Need a Hand? How Appearance Affects the Virtual Hand Illusion

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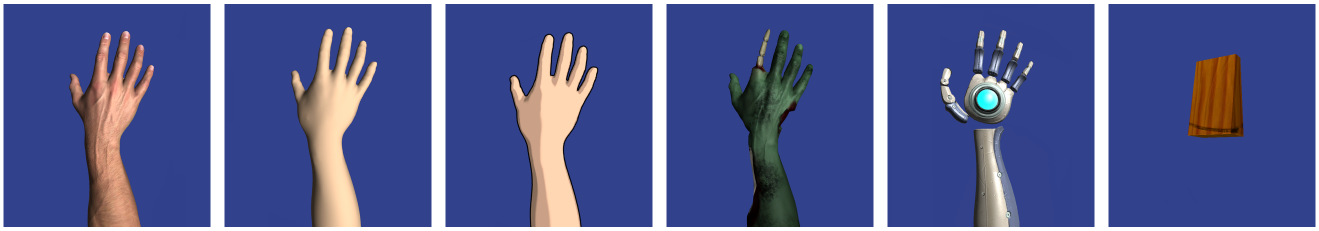

Figure 1: *The six geometric models with distinct appearances used in this study. From left to right: realistic hand, toony hand, very toony hand, zombie hand, robot hand, wooden block*

Abstract

How does the appearance of a virtual hand affect own-body perception? Previous studies have compared either two or three hand models at a time, with their appearances limited to realistic hands and abstract or simple objects. To investigate the effects of different realisms, render styles, and sensitivities to pain on the virtual hand illusion (VHI), we conduct two studies in which participants take on controllable hand models with six distinct appearances. We collect questionnaire data and comments regarding responses to impacts and threats to assess differences in the strength of the VHI.

Our findings indicate that an illusion can be created for any model for some participants, but that the effect is perceived weakest for a non-anthropomorphic block model and strongest for a realistic human hand model in direct comparison. We furthermore find that the responses to our experiments highly vary between participants.

Keywords: rubber hand illusion, virtual hand illusion, virtual reality, body ownership, body awareness, virtual environments, virtual character, realism, presence

Concepts: •**Computing methodologies** → **Perception; Virtual reality;** Animation; •**Human-centered computing** → *Gestural input;*

1 Introduction

Virtual reality has reached the consumer market and exhibited the potential to become a large social and commercial platform for mainstream markets. New, low-cost devices for virtual reality or mixed reality such as the Oculus Rift, Sony's PlayStation VR, or Samsung's Gear VR are already available or have been announced and might even outperform previous high-cost systems [Young et al. 2014]. Techniques to measure hand motions are in the making with the goal of being able to control virtual hands using one's own hand movements as well as interact with objects in virtual reality applications. Prototypes such as the combination of the Leap Motion Controller and the Oculus Rift are already available. Applications for these devices will certainly follow.

Virtual reality's rapid expansion makes it even more important to understand how we interact with virtual worlds. Previous research has shown that people have strong emotional reactions to dilemmas in virtual reality. An example is Slater et al.'s reprise of Milgram's famous experiments on authority and obedience [Milgram 1963; Slater et al. 2006]. This ability of virtual characters to elicit realistic responses from humans has been used in further experiments, and interestingly, this effect holds true even for scenes with abstract human figures with little degree of realism [Pan and Slater 2011].

We investigate the effects of model appearance in the context of the virtual hand illusion (VHI), a body ownership illusion (BOI) that has its roots in the rubber hand illusion (RHI). Participants play a game in an immersive virtual environment using a head-mounted display. The motions of their right hand are tracked. In the first study, participants see one of six models representing different levels of realism, different render styles, and different sensitivities to pain (see Figure 1) in place of their real hand. After participants block flying spheres with their hand for three minutes in the virtual environment, a knife as a virtual threat hits their virtual hand. We measure responses towards the virtual hand being threatened with a questionnaire. In the second experiment, we study the responses of participants who are prone to the rubber hand illusion when they see and control each virtual model, one at a time, giving them the ability to compare between models. Participants block spheres for two minutes with each model in random order, and the knife hits the last model one minute and thirty seconds into the game. A questionnaire is given after each model use.

