Spatial Asynchronous Visuo-Tactile Stimuli Influence Ownership of Virtual Wings

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Abstract. Previous studies revealed that a compelling illusion of virtual body ownership (VBO) might be achieved under a condition of recognizable anatomical and morphological similarities to human body. Though certain deviations from morphology might be acceptable (e.g. virtual tails, longer arm or larger belly), if external limbs are responsible for specific functions in conjunction with a certain virtual scenario. Thus, this study aims at showing a possibility to achieve a compelling VBO illusion over a non-human avatar in a virtual environment. The paper describes a within-subjects study exploring if immersed users could achieve a compelling VBO illusion when inhabiting a virtual body of a bat. Test subjects experienced visuo-tactile stimulation of their arms while seeing an object touching their virtual wings. The mapping between the real and virtual touch points varied across three conditions: no offset between the visual and the tactile input, 50% offset, and 70% offset from the tactile input. The results revealed variations in the degree of experienced VBO across the conditions. The illusion was broken in the absence of visuo-tactile stimulation.

Keywords: Virtual and augmented realities · Novel applications
Interactive environments

1 Introduction

While Virtual Reality (VR) has been developing for more than half a century, its purpose largely remains the same – to create a sense of presence in virtual environment (VE); that is make to our brain believe that we are actually inside the VE, even though physically we are not. VR has the potential to providing compelling experiences of being not only other humans, but even other species. In order to create a believable illusion of being a flying creature inside the VE there are some considerations to ruminate – primary how would the virtual

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body look like in terms of size and shape. In fact having an artificial body inside VE might increase the sense of presence [7]. Previous research showed that similarity between the real and the virtual body is one of the important factors of creating and sustaining a compelling illusion of virtual body-ownership (VBO) [14]. VR allows users to inhabit avatars that differ from their own by altering the morphology of the virtual body [11,16], or even adding extra limbs [19]. Nevertheless researchers were less successful in their attempts to establish VBO over non-corporeal objects [17] and mostly failed to provide a compelling illusion of owning the virtual body.

To the authors' knowledge there have been no studies conducted, where individuals could experience a compelling illusion of ownership over anatomically similar but morphologically different virtual body. That is the virtual body that has a different form, size and shape from a human structure that could be perceived as the users' own body in VR. Out of all flying creatures bats are the only existing flying mammals in nature with the similar anatomy of their wings to a human hands. Very often their wings are also called "hand–wings" [5]. Thus the study will focus on the attempt to generate a compelling illusion of owning the virtual body of a bat.

This experiment is a part of ongoing research about agency and ownership in VR. This paper expands upon our previous work [1]. In an attempt to study the influence of morphologically different virtual shape on users' acceptance of the virtual body we need to take into consideration several combinational factors, such as touch though tactile stimulation, proprioception through passive movements and actions with intentions through active movements, as these are the constituent parts of embodiment. Therefore in this research we address several questions, such as: (1) To which extent might anatomically similar but morphologically different virtual body influence users' experience of VBO and (2) To what degree is it possible to achieve and sustain the sense of ownership of the virtual bat's body using visuo-tactile stimulation.

