

Avatar Embodiment Enhances Haptic Confidence on the Out-of-Body Touch Illusion

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Abstract—In the real world, our bodies influence how we perceive ourselves and how others perceive us. Our body can also affect estimations of object sizes and distances. But how does our body affect our haptic experience? Here, we examined the modulation of a visuo-haptic illusion of touch on a virtual stick in virtual reality, when participants were embodied in an avatar and when they were not. During the experiments participants ($n = 49$) received successions of three taps delivered from two independent controllers while they saw visual stimuli presented sequentially along the virtual stick. The stimulation pattern resulted in a robust illusion of tapping directly on the virtual stick. After each trial, participants were asked to report where they perceived the taps. We found that participants in both the body and no-body conditions displaced the second tap toward the center of the stick, and reported similar levels of certainty about their reported location. However, the illusion of touch on the stick, as measured by the reported location of the tap, was significantly stronger for those who had a virtual body than those who did not. Therefore, our study shows that avatar embodiment can change haptic perception.

Index Terms—Haptics, virtual reality, avatars, embodiment, touch.

I. INTRODUCTION

TO have a body, or to not have a body in VR? Embodiment illusions inside VR can make participants experience a virtual body that is not theirs as their own [1]–[3]. Research in this area, suggests that body ownership is the result of the successful integration of visual, tactile, proprioceptive, and sensorimotor information [4]–[6]. That is, these multisensory signals are combined by the brain to tell us this body is mine. By manipulating one of the sensory signals, the brain can be fooled, thereby generating an experience of ownership over a limb or a

body that is not our own [7]–[11]. Importantly, research on the underlying mechanisms for body ownership has not only revealed how we can experience a different body as our own, but has also found that the body we own can have profound effects on how we interact with and perceive our environment [12], [13], including our sense of touch in VR [14], [15].

Recent research has shown that participants were worse at identifying bumps and holes when they are embodied in a cartoon avatar [12]. Outside of VR, researchers have also found that ownership over a rubber hand leads to an attenuation of the perceived touch from that rubber hand in the same manner that perceived touch is attenuated when we touch ourselves [14]. No such attenuation of the sense of touch was observed if there was no illusion of ownership over the rubber hand [14]. This finding suggests that when it comes to tactile perception, the same mechanisms are at play when we own a body that is not ours as when we are in our own body. However, how our tactile perception is affected by the lack of a body altogether is unknown. Does not having a body pose a problem for the perceptual experience of tactile stimuli in VR? Here, we sought to examine whether the presence or absence of a virtual body affected users' sense of touch in VR.

One of the difficulties in examining the sense of touch in body ownership manipulations is how to measure the change in perception. While questionnaires are often useful in getting a sense of drastic changes in ones perceptual experience, users are often poor judges of subtle, but nevertheless significant differences in their perceptual experiences when asked to report on them [16], [17]. Psychophysics experiments or physiological recordings are often useful to complement questionnaire data and help avoid cognitive biases when reporting VR or tactile experiences [18]. Additionally, the use of peri-experiment metrics also helps reveal stimulus-dependent effects that are not strong enough to show up on a post-experiment questionnaire at the end of the VR experience [18]–[21]. Here, we utilized both peri-experiment and post-experiment reporting techniques together with a tactile illusion to obtain objective and subjective measures of the tactile experience of the participants in VR. The aim was to investigate whether the body plays a role in how we perceive touch in virtual environments. To this end, we manipulated the presence (or absence) of a first-person avatar in the virtual environment while delivering tactile stimuli in an out-of-body cutaneous rabbit illusion [22].

Our setup is capable of providing the sensation of being touched on a virtual object rendered between the hands. This illusion of touch is robust when (i) the vibrotactile stimuli follow the correct temporal pattern, and (ii) are accompanied by

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Fig. 1. Participant (B) holding the virtual stick in the three experimental conditions: (A) Body, (C) No-Body and (D) Controllers Control. To enhance the embodiment illusion in the Body condition, the participant can see his body reflected in the mirror. Inverse kinematics were used to control the upper body and the stick (see supplementary video).

corresponding visual stimuli in the illusory location [22], [23]. Specifically, we hypothesize that if the illusion is altered, the perceived location of the illusory sense of touch between the hands should vary when the participants do not have a virtual body.

