Effects of Hand Appearance and Behaviour on the Rubber Hand Illusion in Virtual Reality

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HCI-E MSc Final Project Report 2017
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ABSTRACT
The rubber hand illusion is a classic psychological experiment in which the body's self-awareness of a hand can be transferred to an inanimate object. After a period where an association between the real hand and a fake hand is built, the extent to which a participant believes that the fake hand is part of their body is measured through a stress response to a threat. This illusion has successfully been induced with virtual reality (VR) through the use of head-mounted displays (HMDs), which cover the user's field of view entirely, and the use of virtual hands. Using motion tracked controllers, similar feelings of hand ownership to that of the rubber hand illusion can be induced. In an attempt to analyse the role of hand appearance and behaviour on this effect, the following experiment had participants complete a series of tasks with one of three virtual hands: a static realistic hand, an arrow, or a realistic hand which is hidden when objects are grasped, substituting the hand with a stand-in object. This is motivated by a similar mechanic in the game *Job Simulator*. After the virtual hand was "threatened", feelings of hand presence and the degree to which the rubber hand illusion was induced were measured through skin conductance measures and by questionnaire. While unexpected confounding variables impacted the significant of results, these variables served to inform and highlight the role of hand behaviour within VR. Visual discrepancies in how a virtual hand interacts with an environment were found to negatively impact feelings of immersion and hand presence, and should be carefully considered when designing VR experiences.

Author Keywords
Rubber hand illusion; virtual reality; hand presence; hand ownership; galvanic skin response.

ACM Classification Keywords
H.5.1 *Multimedia Information Systems:* Artificial, augmented, and virtual realities.

MSC HCI-E FINAL PROJECT REPORT
Project report submitted in part fulfilment of the requirements for the degree of Master of Science (Human-Computer Interaction with Ergonomics) in the Faculty of Brain Sciences, University College London, 2017.

MSc Contribution Type
Empirical

1. INTRODUCTION

The increase in availability of consumer virtual reality (VR) headsets in recent years has resulted in a growth of interest and market for VR products. 2016 saw the release of several major consumer devices, and as VR headsets become increasingly more common in households, so do the number of games and interactive experiences being developed for these platforms. A key aspect to the efficacy of VR systems is to induce feelings of immersion with the user, by making the virtual environment seem real or believable [19]. As the user's body and environment are fully obscured from view when using head-mounted displays (HMDs), immersion is important to build a sense of engagement within the virtual environment. Alongside immersion, the term 'presence' is used frequently in VR research in reference to the sense of self or feelings of "being there" [23], and is often associated with body awareness and ownership.

Many VR experiences that utilise HMDs include a representation of the user's body, particularly if the experience requires a degree of interactivity or participation from the user. These self-avatars can vary from full limb representations, to simply the display of hands. The use of self-avatars has been found to contribute greatly to feelings of immersion [24], however the extent to which they interact with an environment is as important a factor as their appearance. If a limb seen in VR does not behave in a realistic manner, this can break immersion [21]. Current technical limitations with body tracking and object collision [2] often mean that a compromise between realism and mechanics must be found.

This paper investigates how different methods of displaying a self-avatar in VR affect the immersion and feelings of body ownership experienced by the user, with attention to the visuals and behaviour of a virtual hand and its interaction with a virtual environment.

Previous research into presence and body ownership in VR [27] has examined the role of proprioception in how a user builds an association between their own body, and the self-avatar seen within a virtual environment. As many consumer VR hand controllers include tracking features, the placement and position of a real hand can be directly mapped to a virtual hand; on account of these features, variations of classic proprioceptive experiments such as the rubber hand illusion [8] can be carried out in VR. This illusion is typically induced by delivering simultaneous stimuli to a participant's real hand and a visible fake hand, building an association that leads to the participant feeling as though the fake hand is part of their own body. This demonstrates that a sense of body ownership can be transferred to objects outside of the body, under certain circumstances.

The classic rubber hand illusion has been successfully induced in CAVE VR environments using traditional touch-based stimuli [16]. Yuan and Steed [27] also demonstrated that a very similar illusion can be induced with HMD VR systems by instead using accurate hand tracking alongside completion of tasks to build an association between the real and virtual hands. This study found that feelings of body ownership and presence were felt most strongly when the virtual hand looked realistic, which has since been supported by further research into the appearance of self-avatar hands [12].

Based on the study run by Yuan and Steed, the following experiment investigates how the behaviour of a virtual hand, alongside appearance, relates to the induction of the rubber hand illusion. This research is motivated by mechanics deployed in games such as *Job Simulator* (2016), in which the visible hand is hidden when an object in the environment is picked up. The stand-in object retains the same degree of placement and movement as the hand, in order to retain hand presence and immersion whilst keeping the object unobscured and clearly visible. This experiment introduces stand-in objects for a virtual hand in a similar method during the completion of interactive tasks in order to examine their impact on hand presence and the ability to induce the rubber hand illusion.

It is expected that a degree of hand presence will be reported due to the realistic appearance of the hand, but it is unclear the extent of how this presence may be affected by the addition of stand-in objects for the hand during the completion of tasks. Regardless of the direction of any discernible effect, results of this research may be beneficial to the design of self-avatar visuals and gameplay mechanics for future VR games and interactive experiences.

