Allocentric Full Body Illusion Extends Peripersonal Space

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Abstract. Body Self-Consciousness (BSC) is based on a multisensory integration (MSI) process, in which bodily signals and information entering the space immediately surrounding the body - the Peripersonal Space (PPS) - are integrated. The PPS contributes to the development of self-presentation and plays a critical role in shaping how people interact with the surrounding physical and social environment. Alterations in the PPS have been found to be associated with conditions characterised by abnormal anxiety responses or altered states of the BSC, suggesting a possible role in the maintenance of pathological behaviour. Thus, previous research has explored the possibility of manipulating PPS through body illusions. In the present study, we investigated whether a full-body illusion (FBI) presented from an allocentric spatial frame was able to extend the PPS boundary. Participants performed the first run of the PPS task and were then presented with the FBI, followed by a second run of the PPS task for both synchronous and asynchronous conditions. Results showed that PPS increased after the synchronous FBI compared to baseline. As the PPS reflects a change in the MSI, future studies should investigate whether PPS enhancement and allocentric FBI can positively influence body experience in conditions characterised by BSC alterations, such as eating disorders, as well as their effects on the way people interact with their physical and social environment.

Keywords. Full Body illusion, Multisensory Integration, Peripersonal Space

1. Introduction

The body is the basis of self-consciousness in what is defined as Body Self-Consciousness (BSC) [1]. BSC refers to the experience of owning a body (body ownership), being in a specific location within an environment (self-location), and having a body-centred perspective from which the world is perceived (egocentric perspective) [2]. This complex experience results from a multisensory integration (MSI) process in which information from different sensory modalities (e.g., visual and tactile) is encoded and fused into a unique and coherent percept [1]. In particular, bodily experience requires the integration of cross-modal body-related signals as well as information from stimuli entering the space immediately surrounding the body, the peripersonal space (PPS) [3].

PPS refers to the self-other boundary and is an essential component of self-consciousness as it shapes interactions with the physical environment (e.g., avoiding potential threats, interacting with objects) as well as social interactions [4]. MSI plays a

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crucial role in the PPS, allowing us to locate ourselves in space and helping us to localise external entities in close proximity to our body [4]. Indeed, multisensory facilitation occurs within PPS, meaning that crossmodal integration occurs much faster than in extrapersonal space (i.e., space far from the body) [5]. Indeed, a well-established task for assessing PPS requires participants to detect a tactile stimulus (e.g., vibration) on a specific body part while task-irrelevant visual stimuli approach them [5]. The distance at which reaction times (RTs) decrease due to the co-presentation of tactile and visual stimuli is considered an estimate of the PPS boundary [5,6].

Previous research has investigated PPS in psychopathological conditions characterised by abnormal fear responses and/or altered states of the BSC (e.g. phobias, trauma-related disorders) [4] and found an effect of stress and anxiety on PPS estimates. It has been proposed that this may play a role in the maintenance of pathological behaviours such as avoidance of certain stimuli and social isolation [4].

As a result, recent research has begun to investigate whether it is possible to manipulate PPS using the Full Body Illusion (FBI). It was found that promoting embodiment via a smaller or taller virtual body increased the PPS boundary [7], and that using virtual tools that extend the physical boundaries of the body affected PPS [8]. In addition, relatively recent research has found changes in PPS following FBI in both the anterior and posterior body space [9].

Despite promising results, there is still a lack of research in this area, and conflicting results have been found when Virtual Reality (VR) experiences are proposed [10].

In this pilot study, we wanted to investigate whether it is possible to extend PPS using the FBI. Specifically, we used a visual-tactile task to compare PPS boundary estimation before and after exposure to an allocentric (third-person) perspective FBI in VR. First paragraph.Methods

1.1. Participants

For this pilot study, we recruited a total of 15 participants [9 females; mean age: 25.7 (SD=1.80); mean BMI: 21.7 (SD=3.14)]. None of them reported having a current and/or a history of neurological and/or psychiatric disorders.

1.2. Procedure

Participants completed a questionnaire to assess basic socio-demographic information. They then underwent the PPS task to measure baseline PPS limits. Subsequently, the FBI was presented from an allocentric (i.e., third-person) perspective and participants were instructed to stand behind the avatar and focus on its back for 5 minutes [9]. All participants received both synchronous and asynchronous visuotactile stimuli and were required to complete the Embodiment Questionnaire after each condition.