We find that the effects of the model appearance highly vary depending on the participant and that the illusion can either occur or not occur with all models, but that, when given the possibility to compare multiple models, participants rate the illusion weakest with the non-anthropomorphic hand model and strongest with the most realistic human hand model. These results contribute to our knowledge of what degree of realism in characters would offer the most impact and immersion in virtual applications such as digital games, educational software, training simulations, or rehabilitation applications.

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2 Related Work

2.1 Effect of Appearance on Character Motion

Virtual characters vary from being highly cartoony in appearance to very realistic. Previous research has shown that appearance changes how some motions are perceived [Hodgins et al. 1998; McDonnell et al. 2007; Chaminade et al. 2007]. In many cases, the more realistic characters appear, the more prone they are to being expected to move naturally. A similar effect has been shown when only changing the render style and not the shape of a character, with motion anomalies being considered more unpleasant on realistic human than cartoon render styles [McDonnell et al. 2012]. However, realism does not necessarily affect motion interpretation: character appearance does not influence the perception of a character's emotions [McDonnell et al. 2008] or persuasiveness [Zanbaka et al. 2006].

In summary, participants likely have different reactions to different render styles or shapes of virtual characters, especially if they move.

2.2 Effect of Appearance in the Rubber Hand and Virtual Hand Illusions

First demonstrated by Botvinick and Cohen [1998], the RHI is an illusion where participants report that a rubber hand feels like it is part of their own body. Synchronous touching and visual feedback of the candidate effector and the participant's hand induce a feeling of ownership for the fake hand [Ehrsson et al. 2004; Tsakiris and Haggard 2005; Kalckert and Ehrsson 2014]. In many RHI studies regarding realism, different skin colors and hand shapes of believable rubber human hands do not affect the strength of the RHI: as long as the effector appears to belong to a human, the illusion will occur [Farmer et al. 2012; Longo et al. 2009]. However, exceptions to these findings do exist in certain conditions: Hohwy and Paton showed that the RHI can occur for objects that do not resemble hands, but only if the illusion has been created beforehand by a fake hand that is then instantaneously replaced by the object [2010]. Guterstam et al. found that empty spaces can be taken on by healthy participants as part of their own bodies [Guterstam et al. 2013].

The RHI is known as the VHI when it occurs in virtual environments, with the rubber hand replaced by a virtual one that is sometimes controllable with tracking devices such as data gloves or computer mice [Slater et al. 2009; Yuan and Steed 2010; Sanchez-Vives et al. 2010; Ma and Hommel 2013; Ma and Hommel 2015a; Zhang and Hommel 2015]. VHI studies have either compared two or three effector appearance conditions at a time, and the influence of the effector appearance is an important question still. Yuan and Steed conducted the first of these studies; they found that the VHI exists for a realistic hand, but not for an arrow cursor [Yuan and Steed 2010]. Further studies have mixed or contradicting results regarding the initial finding that the VHI only exists when the hand appears roughly like the participant's own hand in shape and animation (see Table 1). Participants feel more ownership for a virtual human hand than a virtual rectangle, but significant ownership illusions are still present for the nonhuman effector [Ma and Hommel 2015b]. Significant ownership illusions are present for a human hand and cat claw, but participants feel more ownership for the human hand and thus also more anxiety for the human effector when threatened [Zhang and Hommel 2015]. Argelaguet et al. [2016] also found that ownership was strongest for a virtual human hand, but observed that agency (a sense of control over a body part or object) is stronger for less realistic virtual hands due to less of a mismatch between virtual hand animations and the participant's actions. BOIs have even been shown to work for highly abstract or nonexistent effectors. Ma and Hommel [2015a] found that participants can take on balloons as part of their bodies, and the VHI is comparable for two-dimensional squares and realistic hands.

Table 1: *Controllable virtual hand representations in previous VHI studies*

Study	Models	Significant Results
Yuan and Steed 2010	realistic hand, arrow cursor	Strong illusion for hand, weak to no illusion for cursor
Ma and Hommel 2015a	realistic hand, balloon, square	Strong ownership for realistic hand, balloon, and square; ownership increased for effectors that look connected to participants' bodies
Ma and Hommel 2015b	realistic hand, rectangle	Stronger ownership for hand over rectangle
Zhang and Hommel 2015	realistic hand, cat claw	Stronger ownership for hand over cat claw
Argelaguet et al. 2016	realistic hand, iconic hand, abstract hand	Strongest ownership for realistic hand, stronger agency for iconic and abstract hand

The previous literature raises a question: Why are BOIs more easily invoked for a wide range of models in the VHI, but not in the RHI?