2. RELATED WORK

2.1. Body ownership in VR

Body ownership in VR has been studied since the inception of the technology, with focus on head mounted displays (HMDs) in particular; as the real body is entirely obscured from vision while wearing a HMD, immersion is typically more profound [10]. The use of self-avatars to display the user's body or body parts while in HMD VR gives both context to the placement of the self within a virtual environment, as well as oftentimes acting as a way to interact with a VR experience or game. In cases where body tracking allows for direct mapping between the real body and virtual counterparts (ie. controllers with hand tracking such as the Oculus Touch or Vive controller, or tracked wearable gloves [25, 13]), feelings of presence are fostered through the direct match between real-world and in-game movements [22].

The term 'hand presence' in reference to VR was popularised by Oculus, particularly through the announcement and release of the Oculus Touch controller [4]. While development continues for more diverse body tracking for commercial VR, hands remain to be the most commonly tracked body part (alongside the head) in current releases. The use of inverse kinematics to generate a wider range of movements with the use of a limited number of tracking points [6, 18] has proven useful in expanding the range of self-avatars, but in some cases has broken immersion due to inaccurate or unnatural tracking [2, 18]. As such, visible hands seen in many commercial VR games appear to be disembodied, without an attached arm.

2.2. 'Tomato Presence' in *Job Simulator*

As consumer units become more readily available, so does the selection of games and entertainment built specifically for VR. In regards to hand ownership and visuals, various games have deployed different systems in order to best fit their play style and structure: *Job Simulator*, released in 2016 by Owlchemy Labs, requires the player to pick up and interact with objects within an environment at a quick pace. In order to not obscure objects that have been picked up from view, and to ensure that the visible hand does not interpenetrate or collide with objects in an unnatural way, the game hides the hand visual while grasping an object. The stand-in object continues to have "perfect rotation and perfect position" [2], and is tracked within the virtual space in the same manner as the visible hand, simply acting as a temporary stand-in object for the player's hand.

According to developers at Owlchemy Labs, players naturally adapt to this switch and do not lose sense of hand presence within the game, even when a stand-in object represents the hand [1] – so much so that during tests, 90% of players did not explicitly realise the disappearing nature

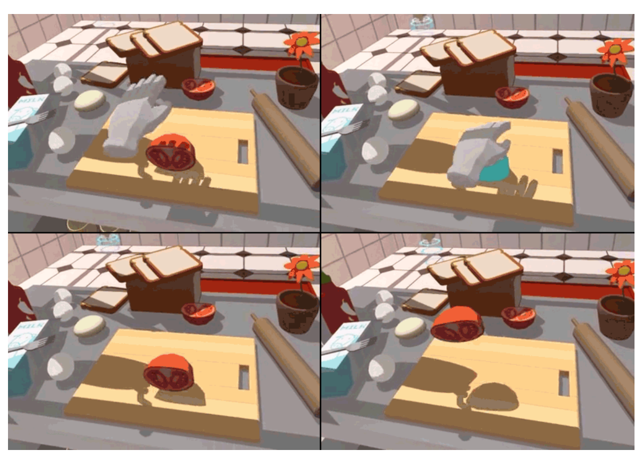

Figure 1. Picking up and moving an object in Job Simulator – note how the hand is hidden once the object is grasped

of the hand visual when playing *Job Simulator* for the first time [3]. The term ‘tomato presence’ was coined to describe this effect, in reference to the first object encountered in early builds of *Job Simulator*. While there has been an array of anecdotal observational data on ‘tomato presence’ [1, 2, 3], at current there has been little direct research into the phenomenon.

2.3. Rubber hand illusion

The rubber hand illusion is a classic experiment within the fields of psychology and neuroscience, in which the body’s self-awareness of a hand can be transferred to an inanimate object. First demonstrated by Botnivick and Cohen [8], the illusion is induced by hiding a participant’s real hand, and placing a fake hand in view. Both the real hand and fake hand are then tapped or stroked simultaneously. The sensation of touch, combined with the visual of the fake hand receiving the same touch, elicits an associative connection in which the participant may begin to believe that the fake hand is part of their body.

As shown in the original paper, this association can be measured through questionnaires, as well as a series of tasks asking the participant to place a marker where they believe their hand is, but in later studies it has successfully been tested by measuring a stress response after threatening the fake hand [7]. Typically this is done through measuring skin conductance (often referred to as galvanic skin response, or GSR) through a sensor on the palm or finger, as an increase in sweat production from glands located on the hand are a physiological marker of arousal [7]. Skin conductance has shown to be a reliable measure when testing in VR, as while measuring heart rate has been found to potentially be a more accurate measure of arousal than skin conductance, it is only suited to experiments containing sufficiently stressful stimuli [14].

It has been suggested that the rubber hand illusion is possible with any object, regardless of how much it looks like a hand [7]. However, other literature has argued that the associated object must have some visual similarities with the real arm [26]. In regards to VR, this is supported by Yuan and Steed [27], who found that effects of the rubber hand illusion were diminished when the visible avatar hand resembled a more abstract arrow. Lin and Jörg [12] also found similar effects where the realism of a visible hand correlated with how strongly a body transfer illusion was measured.

As many VR systems use motion tracked controllers to mimic hand movements with in-game motion, completing simple tasks induces a similar association and feeling of hand ownership as seen during the rubber hand illusion [22]. Using this technique, experiences similar to the rubber hand illusion have successfully been replicated in VR. Participants in Yuan and Steed’s study [27] on immersive VR completed simple tasks while wearing a HMD that included a visible hand and arm. After a baseline period of approximately 3 minutes, a table lamp within the virtual environment fell directly onto the virtual hand, mimicking the “threat” often used to test the level of association during the rubber hand illusion. Stress responses measured by GSR, alongside a questionnaire, showed that participants experienced similar reactions and levels of hand presence to that of the rubber hand illusion. The iteration of the illusion seen in this study was named the “Immersion Virtual Reality (IVR) arm ownership illusion”.