II. MATERIALS AND METHODS

A. Participants

Forty-nine participants volunteered in our experiments. Twenty experienced a condition where they had a virtual body (mean age = 32.2 years, SD = 10.5; 9 females), nineteen experienced a condition in which they did not have a virtual body (mean age = 30.3 years, SD = 6.4; 3 females). Participants were randomly assigned to either the body or the no-body conditions in a between subjects design (Fig. 1). Ten additional participants (age = 34.5 years, SD = 10; 3 females) were recruited for a condition in which they could see the controllers. This condition served to control for the possibility that any changes in the perceived touch illusion were driven, not by the lack of a body, but by the lack of a visual frame of reference between two points along the stick in the virtual environment. A between-subjects design was used instead of a within-subjects design, to assure that participants' responses were not biased by their experiences in the other condition. The effect of a previous body ownership has been shown to influence participants into believing the existence of an 'invisible' body that they own [24], [25]. This way, the experiences and responses given by the participants in each condition are as naive as possible.

All participants were recruited via e-mail from within Microsoft Research, were healthy, reported no history of psychiatric illness or neurologic disorder, and no impairments of touch or vision. The experiment lasted for 30 minutes, was approved by Microsoft Research IRB and followed the ethical guidelines of the Declaration of Helsinki. All participants gave written informed consent and were compensated for their time with meal cards.

B. Experimental Design

To test whether having a virtual body affected the participants' ability to have an immersive haptic experience through the VR controllers, we initially designed two conditions. In

one, the participants had a virtual body (body condition), and in the other they did not (no body condition). In both cases, participants were holding a controller in each hand, which provided exact tracking of where the hands were located. With inverse kinematics they saw and manipulated a virtual stick between their hands in a natural way (see supplementary video).

In the body condition, the participants saw a virtual avatar co-located with them in a first person perspective, as if their real body had been substituted by the avatar. The head, hands, and the body of the avatar moved as the participants did. Additionally, the participants were able to see the virtual body reflected in a mirror to enhance body ownership of the virtual avatar [6].

During the experiment, the participants experienced twenty trials. Each trial consisted of an out-of-the-body cutaneous rabbit illusion [22], followed by a localization period in which participants reported the location of the three taps (vibrotactile stimuli delivered via the controllers are referred to as taps). Following the localization period, the participants then gave a rating for how confident they were on their estimations.

The out-of-body touch illusion was produced by presenting three brief vibrations of the controllers in a specific sequence (see details below). This stimulation produced a robust illusory sensation that a physical object held between the hands had been touched [22], [26]–[28]. After an embodiment phase in which they were allow to move their hands up and down with the virtual stick, participants were instructed to keep a predefined distance between the hands, so the tap positions were comparable across participants and trials. The tap positions were also scaled between the hands so each tap would occur always at each hand location and in the middle point between the hands.

The location estimation was done directly inside the VR setup. A white cylinder that projected outwards in space from the head of the participants (i.e., virtually linked to the HMDs) appeared and was used to point to the perceived location of each tap using a ray-cast (see supplementary video). Once participants were pointing at the location they perceived the first tap, they used a foot-pedal to log their response and proceed reporting the perceived location of the second and third taps in the same manner.

