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Embodiment improves attention allotment for the benefit of dual task performance

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Abstract

Many everyday tasks, like walking down a street, requires us to dual task to also avoid collisions of our swinging arms with other pedestrians. The collision avoidance is possible with ease because humans have an ‘awareness’ of their (embodied) limbs. But how does embodiment and awareness affect attention distribution, and consequently task performance? Here we examined this question with a dual task that required participants to perform a cued button-press (main task) with their right hand, while reacting to possible collisions by a moving object with a left ‘robot’ hand (secondary task). We observed that participants consistently improve main task performance when they perceived the robot hand to be embodied, compared to when they don’t. Furthermore, the performance improvement correlated with the embodiment perceived by the participants. The secondary task performance could be maintained in both cases, suggesting that embodiment of a limb improves attention allotment for dual task performance with it.

Introduction

We live in a world surrounded by a plethora of inanimate objects, tables, bed and chairs inside a house and trees and buildings outside, as well as animate entities like cars and other humans. Hence, most tasks that involve movement, from walking on the street to moving objects, require us to dual-task (Strobach, Wendt, and Janczyk, 2018) to also avoid collisions between these entities and our limbs, and the objects we carry. For example, imagine you are walking down a supermarket aisle. Even though the focus of your attention may be on reading the names of the grocery items, you can still also, very implicitly, avoid colliding with the other shoppers and their shopping cart, with your swinging arm.

Next imagine the same scenario when you are holding a shopping basket in the hand. In both cases, the grocery search (the main task) and the collision avoidance constitute a dual task that is possible because the human brain is believed to be ‘aware’ of its body parts and distributes visual attention between the two tasks.

Humans perceive a sense of ‘bodily self-consciousness’ (Bermúdez, Eilan, and Marcel, 1998; Legrand, 2006) or ‘embodiment’ (Arzy, Overney, Landis and Blanke, 2006; Longo, Schütz, Kammers, Tsakiris, and Haggard, 2008) towards their limbs. Embodiment of a limb is believed to include a sense of ‘ownership’, a sense of an ability to control, or ‘agency’, and a sense of ‘location’ of the limb (Longo, Schütz, Kammers, Tsakiris, and Haggard, 2008). Ownership of a limb is known to improve its visual awareness (Hoort, Reingardt, and Ehrrsson, 2017), suggesting that we will be more aware of obstacles to our swinging arm, than to the swinging basket in our arms, which we do not feel a sense of embodiment towards. But what does high embodiment and high awareness mean in regard to attention? does the arm, which is embodied, attract more attention than the basket, or does high awareness mean that we in fact require less attention for avoiding arm collisions? Consequently, how does the attention to the arm affect the attention assigned to the main task? Answers to these issues remains unclear.

In this study, to answer these issues, we developed a dual task in virtual reality (VR) motivated by the shopping cart collision example. The task required participants to perform a visually cued button press task with their right hand (their main task which required high attention) while reacting to possible collisions by a moving object that sometimes approached their left ‘robot’ hand (the secondary task). Recent studies have shown that the human self is plastic and that multi-sensory stimulations can induce...
a sense of embodiment in humans, towards a rubber hand (Botvinick and Cohen, 1998; Ehrsson, 2012; Graziano and Botvinick, 2002; Tsakiris, 2010; Makin, Holmes and Ehrsson, 2008) as well as functionally similar (Aymerich-Franch and Ganesh, 2016) robot limbs (Aymerich-Franch, Petit, Ganesh, and Kheddar, 2016; Aymerich-Franch, Petit, Ganesh, and Kheddar, 2015). Here, we used multi-sensory stimulations to modulate the sense of embodiment perceived by the participant towards their left robot hand and create two conditions, one in which the robot limb is perceived to be part of the body, and another in which it is more like an object held in one’s hand (similar to a shopping basket). We then investigated how the embodiment (measured using a behavioral measure and reports in questionnaires) affects performance of the main task performed by the right hand. We chose to use a robotic left arm to avoid preexisting attentional biases associated to the shape of the human arm. We hypothesized one of two possible scenarios. First, if increased embodiment of the robot arm attracts more attention towards the robot arm, then this will be evident as a decrease in performance in the right hand main task. On the other hand, an increase in right hand performance is expected if embodiment of the robot arm either enables increased attention towards the main task, or improves the attention distribution between the two arms.