2 Background

2.1 Body Ownership and VBO

Realizing that someone has a body is a complex cognitive process. Self-attribution to a body is the main identification factor of owning the body that is your "own" [20]. Both agency – intentions and executing actions [22] and body ownership (BO) – awareness of one's movements and self-recognition [20] are two consistent parts of a cognitive self-attribution process. Knowing that your body has been moved, by sensing it and not creating action yourself (during the involuntary movement), would infer only BO but not agency [22]. Varela [23] points out that it is problematic to dissociate the body from one's self, therefore it is challenging to replicate this experience. Cognitive psychology clearly distinguishes between agency and BO that together constituting embodiment, described by Varela [23]. Though in relation to VR there might be some confusion, due to the usage of term "VBO", which relates more to embodiment rather than BO as a separate sense from agency. VBO, described by Maselli et al. [14] is integration of different senses, including vestibular sensation and motor control. Furthermore, it has also been defined that VBO should include not only 1st person perspective including humanoid-shaped avatar, but also synchronous visuo-tactile information and synchronous visuomotor correlations [16]. Visuo-tactile information should be understood as belonging to BO, whereas visuomotor correlation – belonging to agency. The problem of embodiment (out-of-body experience) has been further reviewed in VR [3]. VBO illusion is an illusion, where healthy test subjects believe that artificial body is their own physical body [14]. Kilteni et al. [10] defined the sense of embodiment as "being inside, having and controlling" the body, which has spatial representational characteristics: location inside the body, self-attribution and intentions together with actions. This leads to several components that are essential in VE – sense of self-location, sense of BO and sense of agency [10]. Biocca et al. [3] discussed that self-presence is the main factor of embodiment of one's self representation. Self-presence is a psychological matter, as it is a perceptual sense of being inside the body. Based on the coordinate system self-location and presence might be described as complimentary concepts, characterizing spatial representation, as either being located inside the virtual body (egocentric or internal space) or inside VE (allocentric or external space). While inhabiting a virtual avatar our skin acts as a border to the external environment, that is why tactile input plays another significant role in self-location [10]. According to VR research human-shaped avatar enhances VBO illusion as VBO might be highly susceptible to individual differences due to the fact that virtual body obeys certain structural and morphological constrains, like similarities between the biological body and its virtual avatar. Several researchers even speculate if individualized avatars might strengthen ownership by increasing body and self-recognition [10]. The current paper adheres to the concept of embodiment that defines BO and agency as two separate concepts theoretically, though practically mostly inseparable.

2.2 Related Work

The feeling of BO is possible to study through multisensory stimulation by shifting body experience from BO present to BO absent [20]. The original study of Rubber Hand Illusion (RHI) is a perfect example of interaction between vision, touch and proprioception, which manipulates BO experience in a controlled environment [4]. Seeing the tactile stimulation on the rubber hand and detecting the sensation on the real hand results in the displacement of the felt location towards the spatial location of visually induced observation. Different manipulations of BO illusion using RHI modifications could also be seen in other studies [8,9,18]. Longo et al. [13] could distinguish between BO, agency and location. In a further study [12] they suggested that similarities between the rubber hand and the real hand only elicits ownership under the condition when strokes were applied synchronously to both hands. The results of one study suggested that BO illusion could be established only for corporeal objects. For example, a wooden block (a non-corporeal object) could not support the illusion, while the wooden hand, having structural similarities to the real hand, could [21]. However, the view of the human-shaped manikin experiment did not completely dampened the illusion, due to visuo-tactile component present in the experiment [17]. The results of the recent study indicate that BO increases when virtual human hand looks realistic, though during active movement [2]. Furthermore, Steptoe et al. [19] tested acceptance of an extra virtual limb (a tail) as belonging to the virtual body. The experiment showed that the correct gestural input (controlled through active participants' movement) of the extended limb combined with a game context, a 3PP, humanoid looking avatar and synchronous movements are necessary, in order to accept an external virtual limb as belonging to the body and to get the sense of VBO [19].

3 Methods

The aim of this study is to test if it is possible to achieve a VBO illusion over bat's avatar with the help of visuo-tactile stimulation, presented in Fig. 1. Since apart from visuo-tactile sensory input, BO could also be elicited during passive movements it is essential to test the influence of passive movements on VBO illusion. Instead of delivering proprioceptive input to the physical body we will move the virtual body by moving body's object together with the camera in the scene, which might induce the illusion of passive movement in VE. Due to subjective matter of VBO illusion in regards to self-location mentioned in Sect. 2.1 it has also been decided to measure if test subjects felt present inside the VE and/or inside the body.