The exact process underlying BOIs is a dominating theoretical issue in the field. Experimental conclusions point to two general approaches for driving BOIs: they are either sufficiently induced by only bottom-up processes, or they occur as an interaction of top-down and bottom-up processes [Ma and Hommel 2015b]. In support of the latter approach, since our own-body perception relies not only on continuously updated sensory-motor information (bottom-up processes), but also on higher-order cognitive (top-down) processes [Kilteni et al. 2015], it should be logical that shapes differing from the human body should always receive less acceptance for being taken on as part of one's own body.

Yet, the approach of top-down and bottom-up processes interacting to produce BOIs does not account for studies where abstract objects and empty spaces can be taken in as part of one's body. Ma and Hommel [2015b]'s observations on the VHI occurring for balloons and virtual squares implies that a body-like realistic appearance and anatomical plausibility of the candidate effector is unlikely to be absolutely necessary for the illusion to occur. They suggest that top-down factors become more important when there is not enough sensory information to rely on, so body-part resemblance would then compensate for controllability. Thus, if agency is removed as a factor, ownership and location (of the hand) would account for the illusion, and the unmoving physical rubber hand in the RHI is more critically judged because people are substituting top-down processes in place of the ability to move the hand.

The previous body of research implies that any part can be taken on by the body as long as it is possible to control relevant features and behaviors of that effector. However, the question remains of if there are aspects of the VHI specific to particular model appearances. In our study, we investigate the strength of the virtual hand illusion not only for a realistic hand and very abstract representations, but also for representations with different renderings and anthropomorphic models with different sensitivities to pain.

3 Experiment Overview

Our hypothesis is that the illusion can be shown for all hand models, but that the more realistic and sensitive to pain the model appears, the stronger the illusion will be.

We designed two experiments both using the same six controllable hand models: realistic hand, toony hand, very toony hand, zombie hand, robot hand, and wooden block (see Figure 1). The first three models represent different rendered levels of realism of a human hand; the robot and zombie models were chosen as anthropomorphic representations that are non-human and have a different sensitivity to pain; finally, the wooden block was selected as an object that has no shape resemblance with a hand. All models have the same degrees of freedom except for the wooden block. The realistic hand and robot hand are free models offered through the Leap Developer Portal's virtual reality assets. The zombie hand was modified and re-textured from the realistic hand using Autodesk Maya 2014. The toony hand and very toony hand were created by smoothing and decreasing faces on the realistic hand's geometric model to decrease the surface detail, then changing the texture and shading; the toony hand has a tan color in place of the realistic hand's texture, and the very toony hand furthermore has cel shading applied. The wooden block was modeled and textured using Maya 2014, and the virtual environment and games were built in Unity 4.6.2.

In both experiments, participants were placed in a virtual environment and given one of the six controllable hand models. In the first experiment, each participant experienced a single model, played a game as a conditioning phase, was hit by a virtual knife, and was then asked to answer a questionnaire. Results showed large differences between participants, some of which experienced a strong illusion, others no illusion, independently of the model used. We hypothesized, based on these results and previous literature, that some participants are prone to the illusion while others are not. To study the effect of the different models, in a second experiment, participants were first tested to see if they experienced the RHI, then given control of the six virtual hand models one at a time.

We gathered participants' responses using a questionnaire and measured participants' physical reactions towards their virtual hand being threatened. We chose a between-subjects design for the first study, as participants can only be surprised by the threat once, and a within-subjects design for the second study to allow for model comparison despite large differences between participants. To guarantee that our models are distinct from one another, we carried out a brief online survey. We expected participants' ratings of perceived realism and sensitivity to pain to range from highest to lowest for the six models in the order of realistic hand, toony hand, very toony hand, zombie hand, robot hand, and wooden block.

4 Realism and Sensitivity to Pain

4.1 Method

One hundred thirty-seven participants (82m, 55f) between eighteen and sixty years of age were recruited from social networking sites to volunteer for the online survey. Participants were naïve with respect to the purpose of the experiment. Participants were presented with a consent form before the survey, approved by our institution.