Result

Fig. 1. Setup and paradigm. (a) The participants performed the experiment in a virtual environment. They wore a head mounted display and sat on a table with a keyboard under their right hand. They held the Virtuose haptic interface in their left hand. In the virtual environment, the participants observed a table, and a right hand with the keyboard (upper panel). They saw a robot hand instead of their left hand. The
robot hand held a black banana-shaped object that was the shape of the handle of the haptic interface the participants held in their real left hand. The participants were also shown a pink ball which moved near the robot hand. (b) The participants worked in two conditions, EMB and no-EMB. Each condition consisted of five phases, and lasted 20 minutes in total.

Our experiment required participants to wear a VR headset and hold a haptic feedback device (Haption Virtuose 3D) in their right hand (Fig. 1(a), lower). They were shown a robot arm in place of their real left arm (Fig. 1(a), upper). The robot arm was purposely presented displaced, by 10 cm towards the body, from the real arm. This displacement was later utilized to quantify the embodiment (and specifically ownership) felt by the participants towards the robot hand using a measure of proprioceptive drift (Longo, Schüür, Kammers, Tsakiris and Haggard, 2008; Botvinick and Cohen, 1998; Holmes, Full, Koditschek and Guckenheimer, 2006). Any movement of the hand by the human was displayed as the movement of the robot inside the VR environment. All participants performed in two conditions (the order was balanced across participants). In the robot embodiment (EMB) condition, after the calibration and setup in the initialization phase, we induced the feeling of embodiment (see Fig. 1(b)) towards the robot arm using standard visuo-haptic stimulation techniques (see methods for details). In the no-embodiment (no-EMB) condition, the same stimulations were presented asynchronously to prevent embodiment of the robot arm. We utilized a proprioceptive localization task before and after the stimulation phase to evaluate the proprioceptive drift as a behavioral measure of the induced embodiment. We evaluated the cognitive sense of ownership, agency, location, and task performance using a questionnaire at the end of each condition.

![Embodiment modulation across conditions](image)

Fig. 2. Embodiment modulation across conditions. The participants scored twelve questions on a Likert scale after the EMB (red plot) and no-EMB (blue plot) conditions. The white circles show the mean and the dotted circle show the median scores across participants. The box edges show the 5th and 95th percentile of the data and the whiskers show the data range. The questions included two each on their subjective perception of ownership, location, agency of the robot hand, their single and dual task performance, and the anxiety during their performance respectively. We considered the average score from their first six questions as the measure of embodiment (the embodiment score) perceived towards the robot hand. We also measured the proprioceptive drift in each condition.

![Proprioceptive drift](image)

Fig. 2 shows the answers to the questionnaire, and the proprioceptive drift observed in the two conditions. We observed that the ownership (average score in Q1 and Q2), agency (average of Q3 and Q4) as well the sense of location (average of Q5 and Q6) towards the robot arm was consistently higher \((Z(15)=2.516, p<0.05, r_{equivalent}=0.629; Z(15)=2.927, p<0.003, r_{equivalent}=0.732\) and \(Z(15)=3.463, p<0.001, r_{equivalent}=0.868\) respectively) in the EMB condition, in comparison to the no-EMB condition. Overall the robot arm embodiment (average of Q1 to Q6) was higher in the EMB condition, in comparison to the no-EMB condition \((Z(15)=-3.337, p<0.001, r_{equivalent}=0.834)\). Correspondingly, the
proprioceptive drift was observed to be higher in the EMB condition, compared to the no-EMB condition (Z(15)=2.689, p<0.008, r_{equivalent}=0.672).

The initialization and proprioceptive drift measurement was then followed by the same experimental dual task in each condition, which required the participants to perform a main task with their right hand and a secondary collision avoidance task with their left robot hand.

As the main task, the participants were presented with a screen in their right visual field inside the VR, in front of their right hand that rested on a keyboard. The main task required the participants to watch two rectangular panels on the screen, that changed their colors randomly every 500 ms. The participants were instructed to “press the space key as soon as the colors of the two rectangles became the same”, which happened roughly every one to 2 seconds. The participants were informed that the reward points correlated with reaction speed of their presses, and that they will be penalized for erroneous presses (see methods for details). We analyzed the ‘reaction time’ of the participants, defined as the time between when the colour of the rectangles became same, and the key-board press by the participant. This allowed us to quantify and compare the main task performance (between the EMB and no-EMB conditions) by the reaction time and task score exhibited by the participants.

