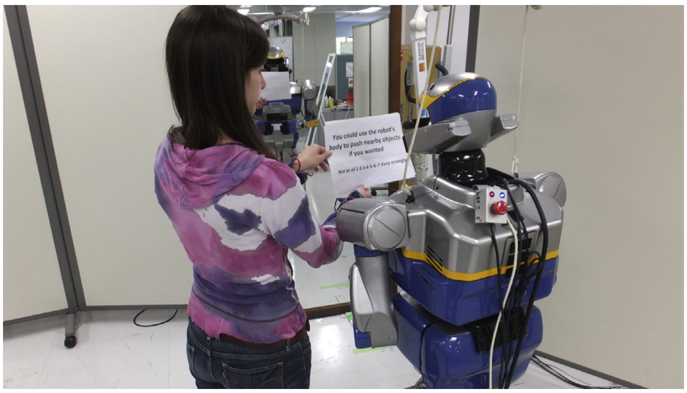

Fig. 4. The robot reaches the second mirror and the experimenter displays the questionnaire through the robot's eyes.

(Seeley-Wait, Abbott, & Rapee, 2009) similar to the corresponding longer versions. In our study, reliability of the short-form embodiment questionnaire we used was excellent ($\alpha = 0.94$), KMO = 0.722, and Bartlett's test of Sphericity = 0.000. Differences in the embodiment score between before and during the two stages of the experience (*induction* and *reduplication*) were used as a measure of the general validity of the experimental design.

2.5.2. Body reduplication (self-location and self-identification)

For the exploration of the artificially induced reduplication of one's own body, participants completed two sets of questions, one set for self-location and another for self-identification (Appendix A). The questions were developed based on the alterations on self-location and self-identification that patients suffer during autoscopic phenomena, according to the description provided by Blanke and Metzinger (2009).

Self-location was assessed twice in each experimental condition: after participants saw the robot's body in front of the second mirror (*induction* stage) and after they saw the human body through the eyes of the robot (*reduplication* stage). Previous works (Blanke & Metzinger, 2009) have identified four possibilities regarding self-location in autoscopic phenomena: (i) self-location in the real body, (ii) in the illusory body, (iii) in both bodies at a time, and (iv) swapping location between both (Blanke & Metzinger, 2009). Following previous studies which have developed a two-dimensional measurement for self-localization at the real and virtual environment (Wissmath et al., 2011), we developed a multi-dimensional measure which assessed self-location in the real (human) and illusory (robot) body, as well as in both bodies at the same time and swapping between both. Thus, participants responded to how strongly they felt their sense of self to be located *in the robot's body, in the human body, in both bodies at the same time,* or *swapping their position between the robot's body and the human body*. They rated the questions in a 7-point scale (1- *not at all*, 7, *very strongly*).

Self-identification was assessed only once, after the *reduplication* stage. For *self-identification*, participants completed another set of questions that explored disembodiment and identification with the human body during the *reduplication* stage. Disembodiment is characteristic of the OBE, in which self-identification is transported to the illusory body. In contrast, in autoscopic hallucination, self-identification remains in the physical body and there is no disembodiment (Blanke & Metzinger, 2009). In heautoscopy, it is difficult for these patients to decide if they are disembodied or not (Blanke & Metzinger, 2009). Four questions assessed the experience of disembodiment: *the body was an illusory body that did not belong to you*, *the body was another person*, *the body looked like you but was not you*, *you had become the robot and abandoned your human body*, and one question rated the sensation of being split in two selves typical from heautoscopy: *you were split in two selves*. The items were rated in a 7-point scale (1- *not at all*, 7- *very strongly*).

2.5.3. Open-ended questions

Participants completed two open-ended questions in which they were required to explain in as much detail as possible what they experienced when they saw their robotic body reflected on the mirror as well as when they saw their real body through the eyes of the robot.

2.5.4. Manipulation check

Participants answered, for each experimental condition, whether they controlled the robot's walk (y/n) and whether they saw what the robot was seeing in 1PP (y/n). All participants passed the manipulation check questions for both conditions.

2.5.5. Demographic information

The initial survey asked basic demographic information (age, gender, field of work or study).

