A Model for Virtual Hand Ownership in Augmented Reality

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ABSTRACT

In the classic rubber hand illusion participants can experience ownership over a fake limb. Variations across media such as the virtual hand illusion in virtual and augmented reality show similar findings. Previous studies have shown that the ownership experience may be the result of the integration of neurocognitive top-down and bottom-up processes. Yet, there are frequently occurring individual differences between participants that cannot be explained solely in this way. We present a two-level processing model for the experience of virtual hand ownership, based on (1) the construction of a tentative hand model and (2) the testing of ownership over this hand model. While the first level processing closely follows existing ownership models, the novel second level processing is suggested to be influenced by a number of new factors that can lead to individual differences. We support the model through a literature review, and moreover use an experiment for the second level. In this experiment, we show that a participant's immersive tendency, a personality trait that describes one's capability to become immersed in mediated environments, influences their susceptibility to owning a virtual hand in augmented reality. Our results illustrate that to a certain extent individual differences in rubber hand illusion studies can be explained by specific personality traits, and we place this in a model to advance our understanding of the underlying mechanisms that shape the experience of ownership.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality; Human-centered computing—Human computer interaction (HCI)—Empirical studies in HCI

1 INTRODUCTION

The rubber hand illusion (RHI) is a well-known experimental paradigm, in which a participant can experience a rubber hand as their own [3], a sensation that has been termed *ownership*. Many variations of this illusion, including supernumerary hand illusions, virtual hand illusions, and virtual body illusions in reality, virtual reality (VR) and augmented reality (AR), show similar findings. Typically the results of RHI experiments show large individual differences: some participants report experiencing ownership to a high degree whereas others report the opposite. A few previous RHI studies have shown that such differences may be explained by variables such as personality traits [12, 26] and proneness to certain mental disorders [2, 4, 8]. Other works have been dedicated to explaining which processes lead to these embodiment experiences; see [23] for a review of existing models. These models generally structure various neurocognitive bottom-up and top-down processes, but do not extensively describe how the aforementioned variables fit into these structurings.

These existing models also do not differentiate between mediated (VR and AR) and non-mediated versions of the illusion. However, if we suggest that these experiences are indeed fundamentally different, by the fact that one *knows* the experience is mediated, then it would follow that the model for the mediated version may have components other than those related to the widely accepted bottom-up and top-down processes, namely those specific to media use. To gain an idea on how such a media-based ownership model may take form, we turn to a concept that is very close to ownership in VR and AR research: *presence*. Often referred to as the sense of "being there", presence is typically used to describe a desired outcome or quality measure of a virtual environment, and has shown to have close connections to ownership and embodiment in general [9, 16, 19]. In their extensive overview, Lombard and Ditton describe media user variables that can effect the generation of presence, such as suspension of disbelief, experience with the medium, and personality [11]. Similar factors are scarcely mentioned in the context of ownership, although Stone et al. informally describe a form of suspension of disbelief: "a fundamental difference between 'feeling' and 'knowing' during the rubber hand illusion that must be overcome to experience the illusion. For example, in the RHI, the individual must override the knowledge that the rubber hand is not his in order to surrender to the feeling that it is, encouraging the incorporation of a foreign hand into the sense of the bodily self" [22].

The goal of our paper is to propose a two-level processing model for mediated instances of the RHI that accounts for commonly occurring variation across participants, by considering the illusion not only a neurocognitive phenomenon in the first level, but also a media experience in itself in the second level. By doing so, we incorporate the influence of user characteristics as an explicit component of the model, while further building on existing bottom-up and top-down based models. We first examine existing ownership models, and then propose a new model, taking inspiration from an existing presence model. Finally, we describe an experiment to empirically analyze the new model.

2 EXISTING OWNERSHIP MODELS

In a comprehensive review, Tsakiris categorizes a number of existing neurocognitive models [23]. In the following, we shall discuss the main categories of these models. First, there are models that rely on a single bottom-up processing stage. For example, Armel and Ramachandran compared visuotactile synchronity, visibility of the real hand, presence of the fake hand, and distance between the body and the fake hand when measuring ownership of the fake hand [1]. Experienced ownership was higher for synchronous stimulation, but also high in cases that negated a learned representation of the body. To explain these peculiar results, the authors attest a Bayesian perceptual learning model: concurrent visuotactile stimulation, i.e. statistical correlations across modalities, constructs a changed body scheme.