3. EXPERIMENT DESIGN

3.1. Design

The design of the experiment is based on a similar study run by Yuan and Steed [27]. The most notable addition to this iteration is the inclusion of a condition in which the virtual hand is hidden when objects are grasped, which substitutes the hand with a stand-in object. This is primarily motivated by a similar mechanic in the game *Job Simulator*.

The experiment included three between-subject conditions, based on the appearance and behaviour of the virtual hand seen during the experiment: a realistic hand that remained visible at all times, a realistic hand that was hidden when objects were grasped, and an unrealistic arrow. The two dependant variables were a stress response measured through skin conductance, and feelings of hand presence determined by a questionnaire. Each condition ultimately contained 13 participants each.

3.1.1 Hypotheses

The initial hypothesis is that participants will experience hand presence and induction of the rubber hand illusion (also referred to in previous research as the “IVR arm ownership illusion” [27]) to a higher degree when a realistic hand is visible during the experiment, compared to when presented with the more abstract arrow. This is informed by findings from previous studies [27, 12]. The second hypothesis is that there will be an additional effect on these variables based on whether the visible realistic hand is hidden or not while grasping objects, however this remains a two-tailed hypothesis with no predetermined direction of effect. Therefore;

Hypothesis 1: Participants will experience hand presence and the rubber hand illusion to a higher degree when using a more realistic hand

Hypothesis 2: There will be an additional effect based on whether the visible hand is hidden or not while grasping objects (two-tailed).

3.2. Materials

3.2.1 Equipment

All software was run on a custom built PC consisting of a quad-core 3.40GHz Intel processor, 32GB main memory, and a GeForce GTX 1080 graphics card.

The VR application was designed in Unity, and was run on a consumer Oculus Rift headset. The Oculus Rift was chosen for the head-mounted display primarily based on the accompanying Oculus Touch controller. The position and

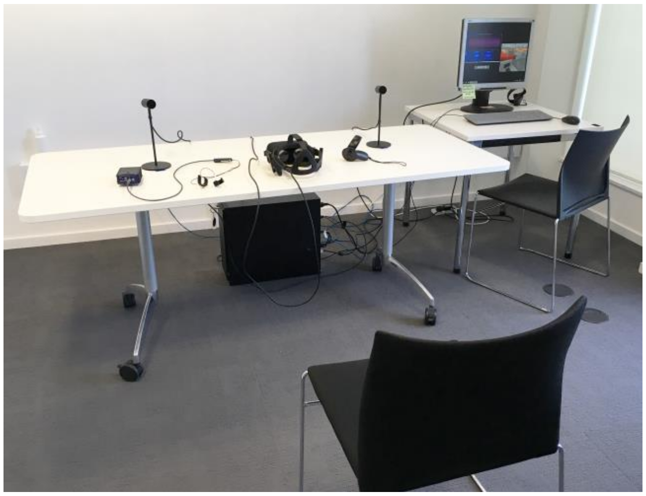

Figure 2. Setup of room and equipment.

Figure 3. Participant with Oculus Rift headset, Oculus Touch controller, and GSR sensor.

orientation of the hand when holding this controller was more appropriate for the actions required of this experiment than other devices, such as the Vive controller. Additionally, Oculus Touch features ‘hand trigger’ buttons [4] on the underside of the device where the palm of the hand rests. The function of picking up objects within the virtual environment was mapped to this trigger, in order for the action to feel as natural as possible. Participants used one Oculus Touch controller in their right hand. Two Oculus tracking sensors were placed on a table in front of participants to accurately track the headset and controller.

Skin conductance was measured with a GSR sensor connected to a NeXus-4 device, and recorded with the packaged BioTrace software. Data was recorded from each participant while they completed the VR portion of the experiment. The two sensors were placed on the index and middle finger of the left hand, and each participant was asked to keep that hand as still as possible on their lap during the VR portion of the experiment. Data was recorded and saved in BioTrace, which was running on the same computer as the main Unity experiment.

Open Broadcaster Software (OBS) was used to record the Unity and BioTrace screens side by side. As the time in which the sign falls varies by participant based on their speed of completion, this aided in pinpointing the precise timestamps used to later analyse the GSR data. Additionally, the ability to watch back POV footage for each participant at a later date assisted in giving context to observational data where needed.

3.2.3 VR Application

The VR application itself was programmed in Unity. The environment was built using assets from the Unity Asset Store, in particular ‘Supermarket Interior’ by Daniil Demchenko [5]. While the portrayal of a self-avatar was limited to the hand, chairs were placed within the environment to match with where the participant was seated in order to sustain a believable setting. The table in front of participants did not match the placement of surfaces within the VR environment, however; the shape of the Oculus Touch controllers combined with the actions required for the VR task meant that collision with the table would be frequent and could break immersion. Ambient supermarket sounds were played through the in-built headset headphones in order to provide further believability to the environment.

While previous research has found that the skin colour or shape of a hand does not impact the strength of the rubber hand illusion [9], the asset for the realistic hand was chosen to appear as neutral as possible in regards to skin colour or specific features. The hand was programmed to open and close as the participant grasped items. The model for the hand was also purchased from the Unity Asset Store.