As the secondary task, the participants were presented with a pseudo-randomly flying ball (speed range: 0.25 - 0.75 m/s) in the left visual field in VR, that sometimes approached the left robot arm of the participants. The secondary task required participants to press a collision avoidance button (ca-button) with their let thumb on the handle of the haptic device held in their left hand when they perceived a danger of collision. The ca-button press resulted in the ball being deflected away from their hand. The participant were not required to actively move their left hand during the Crucially, the ball approached the hand between 5 and 8 seconds. Note that the collision avoidance only required the pressing a button with their left thumb. Thus, in both conditions, the dual task was identical and did not require any hand or arm movement by the participants.

Therefore, apriori, the main task required much higher attention compared to the secondary collision avoidance task. Collisions resulted in penalization of points. The participants were however rewarded points if they could press the ca-button after the ball was closer than 30 cm to their hand. Any presses when the ball was beyond 30 cm earned them no points. This scenario enabled us to quantify the secondary task performance by the number of left hand collisions, and the distance of the hand and the ball, when the ca-button was pressed (See methods for more details).

**Fig 3. Embodiment does not affect Secondary (collision avoidance) task performance.** There were no significant differences between either the distance of the ball from the left hand (see (a), one sample T-test),
or the number of collisions (see (b), one sample Wilcoxon signed rank test) between the EMB (red) and no-EMB (blue) data. The white circles show the mean and the dotted circle show the median values across participants. The box edges show the 5th and 95th percentile of the data and the whiskers show the data range.

Here, we are interested to evaluate the attention distribution between the participant’s hands during our task, and specifically to compare the effect of the secondary collision avoidance in the EMB and no-EMB conditions on the performance of the main task. For this, we first started by examining the secondary task performance in the two conditions. Fig. 3(a) shows the average distance of the ball from the robot’s spherical end-effector (hand) at which a participant presses the ca-button. Like mentioned before, the ca-button press deflected the ball away from the hand. Thus this distance also represents the minimum distance between the ball and the robot hand for that particular trial. The ball distances were observed to be $0.348 \pm 0.161$ cm and $0.341 \pm 0.177$ cm in the EMB and no-EMB conditions respectively (bars in Fig. 3(a)), and were similar between the two conditions ($T(15)=0.23$, $p>0.83$, one-sample $T$-test). The participants could largely avoid ball collisions, and the few collisions that occurred were also observed to be similar in the two conditions ($Z(15)=-0.816$, $p>0.414$, one-sample Wilcoxon signed rank test). Overall these results show that the participants could perform the collision avoidance equally well, both with an embodied and non-embodied robot arm.

**Fig. 4:** Embodiment improves main (right hand) task performance. (a) The reaction times for the right hand button press were collected from the EMB (red data) and no-EMB (blue data) conditions into time bins aligned to the left hand ca-button presses. A 2-way ANOVA showed a significant main effect of conditions ($F(1,15)=5.28$, $p<0.037$), with highest reaction times in the $[-0.5,0.5]$ second time bin compared
to the other time-bins (T(31)=4.89, p< 2x10^{-5}, post hoc test, Bonferroni corrected). (b) The cumulative task scores were higher across participants in the EMB condition. (c) The change of reaction times in the [-0.5,0.5] second time bin between the EMB an no-EMB conditions correlated with the change in proprioceptive drift between the conditions (Spearman r=-0.488, p=0.057).

Next, we examined the main task performance by analyzing the average right hand reaction time. We expected the main task performance to be affected by the left collision avoidance task, but we noted that the collision avoidance task required ca-button presses only every seven seconds on average, compared to the right hand key-board press every 1 to 2 seconds. We therefore recognized that the reaction time may have varied across trials, depending on when the right hand key was pressed relative to the ca-button press. We therefore evaluate the embodiment effect on the main task using a 2-way ANOVA considering also the temporal changes in the effect. Specifically, we collected the reaction times for the right hand button presses into 5 time-bins aligned with the ca-button presses (see Fig. 4(a))—those presented before 1.5 seconds of a ca-button press (marked as [<-1500]); those presented between 1.5 and 0.5 seconds before a ca-button press ([1-1500,-500]); those presented between -0.5 and +0.5 seconds of a ca-button press ([500,500]); those presented between 1.5 and 0.5 seconds after a ca-button press ([500,1500]); and those presented after 1.5 seconds (and before 1.5 sec o the next ca-button press) of a ca-button press ([>1500]).