3. Results

3.1. Embodiment

Kolmogorov-Smirnov test showed that the data was normally distributed ($p > 0.05$) in all dependent variables involved in the analysis to determine embodiment. The feeling of embodiment (Appendix B, Table B1) into the humanoid robot body was significantly stronger after *induction*, when participants saw their robotic body reflected in the big mirror ($t(11) = 4.05$, $p = 0.002$, $\eta^2 = 0.599$, average of all conditions; $t(11) = 3.33$, $p = 0.007$, $\eta^2 = 0.503$, in the *CR* condition; $t(11) = 4.28$, $p = 0.001$, $\eta^2 = 0.625$, in the *NCR* condition) than just before starting the experiment, which supports H_{1a}. Also, the feeling of embodiment in the robot's body was significantly higher after *reduplication* ($t(11) = 3.02$, $p = 0.012$, $\eta^2 = 0.454$, average of all conditions; $t(11) = -3.33$, $p = 0.017$, $\eta^2 = 0.418$, in the *CR* condition; $t(11) = 2.21$, $p = 0.049$, $\eta^2 = 0.308$, in the *NCR* condition), compared to the initial sense of embodiment, before starting the experiment, which supports H_{1b} showing that subjects still remained embodied in the robot when watching themselves through the robots eyes. In addition, the sense of embodiment did not significantly decrease during the *reduplication* stage, when the real body was visible to the participant ($t(12) = 1.44$, $p = 0.174$, $\eta^2 = 0.148$, average of all conditions; $t(12) = 0.636$, $p = 0.537$, $\eta^2 = 0.033$ in the *CR* condition; $t(12) = 1.58$, $p = 0.139$, $\eta^2 = 0.173$, in the *NCR* condition) compared to the *induction*. Interestingly, in response to RQ_2, eliminating control of the robot's body did not significantly decrease the feeling of embodiment during *induction* in front of the mirror ($t(12) = 0.744$, $p = 0.471$, $\eta^2 = 0.044$) or during the *reduplication*, when the human body was visible ($t(12) = 1.619$, $p = 0.131$, $\eta^2 = 0.179$), compared to having control of it.

3.2. Self-location

In response to RQ_1, participants consistently reported high to very high ratings ($Mdn \geqslant 4.5$) for self-location in the robot's body and self-location in the human body, which did not change for the two stages (*induction* and *reduplication*) or the two experimental conditions (*CR and NRC*). Self-location in the robot's body while seeing their own physical body in the *CR* condition obtained the highest rating ($Mdn = 6$). Median scores for self-location in both bodies ranged between 3.5 and 5 and median scores for swapping locations were slightly lower and ranged between 3.5 and 4 (Appendix C, Fig. C1). Following Wissmath et al. (2011) we added up all individual values of illusory (robot) and real (human) location from the self-location questionnaire. The overall mean was higher than the maximum score of the scale (=7) in the *induction* both for the *CR* ($M = 9.33$, $SD = 2.14$) and *NCR* ($M = 8.83$, $SD = 1.85$) conditions and in the illusion of body reduplication both for *CR* ($M = 10$, $SD = 2.04$) and *NCR* ($M = 9.08$, $SD = 1.88$) conditions. In addition, we did not find evidence of a negative correlation between self-location at the robot and the human body. In particular, correlations were not significant for *induction* in the *CR* ($r = -0.246$, $p > 0.05$) and *NCR* ($r = -0.198$, $p > 0.05$) conditions or in the illusion of body reduplication in the *CR* ($r = -0.383$, $p > 0.05$) and *NCR* ($r = -0.513$, $p > 0.05$) conditions.

Overall, these results indicate that participants did not report complementary patterns of location (i.e. when an increase in self-location inside the robot decreases self-location in the human body, or vice versa) but they strongly felt in both bodies at the same time.

Additionally, we performed non-parametric tests to compare self-location in the *CR* and *NCR* conditions during the *induction* and *reduplication* stages. We also compared the *induction* stage with the *reduplication* stage for each experimental condition. Self-location in the robot's body during *reduplication* ($Z = -2.555$, $p = 0.011$) was significantly higher in the *CR* ($Mdn = 6$) than in the *NCR* ($Mdn = 4.5$) condition. In addition, the fact of seeing the own body did not substantially modify self-location- No significant differences were found for any of the comparisons ($p \geqslant 0.05$) with the exception of self-location in the robot's body in the *CR* condition ($Z = -2.124$, $p = 0.034$), which was significantly higher during the *reduplication* ($Mdn = 6$) compared to the *induction* ($Mdn = 4.5$).