The experiment consisted of three phases within the VR application. The first was located in a supermarket aisle, and was designed in order for each participant to spend as long as needed to adjust to the equipment and environment. The second consisted of a simple ‘Simon says’ game to introduce the mechanics of moving and grasping the virtual hand, and to begin to build association between the real and virtual hands. A row of four boxes in front of the participant would flash in sequence, for the participant to then grasp the same boxes in order. This phase was timed to end after 2 minutes. The third and final phase consisted of a supermarket checkout, where participants would pick up objects that came down a conveyer belt to their right, scan then through an area in front of them, and place them down on the counter to their left. During this phase, the 15th item scanned would trigger a sign to fall on the scanning area. As this is triggered during scanning, the aim is for it to collide with where the participant’s hand is. After this event, participants would scan two more items before conclusion of the experiment.

3.2.3 Questionnaire

The questionnaire used was a modified version of the 9-question survey introduced in Botvinick and Cohen's study [8], and later adapted for use with VR experiences [20, 27]. The wording of statements was changed in order to better suit this experiment, as well as the removal of a questions that were not relevant. While the statements therefore differed from previous applications, the structure remained similar; questions 1, 2, 6, and 7 served as control statements, while questions 3, 4, and 5 were the main statements used for analysis.

Other than ticking a "Yes" or "No" for the first question, Likert scales were used for each question. Participants indicated their level of agreement with each statement from a scale of 1 (Strongly Disagree) through to 4 (Neutral) and 7 (Strongly Agree).

Q1	*Before the experiment, had you ever used a virtual reality (VR) headset before?*
Q2	*During the experiment, how immersive did you find the virtual reality environment?*
Q3	*During the experiment, there were moments in which I felt as if the virtual hand/arrow was my real hand*
Q4	*During the experiment, it sometimes felt like I was holding the virtual objects in my real hand*
Q5	*During the experiment, it felt like my real hand was hit by the falling sign*
Q6	*During the experiment, there were moments in which the virtual hand looked like my own hand in some aspects*
Q7	*During the experiment, there were moments in which I had the sensation of having more than one right arm*

Table 1. The questionnaire on hand presence.

3.3. Participants

Fifty participants (28f, 22m) between the ages of 18 and 40 initially took part in the study in exchange for £6 in cash. Participants were recruited through fliers and online participant pool advertisements, and consisted mainly of undergraduate and graduate students from the London area. Eleven of these participants were removed from the study after data collection due to technical difficulties while running the experiment. This brought the number of included participants to 39 (23f, 16m), 13 per condition.

Of these participants, 69.2% reported that they had used a VR headset before, while the remaining 30.8% had not. Due to the practical design of the experiment, participants were required to be right handed.

3.4. Ethics

This study received full ethical approval from the UCLIC Research Department's Ethics Chair, as a department within University College London. Participants were given an information sheet to read and keep, alongside additional verbal clarification of the participant's right to withdraw. Each participant signed a consent form before any testing began. Once the experiment concluded, the design and aims of the study were fully explained by the researcher during a debrief session before each participant was paid.

3.5. Procedure

After reading an information sheet and signing a consent form, the equipment was explained to each participant. First, the Oculus Touch controller was placed in the right hand and the input buttons were explained. Next, once the Oculus Rift headset was properly secured and configured, participants were given as much time as necessary to adjust to the VR environment within the first phase of the application. The GSR sensors were placed on the index and middle fingers of the left hand, which was kept as still as possible on the participant's leg while seated.

The second phase of the experiment consisted of the 'Simon says' game, in which a series of four coloured boxes in front of the participant would flash in a three-part sequence. Participants were asked to reach out and grasp the boxes in the same order once a sequence ended. This phase allowed participants to grow accustomed to the movements and mechanics of the hand, alongside building hand presence [7, 27, 11]. The accuracy of recall was not important, and this phase timed out after 2 minutes.

The third phase placed the participant in front of a supermarket checkout. Items began to travel down a conveyer belt one at a time to the participant's right, in which they were asked to pick each item up and scan them through a black area in front of them, before placing them down on the counter to their left. As each item was successfully scanned, a beep would be heard through the headphones built into the headset. Some items required to be scanned through the appropriate area multiple times before the beep was heard, in order to keep the hand in the desired area for a longer period of time, and to encourage slower movements. The 15^{th} item scanned would trigger a sign (which was present throughout this phase as part of the environment) to fall over, colliding with the scanning area and where the hand would presumably be. While the time at which the sign falls varied, on average it falls after 3 minutes (SD = 24 sec) into this phase. If participants did not naturally continue scanning objects after this event, they were verbally prompted that it was okay to continue. After scanning two more objects, the phase ended and the headset and sensors were removed. Finally, participants completed the questionnaire on hand presence.

Figure 4. The 'Simon says' game, showing the series of boxes and the realistic hand grasping them.

Figure 5. The appearance of the realistic hand (visible) when grasping and moving an object.

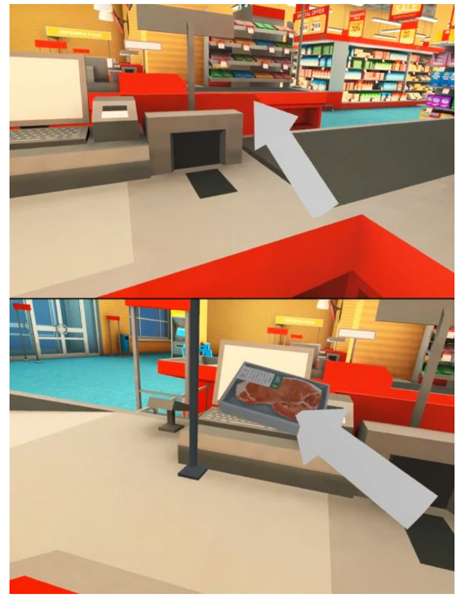

Figure 6. The appearance of the arrow hand when grasping and moving an object.