A 2-way ANOVA on the reaction times, across the factors of conditions (EMB and no-EMB) and time bins showed a significant effect condition (F(1,15)=5.28, p<0.037, \eta^2=0.23) as well as time-bins (F (4,60)=15.59, p<10^{-8}, \eta^2=0.23), with no interaction (F (4,60)=0.75, p=0.56, \eta^2=0.012).

Crucially, the clear effect of condition seen from the ANOVA showed that the participants could react faster with their right hand when they perceived their left robot hand to be embodied (the EMB condition) compared to when they did not (no-EMB condition). It is interesting to note that this improvement emerged after just 10 minutes of embodiment induction. Correspondingly, the performance scores were higher in the EMB condition, compared to the no-EMB condition (T(15)=2.16, p=0.047, one-sample Ttest, Cohen’s d=0.540, Fig. 4(b)).

These results show that the embodiment of the robot arm enabled the participants to improve their main task performance. Across the participants, we also observed a good correlation between the change in proprioceptive drift, and the change in main task performance (Fig. 4(c), Spearman r=-0.488, p=0.057) in the [-500, 500] ms time bin, in which post hoc analysis showed that the reaction times, and hence the attention load, was highest through the two conditions (T(31)=4.89, p< 2x10^{-3}, Bonferroni corrected, Cohen’s d=1.09).

Discussion
In this study we investigated how the sense of embodiment affects the attention assigned to limbs during a dual task, and consequently how this affects the task performance. We developed an experimental dual task (Fig. 1) motivated by collision avoidance instances that we experience regularly in daily life. Our task required participants to perform a task requiring heavy attention, with their right hand, while avoiding collisions of their left robot hand. We modulated the embodiment perceived towards the robot hand (Fig. 2), and investigated how this affected the task performance with each hand. We observed that the embodiment of the left robot hand did not affect the secondary task performance by the left hand (Fig. 3), but enabled the participants to significantly improve their main task performance with the right hand (Fig. 4(a), (b)). Importantly, this improvement could be observed throughout the task period (Fig. 4(a)). Furthermore, the right hand performance improvement correlated with the change of embodiment across the participants (Fig. 4(c)). These results have several implications.

Primarily, these results suggest that embodiment of the robot hand modifies the attention allotment to the two hands. We observed that, while the right reaction times exhibited a general increase in the no-EMB condition (Fig. 4(a)), the reaction time profile did not change between the conditions (see ANOVA result that shows a main effect of condition but no interaction). This indicates the attention re-
allotment did not vary with time, but further studies are required to confirm this issue. However, crucially, the consistent lower reaction times in the main task indicates that a non-embodied robot arm (which is more like an object held in one’s hand) attracts more attention for the collision avoidance task. Conversely, higher attention allotment was possible to the right hand when the robot left hand was embodied. Interestingly, this was possible even when the left hand collision avoidance performance was maintained, suggesting that our brain is able to better optimize the attention allotment in a dual task when the involved limbs are perceived to be part of one’s body (that is, they are embodied).

Moreover, our results highlight attention modulation as a key effect of embodiment. Previous studies have shown that embodiment of a limb leads to increased physiological responses to perceived dangers to the limb (Graziano and Botvinick, 2002; Tsakiiris, 2010; Guterstam and Ehrsson, 2012; Suzuki, Galli, Ikeda, Itakura and Kitazaki, 2015) and increased sensitivity to sensory stimulations (Aymerich-Franch, Petit, Kheddar, and Ganesh, 2016; Aymerich-Franch, Petit, Ganesh and Kheddar, 2017; Makin, Holmes, Ehrsson, 2008), compared to when the same limb is not embodied. Embodiment has also been suggested to improve the control of limbs (Newport, Pearce and Preston, 2009). Tool embodiment, which also leads to changes in body representation (Cardinali et al., 2009; Sposito, Bolognini, Vallar and Maravita, 2012; Ganesh, Yoshioka, Osu and Ikegami, 2014), though not ownership, has also been suggested to be a key reason enabling human tool use (Head and Holmes, 1912; Maravita and Iriki, 2004; Jacobs, Bussel, Combeaud and Roby-Brami, 2009). Mechanisms of attention allotment, due to the embodiment, may provide a unified explanation for all these previous results.