Second, there are models that rely on two levels: a bottom-up processing level, interacting with a top-down processing level. An example of this can be found in the study by Tsakiris and Haggard [24]. They found that visuotactile correlation drove the illusion as a necessary condition, but not sufficient, as shown by conditions including a stick rather than hand, and incorrectly positioned fake hands. Therefore, the illusion must be modulated by top-down influences originating from the known body representation. Another example is the model by Maselli and Slater [13]. In a series of

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virtual reality full body illusion experiments, together with results from limb studies performed on monkeys, they suggest that the first step of the model is driven by bimodal visuoproprioceptive neurons, where a first person perspective is a necessary factor for eliciting an ownership illusion. This supports the theory that top-down mechanisms modulate the processing of the bottom-up stimuli. Interestingly, visuotactile correlation was not found to be a driver of the illusion. According to their experiments, other forms of multimodal stimulation can further strengthen the sense of ownership.

These models by nature describe very generally which processes occur for the average participant of an RHI, meaning they do not explicitly discuss variations in experienced ownership across participants in a single experiment. This variation is a common phenomenon, and most conclusions are drawn on the mean or medians of certain subjective and objective measures. One may expect stimulation incongruence to be such a source of variation, since incongruence acceptance thresholds vary naturally across people; however, in RHI setups the differences between the congruent/synchronous and incongruence/asynchronous conditions are intentionally chosen as subtantially large, such that these thresholds should not interfere. To put this informally, the setup is chosen in such a way that the participant is aware and has no doubt that the incongruent/asynchronous condition is indeed *not* congruent/synchronous.

There are some studies that have focused on specific participant characteristics that can explain the variation, such as sensory and hypnotic suggestibility [12, 26], but it is not always discussed how this would affect our knowledge of existing ownership models. A few exceptions exist, such as the study by Haans et al., where individual differences in ownership experience is suggested to be explained by a single ability, namely cognitive demand: a person has the ability to activate certain cognitive processes to allow the acceptance of a new body model [5]. Other exceptions include studies on (proneness to) certain mental disorders, where it is often suggested that these patients have abnormalities in self-representations or weaker pre-existing body representations [2, 4, 8], referring to a change at the top-down processing level. These studies have moreover focused on groups of participants that tend to experience higher degrees of ownership than others. The opposite group also exists, namely those participants that never experience ownership, even in conditions with the most 'correct' circumstances. Some studies then require exclusion of these participants, because they can not be used to explain the specific researched phenomena [6, 7, 14]. In the following section, we propose that a large portion of these individual differences arise outside of the bottom-up and top-down processing mechanisms described here, but occur afterwards as a result of perceptual hypothesis testing, where certain user variables related to the media use come into play.

3 Proposed Model

The motivation for making hypothesis testing explicit in our proposed model originates from another phenomenon in media experiences, which we will explain in the following. Considering the growing occurrence of RHI experiments in mediated conditions, i.e. in VR and AR, an exploration of factors that may influence media experiences is indeed sensible. To this end, we turn to an experience that is often referred to in the same contexts as embodiment, namely presence. Presence has been defined in many different ways, one common definition referring to spatial presence, or "the sense of being there". Various definitions have been shown to be quantitatively correlated to the concept of ownership, for example through the concept of self-location (the experience of the self being located in a body [9]), and through self-presence (a psychological state in which virtual self/selves are experienced as the actual self in either sensory or nonsensory ways [10]) [16].

One comprehensive model of spatial presence that we highlight here is presented by Wirth et al. [28]. They describe how in a first

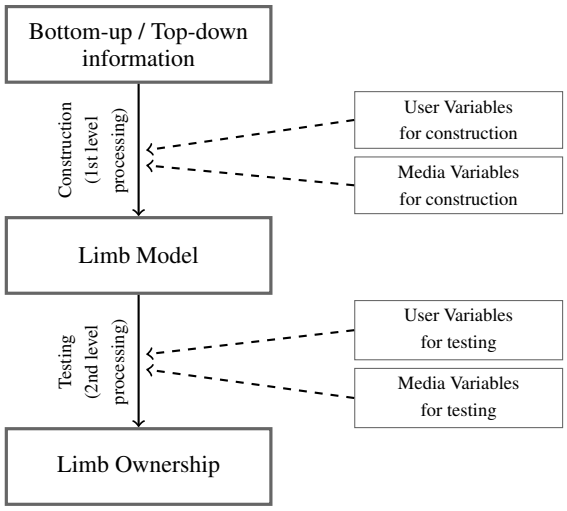

Figure 1: Illustration of the proposed two-level model for ownership. The first level concerns processing of bottom-up and top-down influences and results in the construction of a tentative limb model. The second level concerns testing of the hypothesis whether the limb is owned. Both levels are influenced by user and media variables.