Figure 7. The appearance of the realistic hand (hidden) when grasping and moving an object.

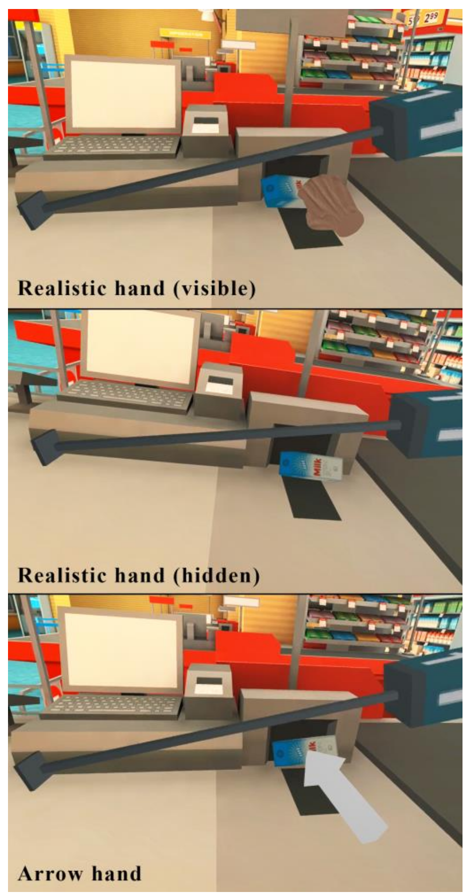

Figure 8. The moment in which the sign falls in each condition.

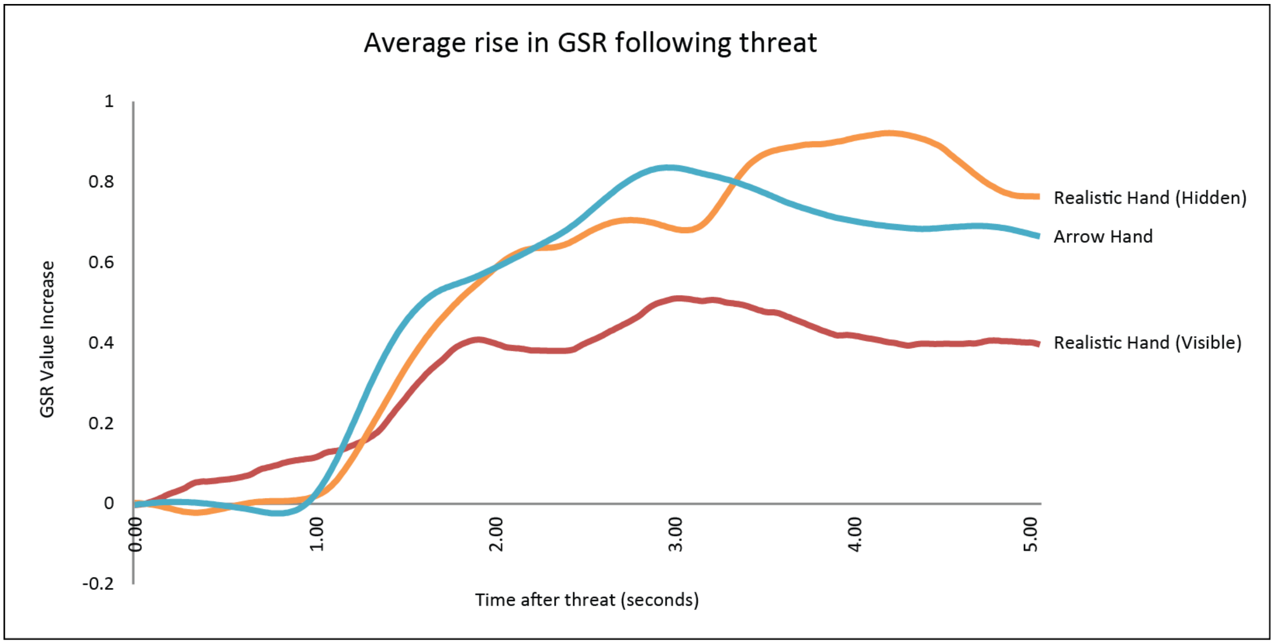

Figure 9. Graph showing average GSR responses (microsiemens) for each condition in the 5 seconds following the threat.

4. RESULTS

4.1. GSR

The 5 seconds following the threat (the sign falling on the hand) were analysed for each participant's GSR response. The average rise of GSR responses per condition during this time span is shown in Figure 9. The following analyses are based on the increase of each GSR value from a baseline taken for each participant 0.03 seconds before the sign falls. This was done in order to account for individual differences.

In order to determine if these differences were significant, a one-way Welch ANOVA was performed on the maximum rise in GSR value for each participant in the 5 seconds following the presentation of the threat. The means per condition are shown in Table (2). No homogeneity of variances was found, as shown by Levene's test for equality of variances (p = .096), and there were no statistically significant differences between any of the three conditions (Welch's $F(2, 21.728) = 1.294$, p = .295).

Condition	Mean (SEM)
Realistic Hand (Visible)	0.585 (0.21)
Realistic Hand (Hidden)	1.799 (0.50)
Arrow Hand	0.979 (0.58)

Table 2. Mean and standard error of the mean (SEM) for the maximum GSR rise of each condition.