Finally, in regard to real life scenarios, our results suggest that task performance is indeed improved when the secondary collision avoidance is performed for one’s own hand, rather than a hand held object (like a shopping basket). A hand held object seems to attract more attention for task performance than one’s own hand. Participants also perceived better dual-task performance in the EMB compared to the no-EMB condition (see Q9 in Fig. 2). Their left hand distance correlated with this report (Spearman r=-0.40, p=0.022, Suppl. Fig. 1). Note that in our experiment the same robot hand attracted less attention when it was not embodied. This means that the higher attention to a hand held object is not because of the shape and size of the object, but rather because the object is not perceived as part of the body. This result is crucial for application of human functional augmentation (Iwasaki and Iwata, 2018; Iwasaki, Ando and Iwata, 2019; Sasaki, Saraiji, Fernando, Minamizawa and Inami, 2017; Suzuki, Ganesh and Miyawaki, 2018) as well as teleoperation (Panzirsch, Balachandran, Weber, Ferre, and Artigas, 2018), and suggests that the embodiment of these robots can enable better multi-task control and performance by the human user.

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Author contribution

Declaration of interest
Authors declare no financial interests pertaining to this study.

Data availability
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.
References


Method

Participants

17 participants took part in this study (Mean age=26.706, SD=3.477, 12 males). The study and sample size was approved by the local ethics committee at the University of Montpellier, France. All participants gave informed consent for their participation in the study. One participant, who’s left hand task performance was an outlier (with ball distance beyond 3 *SD of the mean across participants) was omitted from the study. Overall the participant number of sixteen corresponded to our power analysis in G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007), to provide 80% statistical power to achieve a medium effect size ($d = 0.75$) on binary choices using a one-sample $t$ test against a 50% chance level and an alpha of .05.

Setup and Apparatus

We constructed an experimental environment in virtual reality (VR). The VR space was constructed using the Unity engine (https://unity.com/ja) at a frame rate of 65 Hz. We used the VIVE VR system (https://www.vive.com/jp/) for the VR experience. The participants sat on a chair, in front of a table, and wore a VIVE headset during the experiment and held the handle of VIRTUOSE haptic device (https://www.haption.com/fr/products-fr/virtuose-3d-fr.html) in their left hand. They rested their right hand on a keyboard on the table (see Fig. 1(a)).

Corresponding to the real environment, in the virtual environment as well, the participants could observe a table in front of them. They observed a keyboard and screen in front of their right hand. A virtual right hand was seen resting on the keyboard (again like in real life). They observed a robot arm, connected to their body, instead of their left hand (see Fig. 1(a) upper panel). The robot arm was oriented to correspond to the left hand configuration of the sitting participant. The robot end effector (hand) was however linearly displaced...
by 10 cm from the real hand position. This was required to measure the proprioceptive drift (detailed in section below).

When the subject moved the VIRTUOSE handle, the position information was transmitted to Unity via ROS (https://www.ros.org/), and used to move the robotic left arm in the VR environment such that participants felt as if they were moving their robotic left hand.

**Task and Procedure**

Fig. 1(b) shows the experimental flow. All participants participated in two conditions - the embodiment (EMB) condition and no embodiment (no-EMB) conditions. Each condition was divided in six phases - the initialization phase, proprioceptive drift measure phase (initial), embodiment induction phase, proprioceptive drift measure phase (final) and the dual task phase. This was followed by the questionnaire phase they answered twelve questions on a Likert scale. The phases are detailed below.

1. **Initialization phase**

The subjects adjusted their real sitting position and posture to a position where his or her arm coincided with the position of the arms in VR. After that, the screen blacked out for 10 s. When the VR image reappeared, the robot arm was shifted 10 cm, without their knowledge, towards the participant’s body.