level, individuals construct a 'spatial situation model' (SSM) for the mediated space. Both involuntary attention allocation, influenced by media factors, and controlled attention allocation, influenced by user characteristics, are key in the construction of the SSM. Bottom-up spatial cues are accordingly continuously collected, and are then supplemented by further top-down prior knowledge of spatial environments. With these cues the user evaluates and, if necessary, updates the SSM. The purpose of the first level is to deal with the question: "Is this a room?" In the second level, the purpose is to deal with the question: "Am I located in this room?" Users construct worlds for both the real and mediated environments within egocentric reference frames, and the frame with which the user aligns their actions becomes the primary ego reference frame. If the user repeatedly accepts the mediated frame as the primary ego reference frame, according to the theory of perceptual hypotheses, the user experiences spatial presence. Various media factors make the mediated frame more or less plausible, but of importance are in particular the user variables involvement and suspension of disbelief, and the user trait absorption. The novelty of this model in the context of spatial presence is in the second level, where not only there is an explicit hypothesis testing step (as is also described in [20]), but also importantly which user variables and traits can influence this testing. In the following we explain how we propose to apply this knowledge in a model for ownership, specifically in mediated conditions. See Figure 1 for an illustration.

Starting with bottom-up and top-down information as input, the first level processing outputs a tentative limb model. In this paper, we will not go into detail regarding the structuring of the first level processing. However, we will state that it can be influenced by certain user and media variables. For example, (proneness to) certain mental disorders, as discussed in Section 2, could belong to this group of *user variables for construction*. For RHI experiments, certain user variables are always considered, such as age and gender, and for mediated versions, the knowledge of/experience with the technology, but do not typically explain the large individual differences in the experimental results. According to the previously described spatial presence model, these particular variables are of importance in the context of controlled attention allocation, and not explicitly in the context of hypothesis testing. In this proposed model, we do not explicitly attribute the construction of the tentative model to attention allocation alone, and thus cannot solely place age and gender in the

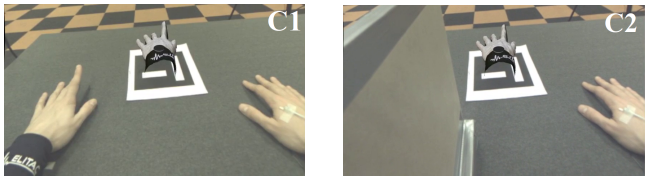

Figure 2: Participant's view during the previous study in (left) condition *C1* with both real hands visible, a supernumerary virtual left hand, (right) *C2* with the right real hand and a virtual left hand visible. Both conditions have with synchronous visuo-tactile and visuo-motor synchrony. Images from [17].

user variables for construction category. Regarding *media variables for construction*, one could imagine that technological properties such as image quality or system fidelity could play a role here. In the second level, the tentative limb model is taken as a hypothesis for perceptual hypothesis testing. This processing could again be influenced by certain user and media variables, and the outcome, after repeated acceptance of the tentative model, is then ownership.

What this ownership model so far does not describe is what kind of user and media variables could influence the second level processing. As this level is novel and not previously considered in ownership research, we again turn to presence for possible indications of variables. Using the suggestions provided by Wirth et al., we see that indeed two ownership studies have informally suggested the influence of suspension of disbelief, that is, "not paying attention to external stimuli and internal cognitions that (might) distract from the enjoyment of the mediated story and environment" [28]. Specifically, Stone et al. describes a participant having to override the knowledge the fake arm is not his and surrender to the feeling that it is, as mentioned in Section 1. Rosa et al. in the Discussion of their AR hand ownership experiment describe that possibly, in order to accept virtual limbs, a "barrier of belief" must be passed and there must be "a priori willingness" towards the experience [17]. To date, there is one questionnaire to measure this, namely the MEC-SPQ, developed by the same team as the spatial presence model [25]. Unfortunately, this questionnaire has not been empirically applied outside of presence, and it's influence outside of this concept is only informally suggested. Therefore, using this questionnaire in the context of ownership may be inappropriate, and is not pursued in this paper.