The perceived location of the illusory touch on the virtual object can be used as (a) an indication of the acuity of the sense of touch in VR (and therefore, an indication of how

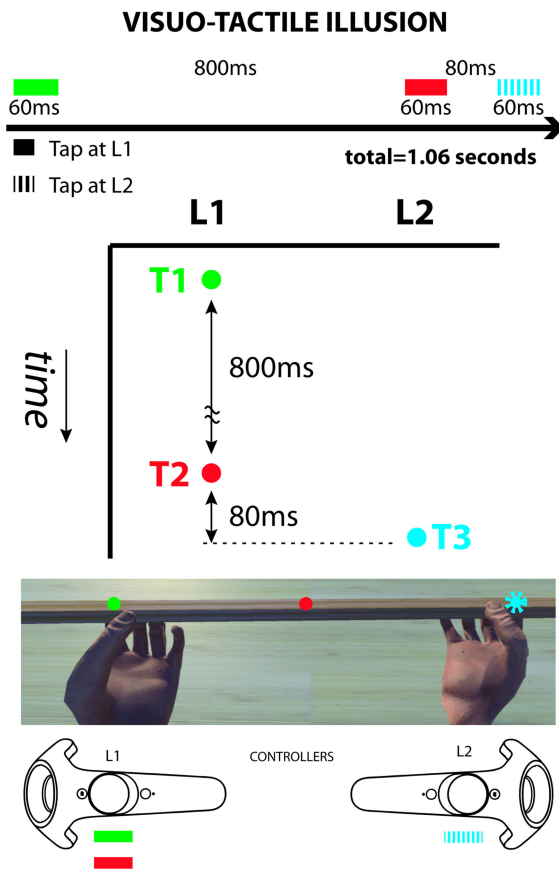


Fig. 2. **Top** Temporal and spatial distribution of the stimuli on one trial of the out-of-the-body touch illusion. **Bottom** VR implementation of the visuo-tactile out-of-the-body touch illusion. Example of one trial in which the visual stimuli moved from left to right across the virtual object. The colors match for illustration purposes. In the actual experiment all taps had the same intensity and in the virtual world the spheres had a neutral white color, see supplementary video for further information.

robust the illusion of touch was) and (b) as an objective measure of the immersiveness of the virtual experience [23].

At the end of the experiment, participants in the body condition completed a set of questions from a standard embodiment questionnaire [29].

In an additional control condition, the participants could see the virtual controllers but not their hands (nor a body). The controllers provided a frame of reference but did not enable embodiment.

1) Out-of-Body Haptic Illusion: The out-of-the-body touch illusion was elicited on each trial of the experiment using a sequence of three brief vibro-tactile taps presented in rapid succession [22], [27], [28], [30], [31]. Specifically, for each trial, the first tap (T1) was delivered at the first location (L1), followed by the second tap (T2) delivered again to L1, and finally a third tap (T3) delivered to the second location (L2). The interstimulus interval (ISI) between T1 and T2 at L1 was 800 ms, and the ISI between T2 at L1 and T3 at L2 was 80 ms. Each tap lasted for 60 ms. (Figure 2). The timing of the taps produces a mis-location effect derived from “post-diction” by which T2 is perceived somewhere in between L1 and L2 [32], [33].

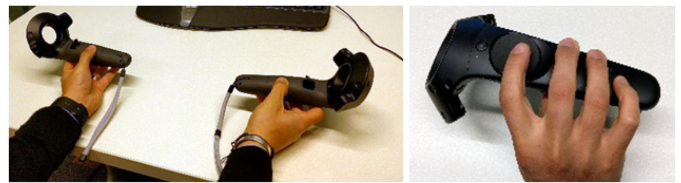


Fig. 3. Hand location of the participants index fingers on the haptic controllers. The hands and fingers of the participants were aligned with the hands of the virtual avatar they saw in the virtual environment.

The taps are felt to be ‘hopping’ from one location to the next (with the Tap 2 being felt on the center of the virtual object held between the hands). In essence participants see the visual stimuli presented synchronously and for the same duration as each of the taps. Consistent with previous work [22], [27], [28], the first of the visual stimulus is presented at L1, the second is presented at the center of the virtual stick, and the third is presented at L2 (See Fig. 2). There is a spatial discrepancy between the second visual stimulus, presented at the center of the wooden dowel, and the second tactile stimulus, located at L1. This sequence of taps and visual stimuli leads to a robust illusion in which the participant localizes T2 as originating in between L1 and L2. This illusion is both temporally and spatially dependent: if T2 was produced in L2, it would not elicit any illusion. Or if T2 was separated by longer time from T3, the sequence would also not produce the illusion [22].