2. **Proprioceptive drift measure phase (initial):**

Proprioceptive drift, measure the modification in the joint level representation of a body, and is a popular measure to quantify embodiment, and specifically bodily ownership (Fuchs et al, 2016). In our study the participant’s real left hand was displaced by 10 cm from the robot hand they observed VR (see setup section above). Given this displacement, after the initialization phase, we checked where the participants perceived their let hand to be. For this, the first blacked out the participant’s vision in the VR. The participants were asked to release the handle of haptic interface and place the left hand on the table with their palm down. A flat plate (attached to legs) was then placed as a cover over the left hand. The plate was placed as close as possible to the hand’s top surface without touching the hand. The participants were then asked to hold a pen in their right hand, and point to the index finger of their left hand by placing the tip of the pen on the cover plate. This was done 5 times. Each time, after the pointing was performed, the experimenter moved the right hand of the participant to a random location before they made the pointing movement again. We recorded the average coordinates of the pointed locations and compared it with the real position of the participant’s index finger along the frontal plane, do define the initial proprioceptive drift.

3. **Embodiment induction phase**

We utilized movement and visuo-haptic stimulation (with a paintbrush), two standard methods (Benz, Sieff, Alborz, Kontson Kilpatrick, and Civillico, 2016; Aymerich-Franch, Petit, Ganesh and Kheddar, 2017) to induce a sense of embodiment in the participants towards the left robot arm and hand. Both the induction methods were utilized for the embodiment induction in all participants.

Movement task: A pink cylinder object appears near the participant’s left hand and the participant were asked to move his or her left arm to try to touch it. In the EMB condition, the movement of the robot arm in the VR was synchronized with the participant's real hand, and moved exactly like the participant's actual arm. In the no-EMB condition, the robot arm started moving after the participants hand (delayed by 0.5-1 sec) and randomly reached an object other than the one reached by the participant. A small force feedback was provided by the haptic interface when the cylinder was touched, and the cylinder disappeared. The movement task was performed for 5 min during which the cylinders were presented at random locations at for 7-12 second (chosen randomly), after which it disappeared even if the participant did not manage to touch it.

Visuo-haptic stimulation: The participants were asked to rest their hand on the table and look at their left real hand in VR. Their real left hand was brushed around the wrist and back of the hand by the experimenter using a paintbrush connected to a VIVE tracker. The tracker enabled us to synchronize the real brush with a brush in VR that the participants saw brushing their robot hand (or end-effector) in VR. In the EMB condition, the real and VR brushes were synchronized so that the participants felt synchronous visuo-haptic stimulation.
In the no-EMB condition, the VIVE tracker was detached from the real brush and the experimenter moved a VIVE tracker and the real brush independently, such that there was no synchrony between the observed movement and the felt haptic sensation. The visuo-haptic stimulation was performed for 5 min.

The movement task was followed by the visuo-haptic stimulation for all participants with a short break of 30 seconds in between.

(4) Proprioceptive drift measure phase (final):

The final proprioceptive drift measure was calculated exactly like the initial measure. The difference of the final and initial proprioceptive measures provided us the proprioceptive drift induced after EMB or no-EMB for each participant.

(5) Dual task phase

Next, the participants worked in the experiment dual task in this phase. The dual task required to perform a main task with their right hand, and a secondary collision avoidance task with their left hand.

The main task required the participants to watch two rectangular panels presented in the right visual field of the VR environment, in front of their right hand. The panels changed their colors (red, blue or yellow) randomly every 500 ms. The participants were instructed to “press the space key as soon as the colors of the two rectangles became the same”, which happened roughly every one to 2 seconds. A correct press earned the participants 20 points. On the other hand, the participants were penalized -10 points when the missed pressing a button when the panel colors were same, or pressed the keyboard when the panel colors did not match. We recorded the right hand reaction times, and the cumulative scores as measures of the main task performance by each participant. The cumulative score was calculated excluding the first 5 seconds of the experiment, in order to exclude possible errors associated with the surprise at the start for the session and task.