1.3. Peripersonal Space Task [6]

The visuotactile task to assess PPS required participants to respond as quickly as possible to a tactile stimulation on their face by pressing a button while observing a task-irrelevant, approaching ball in a virtual environment. The timing between the presentation of the visual and tactile stimuli was varied so that the tactile stimulation was delivered when the visual stimulus was at different distances from the subject (D1 ≈ 45 cm; D2 ≈ 80 cm; D3 ≈ 115 cm; D4 ≈ 150 cm; D5 ≈ 185 cm).

The task consisted of four types of trials: bimodal visuotactile, unimodal tactile, unimodal visual and attentive trials. In bimodal visuotactile trials (N=60), the tactile stimulation was delivered at five different time delays from the onset of the visual stimulation (D5=0.5s; D4=1s; D3=1.5s; D2=2s; D1=2.5s). Thus, the ball could be at five possible distances when the vibration was applied. In unimodal tactile trials (N=60), the vibrations were presented without a corresponding visual stimulus with a temporal delay as described above. In unisensory visual trials (N=60), the approaching ball approached the participant without a corresponding tactile stimulus. In addition, attention trials (N=12) were proposed in which participants had to verbally report the presence of a red dot on the ball. The whole session lasted 15 minutes.

1.4. Full Body Illusion

The FBI used a standard size virtual body created using MakeHumans software and imported into Unity3D to create the immersive scenario. Participants wore a head-mounted display and were asked to stand behind the avatar (≈50 cm) and focus on its back. Participants received a visuotactile stimulation on the virtual and real body for 5 min. The same stimulation was offered both synchronously and asynchronously, varying the temporal synchrony between the felt and seen touch. After each condition, participants completed the Embodiment Questionnaire to assess the strength of the illusion [11].

1.5. Analysis

Performance in the PPS task was analyzed in terms of RTs to the tactile stimulation based on previous research [6]. RTs higher or lower than 2 standard deviations were excluded from the analyses. We computed mean RTs to tactile stimuli at different distances and subtracted it from the averaged RTs to bimodal trials for each participant. In this way, we obtained corrected RTs, where negative values indicated multisensory facilitation.

A 3 (Condition: Baseline, Synchronous, Asynchronous) x 5 (Distance: D1 to D5) repeated measures ANOVA was performed on corrected RTs to investigate the effect of the FBI stimulation and the different distances at which the tactile stimulation was provided. The Greenhouse-Geisser correction was applied when the sphericity assumption was violated as assessed by Mauchly's test.

We performed paired t-tests to compare the adjacent couples (e.g., D1 against D2, D2 against D3) within each condition to identify when multisensory facilitation stopped as a proxy of the PPS boundary [6].

Corrected RTs were fitted to a linear function and the relative slopes were extracted as indexes of segregation between the peripersonal and extrapersonal space(4,12). The function was described by the equation: $y(x) = y0 + k \cdot x$; where x represents the independent variable (i.e., the timing of tactile stimulation in ms), y the dependent variable (i.e., the reaction time), y0 represents the intercept at $x = 0$ and k is the slope of the function [6]. We ran a within-subjects ANOVA to compare the slopes in the different conditions to better characterize changes in PPS boundaries.

2. Results

Results from repeated measures ANOVA analysis showed a significant main effect for Condition ($F(2, 28)) = 25.116$, $p < 0.001$, $\eta^2 g = 0.112$) and Distance ($F(1.73, 24.31) = 38.62$, $p < 0.001$, $\eta^2 g = 0.49$), as well as a significant interaction effect Distance*Condition ($F(2.08, 329.24) = 7.170$, $p <0.001$, $\eta^2 g = 0.158$; Figure 1). Thus, data highlighted significant differences among PPS boundaries between the conditions.