After preliminary demographic questions, participants were presented with the six models used in the main experiments (see Figure 1). The models were labeled from "A" to "F". Six different orders were created randomly to avoid any ordering effects on participants' responses. Participants saw all models at the same time while answering the questions: *How realistic do you perceive hand model "A" to be?*; and *How sensitive to pain do you perceive hand model "A" to be?*. Each question was repeated for every model. Participants were asked to answer each question on a 10-point Likert scale, ranging from '1' (less realistic) to '10' (more realistic) for the realism questions, and '1' (less sensitive) to '10' (more sensitive) for the sensitivity to pain questions.

4.2 Results

A one-way ANOVA followed by Tukey's Q test showed significant differences between each of the hand models for perceived realism and perceived sensitivity to pain with all $p<0.001$ with one exception, the comparison between the very toony hand and zombie hand in terms of realism. As can be seen in Figure 2, the order from highest to lowest realism is realistic hand, toony hand, zombie hand and very toony hand, robot hand, and wooden block. We expected the zombie hand to rate lower on realism than the very toony hand because the zombie hand belongs to a fictional character, but the zombie hand model is as detailed as the realistic hand, which may have contributed to these results. As expected, the order from highest to lowest perceived sensitivity to pain is realistic hand, toony hand, very toony hand, zombie hand, robot hand, and wooden block.

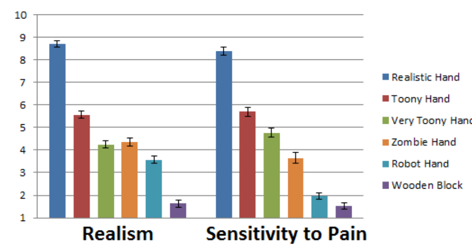

Figure 2: *Perceived realism and sensitivity to pain of the hand models. The error bars are standard deviations of the mean.*

5 Experiment 1

5.1 Method

5.1.1 Participants

Sixty participants (32m, 28f) between eighteen and forty years of age took part in our first experiment in exchange for a $5 voucher. Participants consisted mainly of undergraduate and graduate students recruited from a variety of departments through fliers, e-mails, and in-class announcements. Informed consent was obtained from all participants before and after the experiment. The study was approved by our Institutional Review Board.

5.1.2 Experimental Setup

Participants viewed the immersive virtual environment through an Oculus Rift head-mounted display (HMD) (see Figure 3). Hand tracking information was provided through a Leap motion controller mounted on the Oculus Rift. An Empatica E4 wristband was fitted to the participants' left arm. Exploratory EDA was recorded, but too many recordings yielded values outside of expected ranges to allow for quantitative analysis and were thus discarded. Participants sat at a table during the study so they had a place to rest their elbows if they needed to. The level of the plane in the virtual environment was adjusted to correspond to the real table.

5.1.3 Design

The study had a between-group design, with ten participants in each group. The independent variable, the virtual model in place of the hand, was randomly selected for participants before they entered the immersive virtual environment. The main dependent variable in this study is the strength of the virtual hand illusion, measured with questions testing ownership and implications or signs of ownership. We furthermore ask questions about pain, realism, and immersion.

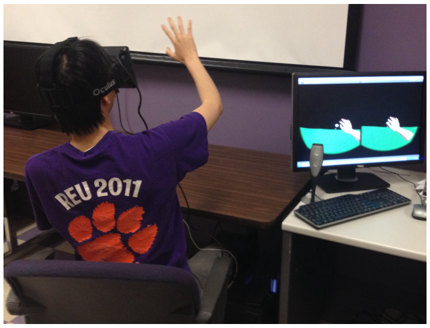

Figure 3: *The immersive virtual environment was viewed through an Oculus Rift. A Leap motion controller mounted to the Rift tracked the right hand.*

5.1.4 Procedure

After filling out an initial demographic questionnaire, participants were placed in the immersive virtual environment. Upon wearing the Oculus Rift, they were asked to keep the left arm stationary and raise the right arm in front of the Rift to view and control the model.

Participants were then asked to take as much time as needed to become used to the model and the environment, a black sky with a green plane. Once participants were comfortable with the setup, they were asked to play two short games. In the first game, participants need to block white, slowly approaching spheres for three minutes. The spheres explode both visually and with a short sound effect if they collide with the virtual model (see Figure 4). The speed of the spheres doubles in the middle of the game. Participants could prop their elbows on the table if they felt tired, but were asked to keep their hand and arm on screen. This first game serves as a conditioning phase to get participants accustomed to the virtual hand and to create the body ownership illusion [Armel and Ramachandran 2003; IJsselsteijn et al. 2006; Yuan and Steed 2010].