C. Materials

All visual stimuli were presented via an HTC Vive head mounted display (HMD) equipped with a position tracking system. The tracking system is enabled by stationary reference units that use lidar technology to track the users head and the handheld controllers. The HTC Vive uses an OLED with a combined resolution of 2160x1200 (1080x1200 per eye) and a refresh rate of 90 Hz. The effective field of view (FOV) for the participants is of 110 degrees. The inverse kinematics was calculated from the controllers and head positions [1].

The participants received vibro-tactile stimuli delivered in rapid succession to the ventral pads of the left and right index fingers from the trackpads of two independent handheld HTC Vive controllers while inside the virtual environment (Figs. 2 and 3). Stimulus presentation and data collection were controlled using Unity 3D Software (version 5.3.6f1) and custom scripts in C#. The HTC Vive’s vibrations were programmed using the SteamVR library with parametric adjustment of strength and duration. The taps were the maximum amplitude allowable by the HTC vive, and all participants reported feeling all three taps on all trials.

1) Body Ownership Questionnaire: In order to prove the extent to which the participants felt that the body of the virtual avatar was their own, the participants in the body condition were given a questionnaire at the conclusion of the experiment which asked them to rate their agreement with the following

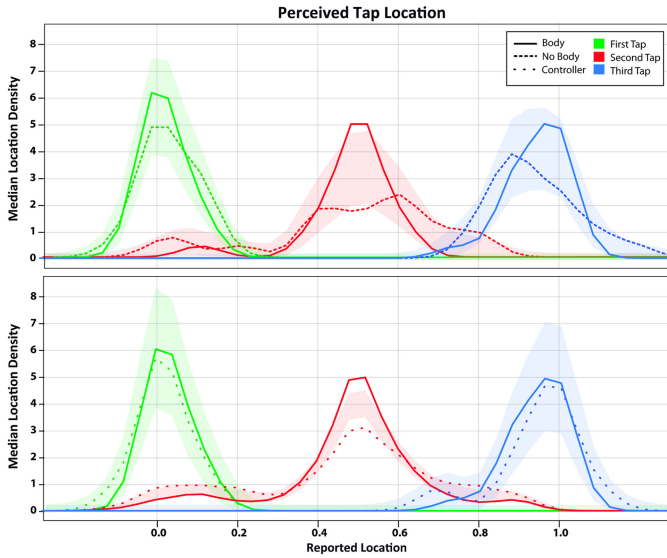


Fig. 4. KDE plots of the three taps. The plots range from 0.0 to 1.0, where 0.0 represents the spatial location of the L1 and 1.0 the L2. Confidence bands (mean 95% CI) represent the null model of no difference between the pair of KDEs. Regions outside the confidence band are significantly different. In the case of the second tap, we observe how the body and no body conditions are significantly different at the location at which they should perceive the illusory second tap (i.e., at 0.5). The same effect is found when participants used the controller vs the body, i.e. they also had a significantly lower strength of the illusion with the controllers present compared to when the body was present.

questions on a scale from -3 (disagree strongly) to $+3$ (agree strongly):

- Q1: I felt as if the virtual body were my body.
- Q2: It felt as if the virtual body I saw belonged to someone else.
- Q3: I felt as if my body was located where I saw the virtual body.
- Q4: I felt out of my body.
- Q5: The virtual body began to resemble my body.
- Q6: I felt as if I had two bodies.