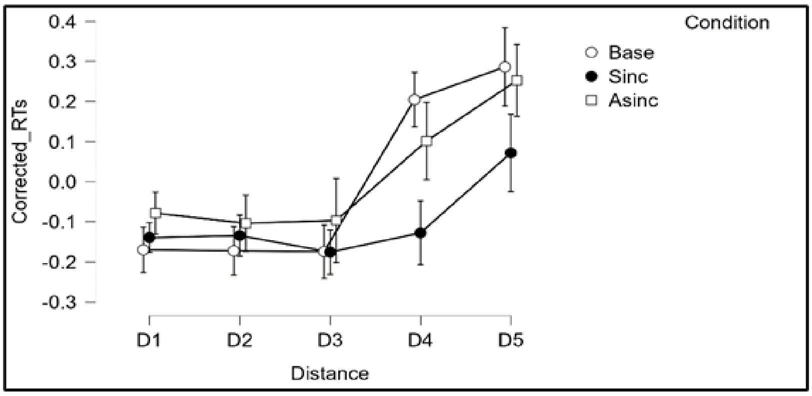

Figure 1. Repeated measures ANOVA considering Condition (baseline, asynchronous, synchronous) and Distance (from D1 to D5) as within factors.

The paired t-test revealed significant differences in reaction times (RTs; i.e., differences in multisensory facilitation effect) between D3 and D4 in the Baseline and Asynchronous conditions ($p = 0.001$, $p = 0.002$ respectively), whereas emerged between D4 and D5 in the Synchronous condition ($p = 0.019$). In the Asynchronous and Baseline conditions indeed multisensory facilitation dropped between D3 and D4 (i.e., corrected RTs were above zero, indexing the absence of facilitation), whereas it dropped between D4 and D5 in the Synchronous condition.

The within-subjects ANOVA including slopes in the different conditions as within factors showed a significant main effect of Condition ($F(2, 28) = 11.42$, $p < 0.001$, $\eta^2 g = 0.32$) on slopes. Post hoc comparisons revealed that significant differences emerged when comparing the Baseline and Synchronous conditions ($p <0.001$, Bonferroni-corrected) and the Synchronous and Asynchronous conditions ($p <0.001$ Bonferroni-corrected), whereas no significant differences emerged between the Baseline and Asynchronous ones ($p = 0.474$, Bonferroni-corrected). Additionally, the slope was smaller in the Synchronous condition (Sync_mean = 0.094, SD = 0.035) compared to the other conditions (base_mean = 0.177, SD = 0.058, async_mean = 0.166, SD = 0.057), indexing an enlargement of the PPS boundary in the Synchronous condition [6].

3. Discussion and Conclusions

In this study, we investigated whether PPS boundaries could be altered by inducing embodiment over a virtual body using allocentric FBI in VR. We found that after synchronous stimulation during allocentric FBI, the PPS boundary expanded towards the location of the avatar, such that the PPS representation shifted from being centred on the location of the physical body to being centred on the embodied body [9]. Therefore, our data confirmed evidence that FBI can affect the BSC in all its components, namely body ownership, spatial perspective and self-location.

We suggest further research to evaluate allocentric FBI to investigate body experience and its underlying mechanisms. As PPS shift reflects a change in MSI [13], allocentric FBI may be effective in altering body experience by working on its underlying process. This is relevant to the study of pathological conditions characterised by altered BSC, such as eating disorders (EDs) [14]. Indeed, there is considerable evidence that patients affected by these conditions report altered body experience (e.g. body misperception), and recent work suggests that this may be related to MSI deficits [14]. Following this idea, previous research has used the egocentric (first-person) FBI to manipulate body perception in patients with EDs, with only short-term and marginally clinically significant results in terms of body misperception [10]. The use of the allocentric version of FBI and its ability to alter MSI may be more effective than the egocentric version in reshaping body experience.

We also recommend investigating the role of cognitive and affective body-related components on PPS and thus MSI processing. For example, body shame might influence PPS limits, with higher levels of negative affect associated with a limited PPS. This is relevant for understanding the factors that influence a dysfunctional body-self relationship.

Finally, we suggest that the effects of expanding PPS boundaries should be better explored: as PPS expansion promotes social interactions [15], and restricted PPS appears to be associated with high levels of stress and anxiety [16], could expanding PPS boundaries influence how individuals interact with their physical and social environment? For example, it has been hypothesised that stress leads to a freezing response in which multisensory-motor resources are allocated only to the space immediately surrounding the body [16]: could manipulating PPS therefore help to cope with stress?

This line of research could improve our understanding of a complex phenomenon such as the BSC and provide insights into understanding pathological conditions characterised by alterations in bodily experience as well as disturbances in the way individuals interact with their environment.

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