3.3. Self-identification

In response to RQ_1, all disembodiment items received scores between $Mdn = 2$ and 3 in both experimental conditions, whereas the sensation of being split in two selves received a higher median ($Mdn = 4$ in the *CR* condition and $Mdn = 3.5$ in the *NCR condition*) (Appendix C, Fig. C2). Experiencing disembodiment (average of the four items) was not related to a stronger sense of embodiment ($r = 0.480$, $p > 0.05$ for the *CR* condition and $r = 0.282$, $p > 0.05$ for the *reduplication* stage in the *NCR* condition). Finally, the difference in disembodiment (average of the four items) approached significance when *CR* and *NCR* conditions were compared ($Z = -1.722$, $p = 0.085$). Participants in the *NCR* experienced slightly higher sense of disembodiment ($Mdn = 3$) than participants in the *CR* condition ($Mdn = 2$). However, the sensation of being split in two selves was not significantly different between the two conditions ($Z = -0.750$, $p = 0.453$).

4. Discussion

Our study recreates an experience of reduplication of one's own body that leads to an illusion which strongly resembles heautoscopy, suggesting that healthy humans can bi-locate in two different bodies at the same time.

Experimental subjects in our study embodied a non-human looking humanoid robot and virtually walked "in the robot's body". Our results revealed that participants felt significantly embodied in both stages of the process (*induction* and *reduplication*) in both experimental conditions (*CR* and *NCR*), which validated our experimental design to further examine our research questions. Evidence that participants felt embodied in the robot was also found in the open-ended question at the end of each experimental condition that encouraged participants to describe what they experienced when they saw "their" robotic body reflected in the mirror: "I felt that it was my own body and I had a strong feeling that I cannot define if it is true or illusory experience... It felt like my own body and it was exciting because my mind was not so fast to decide if it is me or not... It was not scary and I thought about it as a continuation of myself" (Participant 2), "I felt it was me in the mirror" (Participant 5), or "I felt like I had turned into a robot" (Participant 8). Even if there was no body movement synchronization, this participant also "felt that I was able to control the robot using my own limbs" (Participant 8). Also, another participant claimed that "I felt somehow that I'm a disabled person" (Participant 11) when he tried to move the limbs of the robot using their own and he could not. Support for the transported sense of self-location to the robot's body during the embodiment process was also found in the open-ended question: "it was like if my own mind was inside of the robots head" (Participant 4), "I felt like I was in the robots body, but only as a guest" (Participant 12).

Previous studies have been able to demonstrate self-location outside the bodily borders in healthy individuals (Ehrsson, 2007; Lenggenhager et al., 2007). Though these demonstrations have been suggested to be related to heautoscopy (Blanke & Metzinger, 2009; Lenggenhager et al., 2007), they are generally paralleled to OBE. On the other hand, the reduplication of the self during robot embodiment in our study presented strong parallelisms with heautoscopy for three main reasons. First, we found that contrary to other experiments of artificially generated full-body illusions (Guterstam & Ehrsson, 2012), the participants in our experiment consistently reported high ratings of being located not only at the robot body and the human body, but also in both bodies at the same time. Simultaneous location in the real and the illusory body is a differential characteristic of heautoscopy, and supports the conclusions by Furlanetto et al. (2013) as well as Wissmath et al. (2011), that it is actually possible for a healthy person to not only experience the self outside the bodily borders but to feel located in two different bodies at the same time.

Second, participants experienced a sense of being split in two selves. This sensation was also supported by the comments collected in the open-ended question; here are some excerpts: "It was like I was in three selves: I, but not my body at all, robot, but not in the robot at all, and some place where I cannot say where it was" (Participant 1), "I felt like being split in two selves" (Participant 2), "I saw myself standing on one leg (from the robot's "eyes") and I also felt myself standing on one leg, but my flesh body which normally has a good sense of balance kind of struggled, or should I say I struggled keeping the balance because I was the robot at the same time. It was like being split into two bodies experiencing my balance but not seeing my flesh body balance itself because I was looking through the robot's eyes, my mirror image" (Participant 9).

Third, participants did neither report a clear sense of disembodiment nor a clear absence of it. We also found that the feeling of disembodiment was slightly higher in the NCR condition compared to the CR condition. Despite the fact that the ratings were not high in the questionnaire, several participants described an experience very close to disembodiment in the open-ended questions, for example: "I felt it was similar to my body but it was not me" (Participant 5), "I felt mostly on the robotic body than on mine" (Participant 6), "I felt that I saw myself through another myself" (Participant 7), "I saw myself occupying the space, being in space. My body looked weird. Is this how I really look like?" (Participant 9), "For some moments I had the sensation that my human body was in some sleepy state, and the sensation that I was the robot was stronger" (Participant 10), "It was like if I was sleeping and seeing myself from another standpoint without any possibility to move" (Participant 11), or "I saw myself but it wasn't actually me. I was seeing somebody else who looks like me... I wasn't even sure the person was me though, my feeling, my emotion, my thoughts, everything of me was into the robot which was great" (Participant 13) are noteworthy comments made in this direction. These quailitative reports support the finding that the artificially induced reduplication of one's own body was close to heautoscopy since in this manifestation of the autoscopic phenomena patients find it difficult to figure out whether they are disembodied or not, and whether the self is localized within the physical body or in the autoscopic body (Blanke & Mohr, 2005: 187). Finally, one participant's description of his experience was close to an autoscopic hallucination: "I felt the presence of a second being, which in this case was the robot... I felt like the second individual approaching me" (Participant 8).