The participants were presented with a pink ball (5 cm in diameter) in their left visual field. The ball flew near the left robot hand of the participants in a pseudo-random trajectory within 1m X0.8m X1.5m in the virtual environment around the left hand of the participant. The ball approached the robot hand every 5-8 seconds. The ball approached the hand following one of seven manually designed trajectories in each collision. Each of the trajectory was designed by choosing 6 via points to the participant’s hand position and back. A trajectory generator provided in the UNITY software was used to develop the trajectory through these via points given the velocities at the via points (which were set between 0.25 m/s and 0.75 m/s at each point).

As the secondary task the participants were instructed to prevent the ball from hitting their left hand. They were instruct to press the collision avoidance button (ca-button), under their left thumb on the handle of the haptic device, whenever they felt that the ball may collide with the left hand. Pressing the ca-button resulted in the ball being deflected the ball away from their hand. Collisions resulted in a penalization of 5 points.

The participants were however rewarded 1 points if they could press the ca-button after the ball was closer than 30 cm to their hand. Any presses when the ball was beyond 30 cm earned them no points. This scenario enabled us to quantify the secondary task performance by the distance of the hand and the ball, when the ca-button was pressed and the collisions incurred by the participants.

The participants were presented with a pseudo-randomly flying ball (speed range: 0.25 - 0.75 m/s) in the left visual field in VR, that sometimes approached the left robot arm of the participants. As their secondary task, the participants were required to press a collision avoidance button (ca-button) on the handle of the haptic device held in their left hand when they perceived a danger of collision. The ca-button press resulted in the ball being deflected the ball away from their hand. Crucially, the ball approached the hand every 5-8 seconds. Therefore, apriori, the main task thus required much higher attention compared to the secondary collision avoidance task. Collisions resulted in heavy penalization of points. The participants were however rewarded points if they could press the ca-button after the ball was closer than 30 cm to their hand. Any presses when the ball was beyond 30 cm earned them no points. This scenario enabled us to quantify the secondary task performance by the distance of the hand and the ball, when the ca-button was pressed (See methods for more details).
The dual task phase consisted of three two minute trials. The participants performed the above mentioned tasks with their two hands in every trial. The dual task was the same in both the EMB and no-EMB condition. We utilized the data from the first trial, in which we observed significant differences in the in the EMB and no-EMB behaviors, for our behavioral analysis. The behaviors in the second and third trials were observed to be same between the two conditions, probably because of the loss of the embodiment (induced in the embodiment induction phase) perceived towards the robot arm, with time.

Finally, in the end of each condition, each participant answered the following 12 questions on a seven-point Likert scale.

From 1 (not at all) to 7 (very strongly), it seems like…

1. The robot arm is part of your body
2. The robot arm is your arm
3. The robot arm belongs to you
4. The robot arm is in the location where your arm is
5. You could push an object with the arm you see
6. You could move the arm you see
7. You could perform the left hand task well
8. You could perform the right hand task well
9. You could perform tasks on each arm equally well
10. The task on the right hand disturbed the task on the left hand
11. You were anxious about your left hand task
12. You were anxious about your right hand task

The first three questions estimated the ownership perceived towards the left robot hand, by a participant. The fourth question estimates the perceived location of the robot arm, while questions five and six estimated the sense of agency perceived towards the left robot hand by a participant. The average score by a participant across questions one to six was taken as a measure of embodiment perceived towards the robot arm (Longo, Schüür, Kammers, Tsakiris, and Haggard, 2008).

Questions seven to ten estimated the participant’s perception of their performance, while questions eleven and twelve measured the anxiety felt by the participants during the dual task performance.

Data analysis
All data groups were first checked for normality using the Shapiro Wilk Test. Data groups which were found to be normal (p>0.05) were treated using parametric tests, namely T-test (Fig. 3(a), Fig. 4(b)) and ANOVA (Fig. 4(a)). Data groups that were found to be non-normal were compared using the Wilcoxon Sign Rank test (Fig. 2, Fig. 3(b)) and analyzed using the Spearman correlation (Fig. 4(c)).
Supplementary Figure 1.

Sup. Fig. 1. Correlation between perceived task performance and left hand task performance. Participants were asked to rate the statement “You could perform tasks on each arm equally well” as Q9. A correlation between their reported scores and the left hand ball distance showed that with an increase of perception of dual task performance, the participants pressed the ca-button when the ball was closer to the left hand.