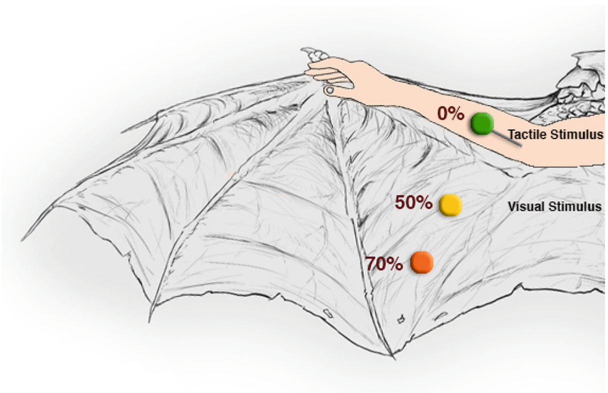

Fig. 1. Visuo-tactile stimulation in test conditions. Green ball represents "offset-0" condition, where the real and the virtual touch points were mapped at the same location, Yellow ball – "offset-50", where the virtual touch point mapped with 50% displacement from the real location, Red Ball – "offset-70", where the virtual touch point mapped with 70% displacement from the real location (Color figure online)

3.1 Study Design

For this purpose we applied a within-subject study design (n = 22) involving three conditions, visualized in Fig. 1, followed by a questionnaire and interview. In the first condition the mapping between the real and virtual touch points were 1:1, that is when viewed from the user's point of view they appeared to be co-located. Mapping was called "offset-0". In the second condition the virtual touch point was mapped with 50% displacement from the real location with respect to the outermost point of the wing. Mapping was called "offset-50". In the third condition the virtual touch point was mapped with 70% displacement from the real location. Mapping was called "offset-70". "offset-70" displacement was adapted after a pilot test, where test subjects reported the least visual spot on the wings. There was no difference between 70% and 90% displacement. All the conditions were applied in randomized order.

3.2 Participants

Twenty two test subjects (13 males and 9 females) with age between 15–54 (M = 32.86, SD = 12.24) took part in the study. The majority of test subjects were recruited from Aalborg University and had no prior experience with VR (18/22). All test subjects had normal vision and no sensitivity disorders.

3.3 Procedure

Test subjects were exposed to the VE for approximately two minutes per condition. During the test, participants were asked to lay down on the floor with their hands stretched in front of them, matching the virtual bat's position. Their head was placed on a pillow to eliminate HMD weight on the neck. Test subjects were asked to place their hands on a predefined position, marked on the floor to ensure the correct placement of their arms. Their virtual wings were visible at the location of their physical hands (shown in Fig. 2).

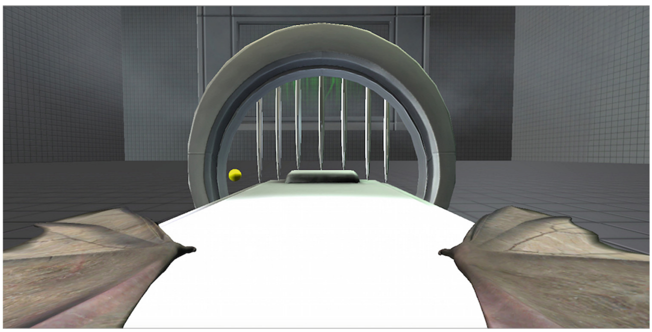

Fig. 2. Virtual bat's position from first person perspective (Color figure online)

The wings were twice as long and wide than the test subjects' hands. Tapping on test subjects' hand was performed by a physical wand. The tip of wand was presented by a yellow ball in the VE. When the conductor finished tapping the bat's body was moved forward towards animated lattice with knives in order to test involuntary movements and the reaction of the body towards the threat. When the body stopped moving before reaching the knives, the last touch was performed on the thumb area and was visually presented by the hammer instead of a yellow ball, simulating a threat to the virtual limbs. Finally interview was conducted at the end of the test.