On the other hand, we did not find evidence that agency significantly affected the sense of embodiment. This finding supports Blanke and Metzinger (2009) statement that, contrary to "many recent authors defending that agency is a necessary condition to actualize minimal phenomenal selfhood... a passive, multisensory and globalized experience of 'owning' a body is sufficient for the minimal conscious selfhood" (p.12). However, even though agency was seemingly not necessary to experience whole body embodiment, we still believe that agency can benefit the sense of embodiment (Aymerich-Franch & Ganesh, 2016). Specifically, as it can be observed in Table B1 (Appendix B), the mean score for embodiment in the *reduplication* stage during the *NCR* condition was slightly lower compared to the rest of the embodiment scores during the experiment. This decrease might be an indicator that the lack of agency combined with seeing the real self might have negatively affected the sense of embodiment in this condition.

Concerning the self-location measure used in our study, it has been pointed out that in existing studies focusing on self-localization in healthy individuals, participants are typically instructed to indicate a single localization (Wissmath et al., 2011), which might force them to choose only one location when they might be actually experiencing two. Thus, following Wissmath et al. (2011) we developed a multidimensional method of assessment that accounted not only for self-location in the illusory body (robot) but also in the real body. Additionally, because of the nature of the experience we wanted to measure, we also included additional items for measuring location at both bodies and swapping locations and examined if these items were answered coherently with the other two. Participants in our experiment described their experience as "surprising", "exciting", "great", "interesting", "completely unusual", and "intense" but also "weird". Two participants felt uneasy in the *NCR* condition as a result of not being able to control the robot: "a little intimidated because I was not in control", "it was not a nice feeling, I felt constrained". Future studies should also assess the enjoyment (Vorderer, Klimmt, & Ritterfeld, 2004) and pleasantness of the experience compared to that experienced by patients that go through real autoscopic phenomena.

We used robot embodiment as a methodological tool to explore artificial reduplication of the self. Robot control in these set-ups can also be implemented by body-movement synchronization or brain-computer interface (Petit, Gergondet, Cherubini, & Kheddar, 2015) in addition to joystick. In our experiment, the decision to use joystick control was based on the fact that we prioritized a relatively easy method for participants to control the movement over the complexity of other methods such as brain-computer interfacing. In addition, we wanted the participant to stay still and in the same position in space throughout the experiment while the whole robot physically moved in space. Body-movement synchronization was not an option in our case given that body-movement tracking is only possible for head and arms but not for walking within the current technology we use. The function of walking was essential to displace the robot in the room and make it approach the mirrors and to the real body of the participant. Using the robot also presented advantages over using avatars in virtual reality. In particular, the robot embodiment set-up allowed participants to see their real bodies in real time, instead of a digital recreation of the real body and to perform the experiment in the real physical environment (instead of a digitally created or manipulated one), which maximized the realism of the experience. Furthermore, our robotic set-up enabled avatar motion, a feature that was not used in similar studies of artificial recreation of autoscopic phenomena (Ehrsson, 2007; Lenggenhager et al., 2007). An interesting question that is still unanswered, is whether the nature of the percieved autoscopic phenomena depends on the induction method; when visuo-movement techniques for induction of embodiment illusions are used compared to when visuo-tactile techniques are used (Ehrsson, 2007; Lenggenhager et al., 2007).

Given the novelty of the study, validated measures for the assessment of the measured experiences were not available to us in this study. In the absence of recognized physiological measure for autoscopic phenomena, we note that our study relies on predefined questionnaires. For this reason we have given a lot of importance to the open ended questions in our discussion, and report the (very interesting) answers we received in detail through this discussion. While the cognitive/verbal interpretation of sensory illusions can vary significantly between the subjects, it is normally possible to judge the core perceptual sensation (or illusion) leading to these interpretations. Note that in the open-ended question, subjects are simply asked to describe "what they experienced" and not anything specific about self-location or embodiment. We therefore believe that open-ended questions are more resistant to bias and can reveal important data that would have been missing if only quantitative measures were implemented.