The critical questions are Q1, Q2, and Q3 because they directly measure the illusion of ownership. Q2, is a reverse score of “I felt the virtual body belonged to me”. We expect participants with high ownership to answer positively to Q1, Q3, and negatively to the Q2 (indicating ownership of the virtual avatar). We also expect negative or neutral responses to Q4, Q5 and Q6 for consistency check as these aspects should not be particularly influenced during the experiment. These questions have been used previously in multiple embodiment experiments [29].

2) *Analysis*: To compare the perceived location of each tap (i.e., vibro-tactile stimuli delivered by the controllers) between participants who received the first two taps on the left index finger and the third tap on the right index finger (left-to-right) with participants who received the first two taps on the right index finger and the third one on the left index finger (right-to-left). Half of the participants were assigned to either direction of stimulation in random order. The responses of the right-to-left group of participants was reverse coded [i.e., equation 1, where x_r : reverse response, and x is the original response. In the

TABLE I
GRAND AVERAGE AND STANDARD DEVIATION OF
THE TYPICAL REPORTED LOCATIONS

Tap	Condition	Reported Location
Tap1	Body	$m=0.02, \text{std}=0.04$
	No Body	$m=0.03, \text{std}=0.06$
	Controller	$m=0.02, \text{std}=0.06$
Tap2	Body	$m=0.49, \text{std}=0.12$
	No Body	$m=0.49, \text{std}=0.23^*$
	Controller	$m=0.46, \text{std}=0.24^*$
Tap3	Body	$m=0.95, \text{std}=0.07$
	No Body	$m=0.94, \text{std}=0.10$
	Controller	$m=0.94, \text{std}=0.14$

*92% increase in the deviation for Tap2 in the No Body condition.

equation 0 would represent the left hand and 1 represents the right hand, see Figure 4). Thus, all responses are interpreted as a function of the time they were associated (i.e., Tap 1, Tap 2, Tap 3).

$$x_r = (1 - x) \quad (1)$$

In order to compare the localization distributions of the different taps across the participants we first calculated the median location per tap per participant, and then implemented a kernel density estimate comparison procedure. Kernel density estimation (KDE) is a non-parametric procedure that produces a smoothed estimate of the frequency distribution of any population. We used the `sm.density.compare` function from the R package `sm` to compare the area between the pair of KDEs, as proposed by [34]. The statistical test and smoothing were done on a bin size of 0.05 and using 100,000 permutations to gain three digits decimal stability on the test.

The `sm.density.compare` function also produces a plot to accompany each test with a confidence grey band, representing the null model of no difference between the pair of KDEs. This grey band is centered on the mean KDE and extends one standard error above and below, thereby indicating which regions of the length-frequency distribution are likely to be causing any significant differences (see Fig. 4).

III. RESULTS

The results of the reported location for Tap 1, Tap 2, and Tap 3, revealed that participants accurately perceived the location of Tap 1 and Tap 3 in both the body and no body conditions. However, the second tap, despite being provided in L1 was mis-perceived as coming from somewhere between L1 and L2 (near 0.5) for both conditions (body and no body). The distribution of means and deviations of the three taps can be seen for both conditions in Table I.

We compared the perceived location for the second tap (T2) from both conditions using a density estimation comparison test (Fig. 4). The results of the test of equal densities revealed that the perceived location of Tap 2 was significantly differently reported in the body condition than in the no body condition ($p = 0.034, df = 1$). Significance values are based on 100,000 random permutations. Further comparisons revealed