4.2. Questionnaire

A Kruskal-Wallis H test was used to analyse the questionnaire data for significant differences between the three conditions of the realistic hand (visible) (n = 13), the realistic hand (hidden) (n = 13), and the arrow hand (n = 13). Distributions of scores were not normal (see figure 10), and there were no significant differences between conditions any of the main experimental statements (Q3, Q4, and Q5). There was also no significant difference for the majority of the control statements (Q2 and Q7), other than Q6. The arrow hand condition was rated significantly lower than both realistic hand conditions in regards to how much the virtual hand resembled the participants' real hand ($H(2)= 6.750$, p = .02).

4.3. Observations

After completion of the questionnaire, participants were debriefed by the researcher and asked for their thoughts on the study. Several participants commented that they were distracted by the realistic looking hands due to the distinctly veined texture on the back of the hand. These participants were also asked how they felt about the skin colour of the virtual hand, and none of them said that the difference in skin colour between the virtual hand and their own was noticeable or bothered them.

Two limitations of the hardware and software were highlighted by participants: when wearing the Oculus Rift headset, as well as with most current consumer headsets, a small gap at the bottom of the viewing area is present where the headset meets the nose. The outside world can sometimes be seen through this gap, and while users are typically distracted from it once a VR experience has begun, some participants commented that they could

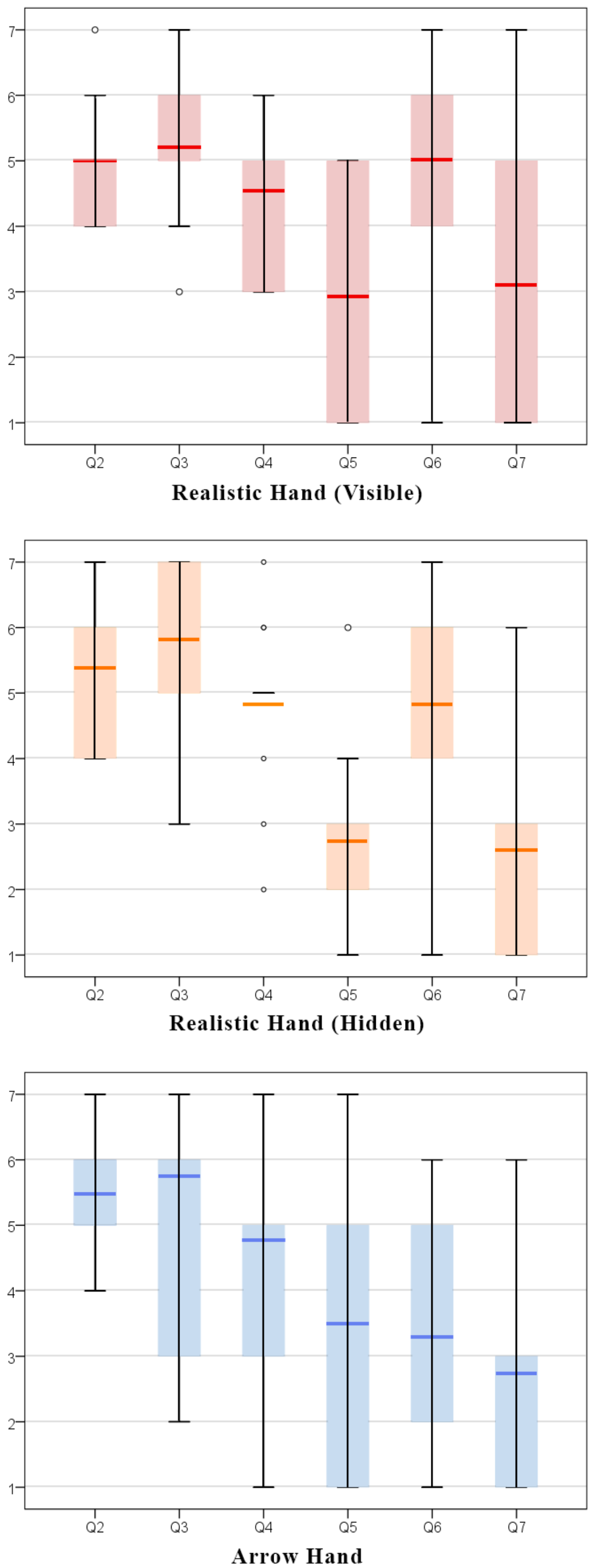

Figure 10. Boxplot showing questionnaire scores for the realistic hand (visible) condition. Bars indicate range, boxes indicate inter-quartile ranges, bold line indicates mean.

Figure 11. The realistic hand (visible) holding an object that is no longer fixed to the grasping point.

occasionally see their real arm while completing the experiment. Secondly, the way in which the static realistic hand grasped objects was sometimes inaccurate or realistic, in that the object occasionally drifted away from the grasping point of the visible hand (Figure 9). While this did not typically affect the ability for participants to complete the supermarket checkout phase of the experiment, some participants commented that it was noticeably strange.

Finally, another frequently mentioned topic was the feeling of wanting to lean on the counter during the supermarket checkout phase of the experiment, only for participants to realise that there was not a physical table present in the same space. The physical table in the room was pushed back in order to avoid collision with the Oculus Touch controllers, which could have led to the breaking of immersion.

5. DISCUSSION

For both the GSR measures and questionnaire scores, there was too much inter-subject variation for there to be a significant difference between the three conditions. It is unclear if the VR experiment elicited the rubber hand illusion to a notable degree. This therefore rejects both hypotheses.