On the other hand, we acknowledge that the lack of behavioral and physiological measures as well as the small number of subjects is the principal limitation of our work. As Dempsey-Jones and Kritikos (2014) pointed out, in body ownership illusions, subjective and proprioceptive outcomes can be distinct. Therefore, while our study does show that participants subjectively felt within both bodies, their own and that of the robot, our results are not enough to conclusively conclude that this feeling was present at the implicit levels of self-location and self-identification.

To conclude, our experiment reports the following main findings. First, it demonstrates that humans are able to experience a sense of embodiment in a non-human looking humanoid robot body. Second, it shows that when healthy humans are exposed to an artificially induced reduplication of their body, they experience a phenomenon that presents strong resemblance to heautoscopy. Finally, this result shows that a healthy human mind is able to (at least subjectively) bi-locate in two different bodies at the same time.

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Appendix A

<u>Embodiment questionnaire</u>
Do you feel as if… *(1.Not at all – 7.Very Strongly)*
The robot's body was your own body
You were located at the position of the robot
You could use the robot's body to push objects near him if you wanted

<u>Self-location questionnaire</u>
Induction stage
When you saw your robotic body reflected in the big mirror, how strongly did you feel… *(1.Not at all – 7.Very Strongly)*
In the robot's body
In the human body
In both bodies at the same time
Swapping your position between the robot's body and the human body several times
Reduplication stage
When you saw your human body through the eyes of the robot, how strongly did you feel… *(1.Not at all – 7.Very Strongly)*
In the robot's body
In the human body
In both bodies at the same time
Swapping your position between the robot's body and the human body several times

<u>Self-identification questionnaire</u>
When you saw your human body through the eyes of the robot, how strongly did you feel as if… *(1.Not at all – 7.Very Strongly)*
The body was an illusory body that did not belong to you (D*)
The body was another person (D*)
The body looked like you but was not you (D*)
You had become the robot and abandoned the human body (D*)

You were split in two selves
*Disembodiment items

Qualitative data collection
Please share your thoughts in as much detail as possible:
What did you experience when you saw your robotic body reflected on the mirror?
What did you experience when you saw your body through the eyes of the robot?

Appendix B

See Table B1.

Table B1
Means and SD for global embodiment before the experiment, during the induction phase, and during the reduplication phase for the controlled robot and non-controlled robot conditions.

n = 13		Induction			Reduplication		
	Initial score	Average	Controlled robot M(SD)	Non-controlled robot M(SD)	Average	Controlled robot M(SD)	Non- controlled robot M(SD)
Embodiment score	2.86(1.57)	4.45(1.41)	4.59(1.37)	4.31(1.75)	4.03(1.61)	4.46(1.61)	3.58(2.1)

Appendix C

Figs. C1 and C2.

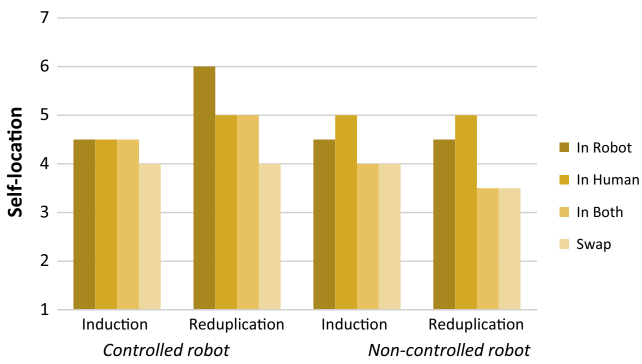

Fig. C1. Reported self-location (median scores) during *induction* and *reduplication* in the CR and NCR conditions.

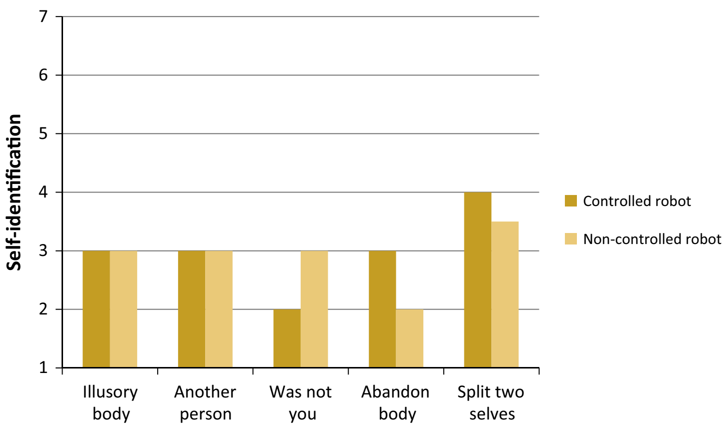

Fig. C2. Median score for self-identification items in the CR and NCR conditions.

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