The second game is a threat stage: a knife comes down at the virtual hand without warning (see Figure 4). This threat was chosen based on Ma and Hommel's study [Ma and Hommel 2013]. When participants were ready for game two, they were asked to keep the model on screen, and a few seconds passed before the virtual knife came down on the model. Upon impact, a slicing sound effect occurred and blood started dripping from the model. After ten seconds, the participant was asked to remove the virtual reality equipment and complete a questionnaire regarding the virtual hand illusion.

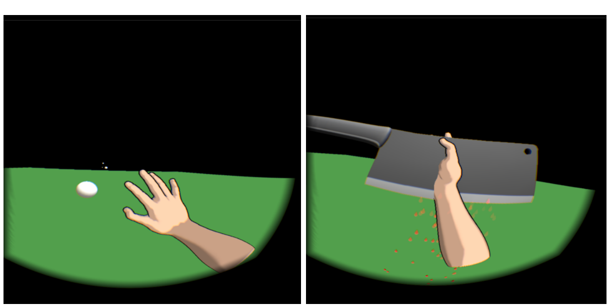

Figure 4: *The ball game (left) serves as the conditioning phase of the study. The knife (right) hits the model.*

5.1.5 Questionnaire

The dependent variables were measured by the participants' answers on a survey (see Table 2) after the virtual environment experience. Versions of the standard Botvinick and Cohen 9-question survey altered for the virtual hand illusion by Ma and Hommel and by Yuan and Steed [Botvinick and Cohen 1998; Ma and Hommel 2013; Ma and Hommel 2015a; Ma and Hommel 2015b; Yuan and Steed 2010] have been adapted for this experiment. For each statement, participants chose a rating on a seven-point Likert scale ranging from 1 for "strongly disagree" to 7 for "strongly agree." At the end of the experiment, participants were also asked to write down any comments they had about their experience.

5.2 Results

One of our first observations when analyzing the results is that many of the statements show surprisingly large ranges and variances in their answers, often including the full range or nearly the full range of possible answers from strongly disagree to strongly agree in each condition. Since a range of 6 is the maximum possible value, a range of 4 for a specific statement and condition indicates clear disagreement among participants. For each statement, the average of the ranges of the six conditions is larger than 4 except for statement Q-A4. Five of the statements even have average ranges larger than 5. One interpretation of these results is that the illusion is strong for some participants and does not work at all for others.

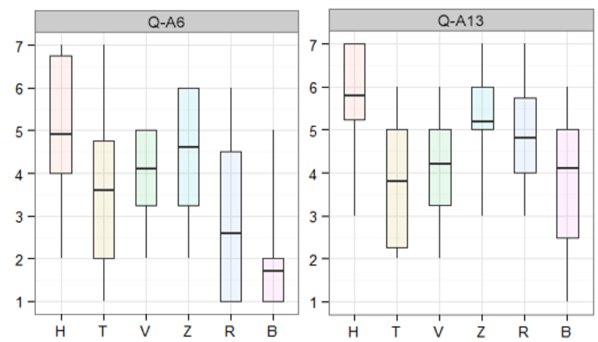

Figure 5: *Boxplots of the questionnaire results with significant effects. H stands for the human or realistic model, T is for toony, V for very toony, Z for zombie, R for robot, and B for wooden block. The full statements can be seen in Table 2. The boxes indicate interquartile ranges and the bars show the range of the ratings.*

Shapiro-Wilk's W test shows that many of the distributions are not normal. The results to the questionnaire were therefore analyzed for differences between conditions using Kruskal-Wallis tests with the appearance of the virtual hand as the independent factor (between-subjects variable with the six values realistic human, toony, very toony, zombie, robot, and wooden block or H, T, V, Z, R, and B, respectively). Mann-Whitney U tests with a significance level of 0.05 were used on selected comparisons. Significant differences between conditions were found for statement Q-A6 ($H(5,60)=20.02$, $p<0.01$), where participants' disagreement with the block beginning to resemble their own hand was significantly stronger than for the realistic hand, toony hand, very toony hand, and zombie hand and participants disagreement was also significantly stronger when using the robot hand than with the realistic hand or the zombie hand; and for statement Q-A13 ($H(5,60)=12.20$, $p<0.05$), where the realistic hand was perceived to be significantly more realistic than the toony hand, very toony hand, and wooden block and where the toony hand was also perceived to be significantly less realistic than the zombie hand (see Table 2 and Figure 5).