The presence study by Witmer and Singer [30] points to another possible variable; the authors found that immersive tendency, one's capability to become immersed, was a predictor of presence. Other studies have explored immersive tendency as a predictor to other experiences besides presence, but so far with mixed results. For example, Quesnel and Riecke found no effect of immersive tendency on awe ratings or goose bumps [15]. On the other hand, Siri et al. found that for digital works of art, individuals with high immersive tendency rate colors as less intense than those with low tendency, thus affecting the evaluation of digital pieces of art [18]. Lastly, Weibel, Wissmath and Mast found a correlation between specific personality traits and immersive tendency [27].

As a first step towards empirically examining individual differences in mediated RHI experiments, as a consequence of the *user variables for testing*, we present an experiment to examine the possible relation between a participant's immersive tendency and their susceptibility to the experience of ownership in AR. We hypothesize that there is a positive relation between one's immersive tendency and experienced ownership.

4 Previous Hand Ownership Study

The experiment presented in this paper is a follow up to an existing study performed by Rosa et al. [17]. Ownership data from this existing study was obtained and related to newly collected immersive tendency data from the same participants. The existing study was therefore not replicated here. The local ethical review board approved our study.

Q	Question
IT1	Do you ever become so involved in a movie that you are not aware of things happening around you?
IT2	Do you ever become so involved in a TV program or book that people have problems getting your attention?
IT3	Do you ever become so involved in a daydream that you are not aware of things happening around you?
IT4	Do you ever have dreams that are so real that you feel disoriented?
IT5	Have you ever gotten scared by something happening on a TV show or in a movie?
IT6	Have you ever remained apprehensive or fearful long after watching a scary movie?
IT7	How good are you at blocking out external distractors when you are involved in something?
IT8	Have you ever gotten excited during a chase or fight scene on TV or in the movies?
IT9	Do you ever become so involved in doing something that you lose all track of time?

Table 1: Shortened version of the Immersive Tendency Questionnaire, ITQ-short, by Weibel, Wissmath and Mast [27].

We shall first provide a summary of the study by Rosa et al. in this section; the experiment performed in our study is presented in the next section. The aim of the study by Rosa et al. was to examine the feasibility of the augmented reality supernumerary hand illusion together with its perceptual-motoric requirements [17]. Results were gathered on experiences of ownership, agency and location of a third virtual hand while the real hands were still visually present. Six conditions were tested on 30 subjects in a within-subjects design, where the conditions varied in number of visible real hands, visual-tactile (VT) synchrony (a virtual smartwatch visibly flashed and vibrated synchronously/asynchronously), and visual-motor (VM) synchrony (the virtual hand moved synchronously/asynchronously to the real hand). The two conditions relevant for the current study are:

C1: 2 real + 1 virtual left hand, synch. VT, synch. VM
C2: 1 real right + 1 virtual left hand, synch. VT, synch. VM

The virtual left hand was positioned in front of the participant (see Figure 2), and the participant would experience a certain stimulation according to the condition specifications for 2 minutes. After these 2 minutes the virtual hand was threatened with a virtual knife and skin conductance responses (SCRs) were recorded. For each condition, subjective responses were collected on ownership, agency and hand-location, all on a 7-point Likert scale. In particular, the direct ownership question was asked:

O1. It seemed as if the virtual hand was my hand.

A video see-through head-mounted display, consisting of an HTC Vive and OvrVision Pro, was used throughout the experiment. Visual-motor stimulation was registered through a Microsoft Kinect for Windows, and visual-tactile stimulation provided through an Elitac Tactile Display. The experiment was created in Unity 5.5.0.

The authors found that according to the subjective responses, experiences of ownership, agency and a changed self-location occurred for certain synchronous conditions. For ownership in particular, conditions with both synchronous VT and synchronous VM feedback, i.e. *C1* and *C2*, resulted in an experience of ownership. SCRs did not show the same effects, but instead followed a habituation effect.