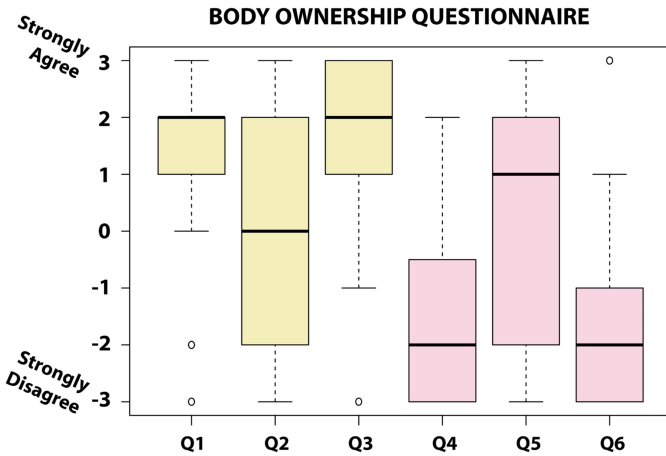


Fig. 5. Box-and-whisker plot of the responses to the body ownership questionnaire for participants in the body condition of the study. Q1, Q2, Q3 are the body ownership questions (light yellow) and Q4, Q5, Q6 are the control questions (light red). Solid horizontal lines indicate the median response, boxes indicate the upper and lower quartiles, and the whiskers represent the upper and lower extremes of the responses. Outliers are indicated as individual points.

that there were no significant differences in the density of the perceived location of Tap 1 ($p = .31$, $df = 1$) nor Tap 3 ($p = .083$, $df = 1$) between the body vs. no body conditions, suggesting that the baseline localization of the participants in the body condition did not differ significantly from the localization of the participant in the no body condition. These effects were also maintained when participants could see the controller as reference.

No significant differences in tactile perception were found exploring the mean values of the tap locations between conditions. The Mixed design ANOVA (position tap-number \times condition), showed a significant within subjects effect of tap ($F = 305$, $df = 1$, $p < 0.001$). A post-hoc t-test revealed significant difference in location between Tap 1 and Tap 2 ($t = 15$, $df = 43$, $p < 0.001$).

A. Body Ownership Questionnaire

In order to be sure that participants in the body condition did indeed feel as though the virtual avatar was their body, we examined the extent to which participants experienced illusory ownership over the virtual avatar using a Body Ownership Illusion Questionnaire. A Wilcoxon signed-rank test comparing the mean agreement with the body-ownership statements (e.g., I felt as if the virtual body were my own) ($M = 0.93$) vs. control statements (e.g., I felt as if I had two bodies) ($M = -0.95$) revealed a significant illusion of body ownership over the virtual avatar for the participants in the body condition of this study $U = 318$, $p < .001$ (see Fig. 5).

B. Confidence

We also examined whether the participants' subjective reports in their confidence over the location they reported for each tap was significantly different in the body condition vs. no body condition. Participants in both conditions reported their confidence levels at the end of each tap location assessment in

a Likert-type scale from 1 to 7 (1 = very uncertain, 7 = very certain). A comparison between the body and no body condition was made for the mean confidence rating for each tap across the participants using Wilcoxon signed-rank test. The results from the participants' self reported certainty about the location of Tap 2 revealed that participants were not significantly more or less confident when they had a virtual avatar's body compared to when they did not have a virtual avatar's body in the environment ($W = 229$, $p = .161$). Additionally, the same comparison between the body and no body conditions for Tap 1 revealed a significant difference between the confidence for their reported location of Tap 1 ($W = 267.5$, $p = .012$), no significant differences were found for Tap 3. The mean estimates and standard deviations of the confidence ratings for Taps 1-3 for the body and no body conditions were as follows: Tap 1 Body ($M = 6.28$, $SD = .068$), Tap 1 No Body ($M = 5.68$, $SD = .08$); Tap 2 Body ($M = 5.04$, $SD = .08$), Tap 2 No Body ($M = 4.65$, $SD = .08$); Tap 3 Body ($M = 5.74$, $SD = .08$), Tap 3 No Body ($M = 5.13$, $SD = .08$). When participants' confidence about Tap 1 was compared to both Tap 2 and Tap 3, there was a significant decrease in confidence ($W = 462$, $p < 0.007$). This drop in confidence in Tap 2 and Tap 3 can be explained by the nature of the post-diction illusion in which these taps are very close in time (80 ms) which can reduce the confidence of participants. No correlations between confidence and body ownership were found (note: participants in the no-body condition did not complete an ownership questionnaire).