Table 2: *Questionnaire and results of our first study. Corresponding concepts in bold belong to core statements designed to test if the virtual hand illusion is occurring; they are either direct ownership questions, or implications or signs of ownership. Kruskal-Wallis tests were used to test for significant results. The mean and standard deviation over all models is provided when no significant differences were found. Results are reported based on Mann-Whitney U tests.*

Questionnaire Item	Corresponding Concept	Mean, Standard Deviation	Results
Q-A1: Sometimes I had the feeling that I was holding a real ball	**Intersensory interactions**	(3.45, 1.63)	
Q-A2: I had the sensation that I felt the knife on my hand in the same location where the virtual hand/block on the screen was in contact with the knife	**Location-related similarity**	(3.11, 1.99)	
Q-A3: I felt like the sensation I felt on my hand was caused by the contact of the knife with the virtual hand/block on the screen	**Intersensory interactions**	(2.95, 2.04)	
Q-A4: The movements of the virtual hand/block on the screen were caused by myself	**Agency**	(6.32, 1.07)	
Q-A5: It sometimes seemed my own hand was located on the screen	**Intersensory interactions**	(5.58, 1.61)	
Q-A6: The virtual hand/block on the screen began to resemble my own hand, in terms of shape, skin tone, freckles, or some other usual feature	Visual similarity	H = (4.90, 1.91); Z = (4.60, 1.71) T = (3.60, 2.12); R = (2.60, 2.01) V = (4.10, 1.28); B = (1.70, 1.25)	H, T, V, Z >B; H, Z >R
Q-A7: Sometimes it seemed as if what I was feeling was caused by the knife that I was seeing on the screen	**Intersensory interactions**	(3.10, 1.85)	
Q-A8: Sometimes I felt as if the virtual hand/block on the screen was my own hand	**Ownership**	(5.17, 1.53)	
Q-A9: Sometimes I felt as if my real hand was becoming virtual	Filler or control	(4.28, 2.15)	
Q-A10: It seemed as if I might have more than one right hand	Filler or control	(2.12, 1.44)	
Q-A11: I anticipated feeling pain from the knife on the screen	Pain	(2.73, 1.81)	
Q-A12: During the experiment there were moments in which it seemed that my own hand was being hit by the knife	**Ownership**	(2.91, 1.88)	
Q-A13: I thought the virtual hand/block on the screen looked realistic	Realism	H = (5.80, 1.40); Z = (5.20, 1.32) T = (3.80, 1.47); R = (4.80, 1.23) V = (4.20, 1.32); B = (4.10, 1.14)	H >T, V, B; Z >T
Q-A14: I was so immersed in the virtual reality, it seemed real	Immersion	(4.53, 1.58)	

The comments at the end of the questionnaire yield some interesting insights. One participant in the wooden block condition wrote, "It seemed real at points and I felt my palm opening to catch the ball". Another one in the same condition said that "about 2/3 of the way through the 1st level, it started to feel like I was actually blocking the balls." Other participants commented on the knife: "The knife was scary and unexpected. I kept trying to shake it off and save my hand" (toony hand condition). "I definitely felt something in my arm, like it had been pinned to the table." (zombie hand condition). However, some participants did not feel any effect: "The hand in the virtual reality seemed to move and look much like my hand [...]. When the knife fell, however, I did not feel any sensations which caused me to believe that it had fallen on my actual hand." Finally, ten participants (three each in the realistic, very toony, and robot conditions, one in the zombie condition) commented about the hand disappearing at some point or the fingers moving unrealistically, for example, "Sometimes, when I would move my thumb a certain way or make a fist, my thumb went through my other fingers."

5.3 Discussion

Only two statements showed significant differences between the hand models, Q-A6 and Q-A13, and both of these are not core statements related to the illusion. Interestingly, in Q6, the zombie hand model, green with bones protruding and pieces of flesh missing, is grouped with the other organic models (human, toony, and very toony) in that participants think it begins to resemble their own hand significantly more than the robot hand and block.