5 Experiment

In the previous study, the authors did not further investigate the cause of the individual differences found in the ownership results. They ex-

plain that some participants commented that they consciously knew the scenario was not real, despite it looking real, thus suggesting that whether an experience of ownership occurs may be an active decision of the participant. They suggest that some participants may be more willing than others to accept this fictive scenario. The purpose of the current experiment is to examine the existence of a relation between experienced ownership and a variable that was presented in the proposed model in Section 3, namely immersive tendency.

5.1 Participants

Of the 30 previous participants, 2 no longer had the same contact information and could not be reached; 23 of the remaining participants consented to take part; age mean 22.3, s.d. 2.3 (at the time of the previous study); 5 female, 18 male. It was confirmed that age and sex did not effect the results of this study.

5.2 Material

A shortened version of the original Immersive Tendency Questionnaire (ITQ) by Witmer and Singer was used [30], which is based on the analysis performed by Weibel, Wissmath and Mast [27] (from hereon ITQ-short), see Table 1. These questions were answered on a 5-point Likert scale. We did not use the original long version because it had been constructed on a theoretical basis and was lacking statistical validation.

Regarding the ownership data, we used part of the subjective data from [17], namely the responses to the most direct ownership question "It seemed as if the virtual hand was my hand." (O1) for the conditions *C1* and *C2*. These conditions were chosen because they are theorized to create a sense of ownership, and the results showed individual differences between participants; that is, they lead to positive and negative ownership responses. These two conditions were not statistically significantly different for the original 30 participants in the previous study.

We did not include the results of the four other conditions from the previous study, because those results either showed consistently weak ownership without individual differences, or there was no ownership at all. The SCR data was also not included because the results may have been driven by a habituation effect. Also, results from questions on agency, self-location, and related ownership experiences were not included here. Immersive tendency data was also collected for the participants of a different previous body ownership study, also by Rosa et al. [16]. This data was finally not used due to a low response rate to the ITQ-short, and because after filtering for these respondents the data no longer contained both positive and negative results, making it inadequate for inspecting individual differences.

5.3 Procedure

All previous participants were sent an information and consent letter approximately 17 months after the execution of the experiment by Rosa et al. [17]. If they consented, they were digitally sent the ITQ-short one week later, that they could fill in in their own time outside of the laboratory. This approach was chosen to ensure a high rate of reparticipation. Each participant could take part in a raffle for one 10 euro gift card to an online department store. The questionnaire was closed nine days after sending, and no more responses were recorded. All participants who consented responded within this time. The raffle was awarded 5 days after the questionnaire was closed.

6 Results

All responses to the ownership questions and immersive tendency questions were ordinal, so an ordinal regression was performed in R with factor C (condition; 2 levels) and ordered factor IT (immersive tendency median; 3 levels since only values 2, 3, and 4 occurred) without interaction variable. The assumption of proportional odds

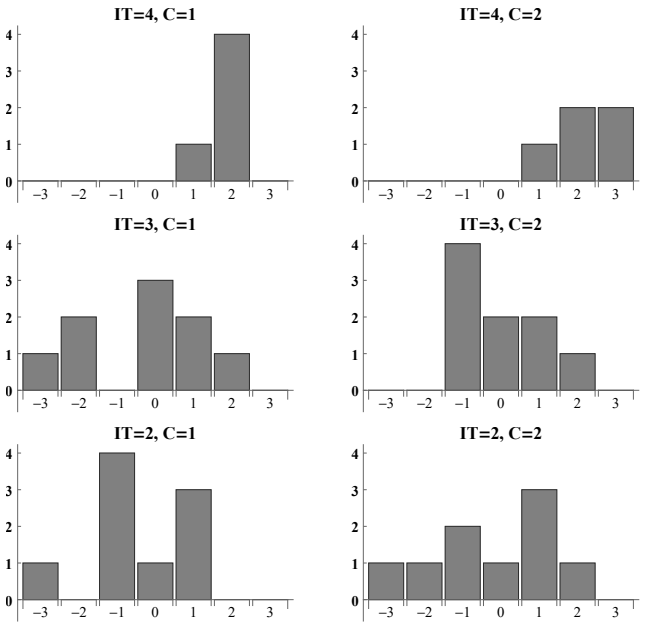

Figure 3: Histograms of the ownership responses, categorized by immersive tendency (*IT*) and condition (*C*). For simplicity, the 7-point Likert scale ownership data *strongly disagree , . . . , strongly agree* is converted to -3 , . . . , 3. The main effect over *IT* can be seen through the more negative responses for *IT=2*, the middle responses for *IT=3*, and more positive responses for *IT=4*.