IV. DISCUSSION

The most critical result in this study shows that the participants with a virtual avatar in the virtual environment, were more consistent in reporting the perceived location of the illusory tap than the participants in the no body conditions. That is, the participants who had a body in the virtual environment had higher spatial acuity (Fig. 4) of the illusory percept (Tap 2) than those without a body. This is signified by the significantly wider spread of the perceived location for Tap2 in the no avatar conditions. The fact that Tap 1 and Tap 3 were similarly perceived across all conditions (body, no-body and controllers) indicates that the differences observed for Tap 2 cannot be explained by between subject variability. That is, the differences in the variability of the perceived location of Tap 2 between the body and no-body conditions (note: no-body conditions include both no-body and controllers) can be attributed to the experimental manipulation (i.e., presence vs. absence of a body).

This suggests that although participants experienced the illusory sense of touch differently in the body and no body conditions (Tap 2), the sense of touch at the locations of their real hands was not altered (i.e., Tap 1 and Tap 3). Participants were as capable of locating the first and third tap in the body and no body conditions, but not the illusory second tap. Participants in the no body conditions did not experience as vivid of an illusion of touch (Tap 2) between the hands as the participants in the body condition.

Despite Tap 2 was actually located at one of the hands (L1). This in and of itself has important implications for haptic perception in VR as it demonstrates that participants can experience a sense of touch in a spatial location outside their body, and between two independent handheld controllers [22], [23], [27], [28].

Previous research outside of VR on the out-of-body cutaneous rabbit illusion has limited this illusion to instances in which the participants are actually holding an object between their hands, and in which their eyes are closed [31]. The findings presented here are consistent with those of Lee and colleagues [26] which found that one can also experience an illusory sense of touch on an object between one's hands if an object is rendered between the hands in a 2D augmented reality display. These findings are also consistent with subsequent work by [22], [23], [27], [28] demonstrating an out of the body illusory sense of touch in immersive VR. Here we expand this work, and demonstrate that rendering an object between the hands, even if you don't see the hands, can also elicit an illusory sense of touch between two independent vibrotactile sources (i.e., the controllers) in immersive VR.

A. Subjective Reporting

One of the interesting findings from this study, was that the participants' objective and subjective reports of the illusion of touch (i.e., perceived location of Tap 2) differed. Participants reported being as confident about their reported location for Tap 2, despite the differences in spatial acuity for the illusory tap (Tap 2) between the body and no body conditions.

This divergence suggests that subjective measures of immersiveness, or of a particular experience in VR, can sometimes be misleading. People are not always very accurate when asked to report their internal cognitive states [16]. And there might be possible disconnects in subjective reporting when measuring subtle changes on other aspects of the experience such as Presence and Embodiment [3], [17].

In fact, given the robustness of the out-of-the-body cutaneous rabbit illusion to changes in the VR environment, a variant of the illusion has been used to further study immersion in VR [23]. Using this technique, the drifts in tap localization were useful as an objective metric of users' level of immersion in a visuo-haptic VR manipulation.

B. Single Cause Theories

Due to the timing of the vibro-tactile stimuli provided in the out-of-the-body touch illusion, Taps 1 and 3 are clearly perceptible, but Tap 2 is rendered ambiguous. Here, we attempt to overcome this ambiguity by presenting a visual stimulus (i.e., the white sphere) at the same time as Tap 2. However, the spatial location of the visual stimulus is incongruent with the actual spatial location of the second tap (which is at L1). We predicted, and observed, that the simultaneity of the visual and vibro-tactile feedback would lead to multisensory integration of the visuotactile stimuli and therefore, an illusory sense of touch in the location where the participants observed the visual stimulus [33]. However, the translocation of the second tap

(Tap 2) was more robust when the participants had a body, which suggests that having a virtual body provides a significant advantage when integrating stimuli from different sensory modalities.