This is contrary to what was expected, particularly in regards to the first hypothesis; the arrow hand, which served as a control group, elicited a higher response in the GSR data than the constantly visible and static realistic hand. This initial hypothesis was drawn based on results from multiple studies that found a higher stress response when the visible hand during the rubber hand illusion had a more realistic appearance [27, 12]. Despite this, participants did rate both realistic hands as looking more like their own compared to the arrow hand, to a significant degree. This therefore implies that something other than the initial appearance of the hands had a factor in how they were perceived by participants.

This idea is corroborated by the hidden realistic hand, which elicited a GSR response with more similarities to the arrow hand than the static realistic hand. As some participants mentioned, the way in which the constantly visible realistic hand grasped objects was sometimes strange, or unrealistic. This was due to the way the hand interacted with objects. As the majority of the objects were too large to fit within the palm of the hand, and the hand was only programmed with simple “open” and “closed” animations, objects would often appear perpendicular to the closed hand rather than being directly held by it. While this did not affect the ability to complete the task, the visual discrepancy between the hand and the object may have broken immersion. Previous studies that include similar tasks have typically included the grasping of small balls, which fit into the palm of the hand more easily and are not so susceptible to these issues [27, 12].

Another potential factor to these results is the appearance of the realistic hand itself. While care was taken to choose a generic looking hand that could be identified with by most participants based on skin colour, some commented on the veined look of the hand and how it was strange to them. This was perhaps an oversight when choosing the hand, as while specific skin colour does not typically impact feelings of hand presence [9], the appearance of distinctive features that were not relatable could be immersion breaking. This also highlights that while the hand was realistic in appearance, the environment was a more stylised supermarket that could be seen as cartoon-like. The aesthetic disassociation between the hand and the environment (which was not an issue with the arrow hand, due to its abstract appearance) may have lessened any effects of immersion.

Additionally, the relative realism of the hand combined with its limited range of movement and the stylised nature of the environment may have triggered feelings similar to that of the “uncanny valley”, in which animated realistic representations of human features that fall short in some way are perceived as “unsettling” or “eerie” [15, 17]. While this term is typically used in relation to human faces, research has found that it can be elicited through the perceived realism of hands [17].

While the proposed hypotheses were rejected, the results of this study potentially provide context to the efficacy of ‘tomato presence’ as seen in *Job Simulator*. As stated by the developers, one of the key reasons Owlchemy Labs chose to hide the virtual hand when grasping objects was to avoid occasions where interpenetration with objects or unnatural collisions could break immersion [2]. As similar events occurred with the static realistic hand, this could explain why the hidden realistic hand that was substituted with the stand-in objects (that behaved with mechanics similar to ‘tomato presence’) was rated higher for hand presence and elicited a higher GSR response from participants, as it avoided these issues. The arrow hand also avoided issues such as these, as objects stayed close to the intended grasping area during movement. Therefore, the developers of *Job Simulator* may be correct in their assumptions about the role of distracting elements and visual discrepancies lowering feelings of hand presence when grasping objects.

With these factors taken into consideration, it seems highly plausible that visual discrepancies break immersion and are a larger factor in hand presence and immersion than hand appearance by itself.

6. CONCLUSION

The study outlined in this paper sought to analyse the effects of different virtual hand appearances and behaviours on immersion, hand presence, and the induction of the rubber hand illusion in VR. Particularly, how the ‘tomato presence’ effect of hiding a virtual hand when grasping an object (as seen in games such as *Job Simulator*) affects these variables.

Despite the initially unexpected outcome wherein this study did not find statistically significant results, the distribution of data and participant observations served to highlight the impact of visual and behavioural discrepancies on immersion and hand presence. While the experimental conditions were primarily based on the appearance of the hand, the mechanics of which the hand behaved within the VR environment had an unexpectedly larger impact on measures. The unnatural behaviour of the static realistic hand seemed to decrease feelings of immersion and hand presence more so than the intended control condition of an abstract arrow hand. While not the intended result, this still informs us about the key theory of ‘tomato presence’ (hiding the hand in order to avoid unnatural interpenetrations or collisions) and its role in feelings of hand presence and avoidance of immersion breaking. This study could help to inform future work on the best protocols to follow when programming the appearance and behaviour of virtual hands, both in academic research and in game design.

6.1. Future Work

The findings of this study could potentially inform the design of future work. As unexpected variables affected the result of this experiment, the obvious next step would be to run a similar experiment with more focus on how the virtual hands look and behave. For example, the “realistic hand” seen in this study could feasibly be replaced with a hand that behaves more naturally, but aesthetically looks more stylised in order to better match the environment and reduce feelings of the “uncanny valley”. As the hand seen in *Job Simulator* is similarly cartoon-like to match the style of its game world, a study that better reflects this could produce a stronger study.

Alongside the manner in which the experiment is designed, a further analysis of data could produce notable results. Due to time constraints while running this study, the GSR data was not de-trended. As GSR data generally goes up over time, de-trending involves fitting a linear model to the session data in order to counteract this. While this would have been unlikely to change results in a meaningful way, it is another layer of analysis that could find interesting results.

ACKNOWLEDGMENTS

I would like to express my gratitude to Anthony Steed for his supervision and assistance during this project, including the programming of the experiment and conversion of the GSR data for use in Excel. Additionally, I would also like to thank María Murcia-López for her assistance, and David Swapp for the loan of equipment.