was upheld for C ($p = 0.8104$) and IT ($p = 0.0718$). The model was significant ($\chi^2(3) = 14.298, p = 0.0025$), Nagelkerke pseudo $R^2 = 0.276$. The main effect over IT was statistically significant ($\chi^2(2) = 12.8166, p = 0.0016$) with parameter estimate $\beta = 3.3648$ ($z = 3.119, p = 0.00182$), whereas the main effect over C was not ($\chi^2(1) = 1.4673, p = 0.2258$). The IT parameter estimate indicates that if a participant shows one unit increase in IT (e.g. from 2 to 3), then we expect a 3.3648 increase in the ordered log odds of experiencing a higher level of ownership, assuming all other variables in the model are held constant. The post-hoc tests with Tukey adjustment showed that IT=2 (ownership median= -0.5) and IT=3 (median= 0) differed significantly from IT=4 (median= 2) ($p < 0.05$). See Figure 3 for an overview of the data.

7 Discussion

The goal of our paper is to propose a two-level processing model for mediated ownership. The first level processing concerns construction of a tentative limb model, and the second concerns testing of this tentative model. Construction may be influenced by previously studied factors such as proneness to mental disorders and system fidelity. Testing, on the other hand, is a novel feature in ownership models, thus immersive tendency was suggested as a user variable for testing. The influence of this variable was confirmed in an augmented reality hand illusion experiment, showing that participants with higher immersive tendency experienced a higher degree of ownership over the virtual hand. Our findings contribute to, on the one hand, research on the processes underlying the RHI, and on the other, the growing body of work confirming that individual differences that occur in (variants of) RHI studies are, at least in part, associated to certain personality traits.

As highlighted in Section 3, the novelty of the proposed model is in the second level processing, where after a tentative hand model has been formed, the hypothesis of whether this model could be *my* hand is explicitly tested, and ownership could arise. Here we explain the differences and similarities between this proposed model

and existing ownership models. In both of the models proposed by Tsakiris and Haggard [24] and Maselli and Slater [13], bottom-up stimuli are only registered in the parietal area 5 neurons when there is enough multimodal congruence between the fake and the real hand. If there is then also affirmation from top-down influences, this population of neurons is activated, and can result in the sense of ownership. In these cases, there is no differentiation between the positive registration of the stimuli, while considering existing self-representations, and the development of the sense of ownership. Putting this in terms of our proposed model, this would mean that a new hand model is formed as ownership occurs. According to Maselli and Slater, ownership would not occur when the top-down influences are incorrect, even when the bottom-up stimuli are correct. Again putting this in terms of our proposed model, this becomes an interesting case: is a hand model formed, but without ownership, or is there no model and also no ownership? We argue that the former is the case: even in experimental conditions where there is no ownership but bottom-up stimuli are congruent, participants are always aware of a suggested hand model, and simply do not accept it due to other inconsistencies, and possibly other user variables. It should be pointed out that we are not showing that these existing models are incorrect. Indeed, we agree that in our proposed model the bottom-up and top-down processing occurs at least similarly to what is described in existing models. Instead, we make one particular processing level explicit, that occurs implicitly in existing models. Therefore, previous results that are explained by these existing models should also be explained by our proposed model.

Evidently, more research is required to confirm every aspect of the proposed ownership model, such as possible user and media variables for testing. For example, in Section 3, suspension of disbelief was suggested as a possible influence of hand ownership, based on the spatial presence model by Wirth et al. [28]. We suggest that in AR this influence becomes more critical than in say VR, since the barrier that must be overridden may be even larger, due to the current obvious disparity between real and virtual. That is, the virtual hand could be considered even less real than a prosthetic hand. Wirth et al. further suggested that involvement, i.e. disposition for total attention, and absorption, i.e. emotional engagement with a media experience, could influence spatial presence; this was later confirmed as a positive interaction effect on spatial presence [29]. While not directly measured here, it should be mentioned that Weibel, Wissmath and Mast identified emotional involvement, i.e. emotional reactions during media use, and absorption, i.e. focused attention and distractor blocking, as the two dimensions of their ITQ-short [27]. Although not measured through the same set of questions, the highly overlapping definitions suggest that both cases measure the same concept. Future research can further investigate these variables and their relations.