The visual feedback was delivered through HMD (nVisor SX60 with a resolution of 1280 × 1024 pixels, diagonal eye FOV of 60°). Both HMD and wand positions with attached markers were tracked by OptiTrack motion capture system with 13 cameras that captured the transformed position of these two markers in space. Headphones (Sennheiser HD570) provided audio feedback of the touch sound and surrounding soundscape. The virtual scene was developed in Unity 3D.

3.4 Measures

VBO was measured using a questionnaire, involving series of Likert scale items, ranging from '1' (totally disagree) to '7' (totally agree), adapted from [6,11,15,16,18]. After each test, participants were asked to fill in the questionnaire shown in Fig. 3. Personal interview questions, tailed by explanations and discussion, included presence (as being there – inside VE), feeling of VBO (as the body was test subject's own), questions about movement (if participant felt that his/hers virtual body was moved, if participant was only observing the movement of a virtual body, if participant controlled the movement).

1. During the experiment, there were moments where I felt as if the virtual wings belonged to me, despite the differences in physical shape between the wing and the hand.
2. During the experiment, I felt that my physical hand was located at the same spot where the virtual wing was.
3. During the experiment, there were moments when I felt as if the virtual wing was my own hand.
4. During the experiment, there moments when I felt as if I was located inside the bat´s body.
5. Even though the virtual body I saw in the environment might not have had the same physical shape that I have, I felt as if the virtual body belonged to me.
6. There were moments during the experiment when I felt that the touches on my arm were caused by the yellow ball I saw on the screen.
7. I felt that the touch of the yellow ball on the wing corresponded to the same place as the touched I felt on my arm.
8. There were moments during the experiment when I felt hits on my physical body, when the virtual wing was hit with the yellow ball.

Fig. 3. Questionnaire

4 Results

Analysis of the data focused on aggregate scores, calculating VBO score per condition. Results obtained from the questionnaire was not normally distributed according to Kolmogorov-Smirnov test ($p > .05$). Consequently, the data was treated as ordinal. Friedman's test showed significant difference of scaling factor on VBO at $p < .05$ level for three conditions [$F(12, 780) = 138.95, p < .01$]. Results are presented through boxplots of three conditions in Fig. 4. Collected mean and median per condition can be seen in Table 1.

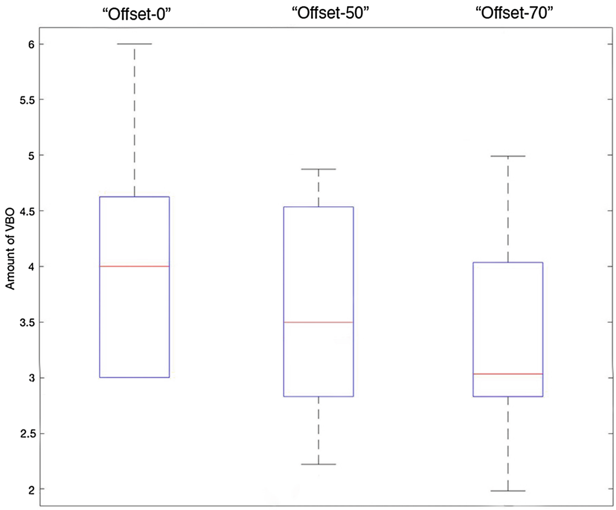

Fig. 4. Boxplot of VBO of three conditions's grand means, reviewing 7-point Likert scale, presenting medians, interquartile ranges, minimum and maximum ratings. The higher the results are on scale the more is VBO achieved.

Table 1. Table of collected mean and median per condition

Conditions	Mean	Median
(1) "offset-0"	3.96	4
(2) "offset-50"	3.8	3.5
(3) "offset-70"	3.59	3

The higher the answers were rated the more VBO illusion test subjects got in regards to Likert scale. Pairwise comparison using Mann-Whitney-Wilcoxon rank sum test ($p < .05$) revealed difference between "offset-0" and "offset-70", but no difference was found between "offset-0" and "offset-50". Significant difference of the results imply the influence of morphological differences between the human and the virtual bodies. Furthermore, no difference between "offset-0" and "offset-50" might indicate that the same amount of VBO could be perceived with 50% visual deviation from the primary touching point without noticeable implications.