REFERENCES

1. Tomato Presence!. *Owlchemylabs.com*, 2017. http://owlchemylabs.com/tomatopresence/.
2. 'Job Simulator' Postmortem: VR Design, Tech, and Business Lessons Learned. *GDC*, Alexander Schwartz, Devin Reimer (2017).
3. Being There: Designing Standing VR Experiences with Tracked Controllers. *Oculus Connect 2*, Alex Schwartz, Devin Reimer (2015).
4. The Oculus Rift, Oculus Touch, and VR Games at E3. *Oculus.com*, 2015. https://www3.oculus.com/en-us/blog/the-oculus-rift-oculus-touch-and-vr-games-at-e3/.
5. Supermarket Interior. *Unity Asset Store*, 2015. https://www.assetstore.unity3d.com/en/#!/content/38178.
6. Manus VR brings arm, hand and finger tracking to VR. *YouTube*, 2016. https://www.youtube.com/watch?v=t4TIF7a-Fms.
7. Armel, K. and Ramachandran, V. Projecting sensations to external objects: evidence from skin conductance response. *Proceedings of the Royal Society B: Biological Sciences 270*, 1523 (2003), 1499-1506.
8. Botvinick, M. and Cohen, J. Rubber hands 'feel' touch that eyes see. *Nature 391*, 6669 (1998), 756-756.
9. Farmer, H., Tajadura-Jiménez, A. and Tsakiris, M. Beyond the colour of my skin: How skin colour affects the sense of body-ownership. *Consciousness and Cognition 21*, 3 (2012), 1242-1256.
10. Heeter, C. Reflections on Real Presence by a Virtual Person. *Presence: Teleoperators and Virtual Environments 12*, 4 (2003), 335-345.
11. IJsselsteijn, W., de Kort, Y. and Haans, A. Is This My Hand I See Before Me? The Rubber Hand Illusion in Reality, Virtual Reality, and Mixed Reality. *Presence: Teleoperators and Virtual Environments 15*, 4 (2006), 455-464.
12. Lin, L. and Jörg, S. Need a hand?. *Proceedings of the ACM Symposium on Applied Perception - SAP '16, (2016).*
13. Marchesi, M. and Riccò, B. GLOVR: A Wearable Hand Controller for Virtual Reality Applications. *Proceedings of the 2016 Virtual Reality International Conference on - VRIC '16, (2016).*
14. Meehan, M., Insko, B., Whitton, M. and Brooks, F. Physiological measures of presence in stressful virtual environments. *Proceedings of the 29th annual conference on Computer graphics and interactive techniques - SIGGRAPH '02*, (2002).
15. Mori, M., MacDorman, K. and Kageki, N. The Uncanny Valley [From the Field]. *IEEE Robotics & Automation Magazine 19*, 2 (2012), 98-100.
16. Padilla, M., Pabon, S., Frisoli, A., Sotgiu, E., Loconsole, C. and Bergamasco, M. Hand and Arm Ownership Illusion through Virtual Reality Physical Interaction and Vibrotactile Stimulations. *Haptics: Generating and Perceiving Tangible Sensations*, (2010), 194-199.
17. Poliakoff, E., Beach, N., Best, R., Howard, T. and Gowen, E. Can Looking at a Hand Make Your Skin Crawl? Peering into the Uncanny Valley for Hands. *Perception 42*, 9 (2013), 998-1000.
18. Roth, D., Lugrin, J., Buser, J., Bente, G., Fuhrmann, A. and Latoschik, M. A simplified inverse kinematic approach for embodied VR applications. *2016 IEEE Virtual Reality (VR)*, (2016).
19. Sanchez-Vives, M. and Slater, M. From presence to consciousness through virtual reality. *Nature Reviews Neuroscience 6*, 4 (2005), 332-339.
20. Slater, M. Towards a digital body: The virtual arm illusion. *Frontiers in Human Neuroscience 2*, (2008).
21. Slater, M. and Steed, A. A Virtual Presence Counter. *Presence: Teleoperators and Virtual Environments 9*, 5 (2000), 413-434.
22. Slater, M., McCarthy, J. and Maringelli, F. The Influence of Body Movement on Subjective Presence in Virtual Environments. *Human Factors: The Journal of the Human Factors and Ergonomics Society 40*, 3 (1998), 469-477.
23. Slater, M., Usoh, M. and Steed, A. Depth of Presence in Virtual Environments. *Presence: Teleoperators and Virtual Environments 3*, 2 (1994), 130-144.
24. Steed, A., Frlston, S., Lopez, M., Drummond, J., Pan, Y. and Swapp, D. An ‘In the Wild’ Experiment on Presence and Embodiment using Consumer Virtual Reality Equipment. *IEEE Transactions on*

Visualization and Computer Graphics 22, 4 (2016), 1406-1414.

25. Tecchia, F., Avveduto, G., Brondi, R., Carrozzino, M., Bergamasco, M. and Alem, L. I'm in VR!: using your own hands in a fully immersive MR system. *Proceedings of the 20th ACM Symposium on Virtual Reality Software and Technology - VRST '14*, (2014).
26. Tsakiris, M. and Haggard, P. The Rubber Hand Illusion Revisited: Visuotactile Integration and Self-Attribution. *Journal of Experimental Psychology: Human Perception and Performance 31*, 1 (2005), 80-91.
27. Yuan, Y. and Steed, A. Is the rubber hand illusion induced by immersive virtual reality?. *2010 IEEE Virtual Reality Conference (VR)*, (2010).