A few points of discussion concerning the generalization of the proposed model are necessary. Firstly, it is still an open question whether ownership of a limb and a body are comparable phenomena, and to date there is no empirical study comparing the two. Both types of illusions typically use analogous (multisensory) stimulation and find resembling results, suggesting similar underlying neurocognitive processes. Thus here we do not reject the possibility of the model being applicable to both limb and body ownership in mediated conditions. We refer the reader to the discussions by Tsakiris [23] and Slater et al. [21] for more information. Secondly, the motive to make the second level processing for hypothesis testing explicit in the proposed model was the distinction between nonmediated (i.e. traditional) and mediated (i.e. in VR and AR) hand illusions. Immersive tendency was then confirmed as a possible *user variable for testing* in a mediated (AR) setting. However, we cannot rule out that this variable could play a role in nonmediated RHI settings as well. Possibly, for many participants the entire RHI experience, taking into account this takes place in a strict experimental setup, could be experienced as something so distant from daily life that it in itself is a media experience. Indeed, a study by Ijsselsteijn, de Kort and Haans compared ownership of fake and virtual hands in reality, VR (here regarded as AR with more virtuality) and mixed reality (AR with less virtuality) [6]. The authors found ownership in all three conditions, with a high degree of ownership in the nonmediated case, and low in both mediated conditions. They explained that this could be due to the inferior quality of the mediated conditions. In the context of generalizing our proposed model, *if* individual differences in that study were correlated with immersive tendency, the variation in each condition would remain constant. Although not formally tested, it seems that the individual differences in all questions are indeed equal, given the conditions were performed in a within-subjects manner (see Figure 2 from [6]; note that the Likert scales were treated as continuous, thus the variation is portrayed by standard errors and the absolute differences are not reported).

Finally, a remark must be made regarding a possible limitation in our experiment. First, there is no control for an individual's compliance regarding questionnaires. Another ordinal regression including asynchronous conditions that did not result in ownership (*C4* and *C6* from the previous study, thus 4 levels of *C*), the immersive tendency median and possible interaction, shows only statistically significant main effects and no interaction effect. This confirms that participants with high immersive tendency always respond higher than those with low tendency, but not necessarily strongly positive. Inspection of the data confirms that this was not the case: of the five participants who responded positively in both *C1* and *C2* (i.e. 1,2,3 in scale -3...3) *and* had high immersive tendency, all had lower responses for both *C4* and *C6*, where the three highest scoring participants had only weak positive results (i.e. 1 in scale -3...3). Second, because the current study was performed 17 months after the previous study, it is not certain whether the participants retained the same level of immersive tendency as they would have had during the previous study; studies on personality changes as an effect of age typically examine a period of decades (see for example [31]). The reason for still performing the current study as a follow up was that it was desirable to build on a published study that indeed found individual differences in experienced ownership. As the current study suggests that ownership results are indeed dependent on the chosen participants, execution of a new RHI based study would not guarantee the presence of individual differences.

8 Conclusion

In this paper, we proposed a new two-level processing model for virtual hand ownership in mediated conditions. The first level concerns the construction of a tentative hand model, and the second level the testing of the hypothesis: "Is this my hand?" Both levels are influenced by possibly overlapping user and media variables. In an experiment, we show that a participant's immersive tendency could be such a user variable, by showing that experienced ownership of a virtual hand in augmented reality was higher for participants with a higher immersive tendency. This variable may therefore partly explain often occurring individual differences in RHI studies. This paper contributes to two connected growing areas of research. Firstly, we have provided new views on the underlying mechanisms of ownership, by expanding upon existing models. We suggest that besides immersive tendency, suspension of disbelief is another likely influencing user variable. We explain that it may be possible to generalize this model to nonmediated conditions, and to both limbs and bodies. Secondly, we have shed light on how certain personality traits can result in large individual differences in RHI studies, specifically one related to media use, and therefore must be made explicit in ownership models. We encourage future research to further explore other personality traits in the context of the RHI.

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