During the interview test subjects reported a strong wish to move away from the threats. Some of them (17/22) tried to move their head away, even though it was difficult, as the head was placed on a pillow. When test subjects' thumb area was stimulated with the virtual hammer, especially during the "offset-0", the majority (18/22) reported a strong wish to move their thumb away from the hammer. In "offset-50" condition 15 test subjects reported a wish to move away their thumb. In "offset-70" only 2 out of 22 participants wanted to move away their thumb.

During the interview test subjects outlined that the illusion was immediately broken in the absence of visuo-tactile stimulation. This leads to a hypothesis that VBO illusion might be sustained only during stimulation of the physical body and visually synchronized touch representation. All test subjects reported unintentional movement as belonging to presence, but they lost ownership of their virtual wings. According to their comments they felt like being "an observer" while bat's body was moved, and they no longer perceived wings as their own.

5 Discussion

Results showed a possibility to achieve some degree of VBO illusion over morphologically different from human-shape virtual body using visuo-tactile stimulus with visual deviation stretched up to 50% from the origin of physical touch point. Even though no significant difference was found between the first and the second conditions, degree of ownership decreased based on mapping. Unfortunately, it was difficult to sustain the illusion as soon as stimulus was absent, which indicates a strong connection between physical body and it's virtual representation.

Visual simulation of passive movements without vestibular and proprioceptive inputs did not provide the same effect as when performing involuntary body movements in the real world (e.g. lifting user's finger or arm), therefore test subjects felt as being observers of a virtual body while being moved during the experiment. Camera movement together with the virtual body might have created only an illusory self-motion effect, which was not enough for achieving the sense of VBO.

Results from the interview, including self-reported fear of the threats, revealed a strong sensation of presence in the environment. However, during presence of threats test subjects reported a strong wish to move away from it. Stimulation around thumb area was noticed as giving the best VBO sensation. Albeit test subjects reported absence of VBO feeling during the interview, results show the highest score, especially in "offset-0" mapping condition. This might have happened due to results' subjectivity and post-interview timing (as they were interviewed only after trying all three conditions). Nevertheless, above mentioned indicates that certain deviations from human morphology might still be acceptable even without voluntary movements involved. Reducing the size of the wing area (too large wings in comparison to hands) by matching test subjects' hand length might possibly improve the illusion.

6 Conclusion

Friedman's test revealed a significant difference between the three conditions during visuo-tactile stimulation and presence of the threats, indicating that the highest VBO amount belonged to "offset-0" condition. However, synchronous visuo-tactile stimulus needs to be permanently present in order to sustain the illusion. Apart from visuo-tactile stimulus VBO might involve passive movements, which should activate vestibular and proprioceptive input of the physical body and might strengthen the illusion. Watching virtual body being moved was not enough. Illusory self-motion is not able to simulate the mentioned input and therefore made test subjects' feel as observers of a virtual body inside the VE. Proprioceptive awareness of the physical body plays a significant role and should not be underestimated.

The influence of agency on VBO illusion should be studied in the future, as active movements were disregarded in this experiment. Furthermore, participants expressed that they missed movements and speculated if they might have achieved a higher VBO illusion if they were allowed to move, which suggests a need for agency for a sustainable illusion over anatomically similar but morphologically different virtual body.