This finding is in line with the Bayesian causal inference theory of perception which states that the brain associates the probability of a single cause based on the reliability weights of all incoming input [35]. In our paradigm, having a body in the virtual environment increased the probability weight of the visual stimuli occurring in the virtual environment, and therefore rendered a more robust integration of the visual and tactile stimulation, and a more robust illusory sense of touch. These findings are in line with those from previous work demonstrating the importance of the body for the integration of multisensory stimuli [35]–[37].

C. Multisensory Integration Flexibility

Previous studies that investigated visuo-tactile perception in VR have shown that humans tend to be more flexible regarding the temporal dynamics of touch when they have a virtual body [15], [33]. For instance, Maselli and colleagues found that participants' temporal window for visuo-tactile integration was significantly widened when they experienced ownership over a virtual avatar in VR [15]. Together with the findings presented here, these findings suggest that body ownership has an important role in how we perceive tactile stimuli and more widely our environment. Indeed, it seems as though the sense of body ownership enables our perceptual systems to be more flexible.

The described temporal flexibility in visuo-tactile integration may be enabling stronger "postdiction" perceptual effects when participants have a body [33]. This might be one of the reasons why participants in the body condition in our study perceived an enhanced accuracy on the touch spatialization, while those in the no body condition showed higher dispersion on touch perception. This is important, as changes in perception translate into our memories and our behaviors when interacting with the environment.

D. Beyond Tactile Perception

Our main results are centered around how a virtual avatar might influence our sense of touch, and more generally, sensory interpretation. However, ultimately, sensory perception is the basic input that shapes all of our experiences [37], [38]. The fact that there is a different interpretation of the afferent input that occurs when participants have a body (as we have shown here) is surely affecting more complex higher levels of cognition, behavior, and emotion. Our brains construct our reality on the basis of a continuous stream of information from our sensors. Thus, if having a body or not changes our sensory experience in VR, this will likely affect many other levels of the users experience and behavior within and outside VR.

It could be argued that the body acts as a frame of reference that helps with memorizing the locations of the touches on the wooden dowel. However, that is not the only possible explanation since in both conditions the perception of the touch is well

reported when the visual (sphere) and tactile stimuli are aligned (e.g., Tap 1 & Tap 3).

The findings presented here are consistent with previous studies which have shown that the body we experience as our own can alter size and distance perception [39] or cognitive resources such as memory [40]. The influence of one's body on the perception of our environment is important since it leads to important changes not only in our experience of virtual environment, but also in one's behavior. For example, in one experiment participants were less able to play the drums when embodied in a business dressed avatar [41]. Another study found that participants who self-recognize in look-alike avatars are more likely to improve self-counseling [21], [42]. Our results might also be modified when using look alike avatars, especially given the variation on the responses of Q2 and Q5 and recent findings on individual differences on embodied perception [13]. Having a virtual avatar can also have long lasting effects and even reduce racial bias [43]. Our experiment shows yet one more example of how having a matching first-person virtual body in VR changes the users experience; namely, the tactile experience.

V. CONCLUSION

Our study has implication on tactile integration in VR and challenges the use of commercially available VR setups that include controllers but do not render an embodied avatar for the participant. While, controllers alone seem to provide reliable haptic feedback if they do not require very accurate spatialization within VR or the interpolation of touch. This was the case for Tap 1 and Tap 3 in our experiment. Our results suggest that having a virtual avatar may be critical for producing accurate spatialization of touch from more ambiguous haptic feedback within the virtual environment.

Furthermore, the results presented here suggest that there is a disconnect between subjective statements of the participants in how they report their experiences and the objective measures of their experiences when exposed to subtle changes. Hence, we propose the use of haptic perception as possible objective metric to better explore how participants' VR experience is altered by different types of manipulations. Given the ability of the out-of-the-body cutaneous rabbit illusion to capture subtle changes, we believe that drifts in haptic perception may also be observed when participants are embodied in different types of avatars, or even show changes if participants undergo particular virtual body alterations such as changes in size, gender, or race [2], [43], [44].

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