References

1. Andreasen, A., Nilsson, N.Chr., Serafin, S.: Spatial asynchronous visuo-tactile stimuli influence ownership of virtual wings. In: IEEE Virtual Reality 2018. IEEE Press (2018)
2. Argelaguet, F., Hoyet, L., Trico, M., Lécuyer, A.: The role of interaction in virtual embodiment: effects of the virtual hand representation. In: 2016 IEEE Virtual Reality (VR), pp. 3–10. IEEE (2016)
3. Biocca, F.: The cyborg's dilemma: progressive embodiment in virtual environments. J. Comput.-Mediat. Commun. **3**(2) (1997)
4. Botvinick, M., Cohen, J.: Rubber hands' feel'touch that eyes see. Nature **391**(6669), 756 (1998)
5. Fenton, M.B., Simmons, N.B.: Bats: A World of Science and Mystery. University of Chicago Press, Chicago (2015)
6. Gonzalez-Franco, M., Perez-Marcos, D., Spanlang, B., Slater, M.: The contribution of real-time mirror reflections of motor actions on virtual body ownership in an immersive virtual environment. In: 2010 IEEE Virtual Reality Conference (VR), pp. 111–114. IEEE (2010)
7. Heeter, C.: Being there: the subjective experience of presence. Presence: Teleoperators Virtual Environ. **1**(2), 262–271 (1992)
8. IJsselsteijn, W.A., de Kort, Y.A.W., Haans, A.: Is this my hand I see before me? The rubber hand illusion in reality virtual reality and mixed reality. Presence: Teleoperators Virtual Environ. **15**(4), 455–464 (2006)

9. Kalckert, A., Ehrsson, H.H.: Moving a rubber hand that feels like your own: a dissociation of ownership and agency. Front. Hum. Neurosci. **6**, 40 (2012)
10. Kilteni, K., Groten, R., Slater, M.: The sense of embodiment in virtual reality. Presence: Teleoperators Virtual Environ. **21**(4), 373–387 (2012)
11. Kilteni, K., Normand, J.-M., Sanchez-Vives, M.V., Slater, M.: Extending body space in immersive virtual reality: a very long arm illusion. PLoS One **7**(7), e40867 (2012)
12. Longo, M.R., Kammers, M.P.M., Gomi, H., Tsakiris, M., Haggard, P.: Contraction of body representation induced by proprioceptive conflict. Curr. Biol. **19**(17), R727–R728 (2009)
13. Longo, M.R., Schüür, F., Kammers, M.P.M., Tsakiris, M., Haggard, P.: What is embodiment? A psychometric approach. Cognition **107**(3), 978–998 (2008)
14. Maselli, A., Slater, M.: The building blocks of the full body ownership illusion. Front. Hum. Neurosci. **7**, 83 (2013)
15. Maselli, A., Slater, M.: Sliding perspectives: dissociating ownership from self-location during full body illusions in virtual reality. Front. Hum. Neurosci. **8**, 693 (2014)
16. Normand, J.-M., Giannopoulos, E., Spanlang, B., Slater, M.: Multisensory stimulation can induce an illusion of larger belly size in immersive virtual reality. PLoS One **6**(1), e16128 (2011)
17. Petkova, V.I., Ehrsson, H.H.: If I were you: perceptual illusion of body swapping. PLoS One **3**(12), e3832 (2008)
18. Slater, M., Perez-Marcos, D., Ehrsson, H.H., Sanchez-Vives, M.V.: Towards a digital body: the virtual arm illusion. Front. Hum. Neurosci. **2**, 6 (2008)
19. Steptoe, W., Steed, A., Slater, M.: Human tails: ownership and control of extended humanoid avatars. IEEE Trans. Vis. Comput. Graph. **19**(4), 583–590 (2013)
20. Tsakiris, M.: My body in the brain: a neurocognitive model of body-ownership. Neuropsychologia **48**(3), 703–712 (2010)
21. Tsakiris, M., Carpenter, L., James, D., Fotopoulou, A.: Hands only illusion: multisensory integration elicits sense of ownership for body parts but not for non-corporeal objects. Exp. Brain Res. **204**(3), 343–352 (2010)
22. Tsakiris, M., Schütz-Bosbach, S., Gallagher, S.: On agency and body-ownership: phenomenological and neurocognitive reflections. Conscious. Cogn. **16**(3), 645–660 (2007)
23. Varela, F.J., Thompson, E., Rosch, E.: The Embodied Mind: Cognitive Science and Human Experience. MIT Press, Cambridge (2017)