In this first experiment, we cannot support our hypothesis that the VHI is stronger for models perceived as more realistic and sensitive to pain. In all of the conditions, some participants strongly agreed with the statements. Based on this, we can conclude that the illusion can happen with all of the tested models. There are trends showing the possibility that the VHI is weakest for the wooden block and strongest for the realistic and the zombie hand shapes. We run a second study, allowing each participant to experience all the models, to further investigate these observations.

6 Experiment 2

6.1 Method

6.1.1 Participants

Fifteen participants (14m, 1f) between eighteen and forty years of age took part in the second experiment in exchange for a $5 voucher. As in the previous experiment, participants consisted mainly of students and the study was approved by our IRB.

6.1.2 Experimental Setup and Design

This experiment had a within-group design to allow participants to make direct comparisons among the different models. It first consisted of a pre-test to see if participants could experience the rubber hand illusion. Afterwards, it used the same equipment and setup as the first study. The order of the six virtual models in place of the hand, the independent variables, was randomly generated for each participant before entering the immersive virtual environment. The dependent variables are the same as in the first study, with a slightly adapted and shortened questionnaire.

6.1.3 Procedure

After filling out an initial demographic questionnaire, participants were seated at a table emulating Botvinick and Cohen [Botvinick and Cohen 1998]'s setup. Participants placed their left hand behind a barrier on the table obstructing their view. A life-sized rubber model of a left hand was placed in front of them. Two paint brushes were used to stroke the rubber hand and real hand synchronously for two minutes. The participant then filled out a short questionnaire that allowed us to find out if the participants felt the illusion.

Then, participants were placed in the immersive virtual environment in the same way as in the first experiment. Upon wearing the Oculus Rift, they were asked to keep the left arm stationary and raise the right arm in front of the Rift to view and control the model.

Once participants were comfortable with the setup, they were asked to play two-minute game sessions using different hand models, with the goal of blocking objects that come their way. The speed of the spheres remains constant through the entire game. The knife only drops on the last model. After every game session, participants were read statements and asked to choose a rating on the seven-point Likert scale, ranging from 1 for "strongly disagree" to 7 for "strongly agree." The statements (see Table 3) were adapted from the questionnaire in Experiment 1.

6.2 Results

The RHI did not occur for three participants, so their data was excluded from the analysis. The results to the questionnaire were analyzed for differences between conditions using the Friedman test and Wilcoxon tests where necessary with the appearance of the virtual hand as the independent factor (within-subjects variable with the six values realistic, toony, very toony, zombie, robot, and wooden block or H, T, V, Z, R, and B, respectively).

Significant effects with $p<0.05$ were found for all statements except for Q-B2 ($p \approx 0.18$) corresponding to agency and statement Q-B6, which was only significant at the 0.1 level with $p \approx 0.068$ (see Table 3 and Figure 6). As there are no standard posthoc tests for Friedman tests, we used Wilcoxon tests on selected comparisons with $p<0.05$ as significance level. Nearly identical results were found when using a Newman-Keuls posthoc.

Participants rated the wooden block significantly lower than all other models in four of six of the core statements, those corresponding to location-related similarity and ownership. The zombie hand was rated significantly lower than the human, toony, and very toony hand in one ownership question (Q-B5), and the zombie, very toony, and block hand were rated significantly lower than the human hand in another ownership question (Q-B7). For question Q-B4 corresponding to visual similarity, there was a significant effect of the virtual hand beginning to resemble participants' hands with the human, very toony, and toony hands being rated highest, followed by the robot and zombie hand as a second group, then the block with the lowest rating. For intersensory interaction, participants said that what they were feeling was caused by the ball significantly less often when using the block model than when using the realistic human model (Q-B6). In terms of realism (Q-B8), the block was rated significantly less than all other models for looking like a realistic virtual hand, and the human hand had a significantly greater rating than all models except for the toony hand. Finally, participants rated the block significantly lower than all other models for making them feel immersed in virtual reality.

Verbal comments at the end of this study gave interesting insights as well. Several participants said they would have felt more connected to the hand if it had moved synchronously with their own hand at all times or if the model did not disappear sometimes during the study. One participant said, "I want to ask what you are using for the heat haptics. I felt a heat sensation where the ball hits me. Every time a ball hit." There were also some interesting comments regarding the non-human hands. One participant said, "The robot hand and wood were disconnected from me...I would have gotten more of a shock [if the knife had hit one of the human-like hands]." One participant with the zombie hand being threatened by the knife said, "I was having fun inspecting the hand, but I [also] didn't want to look at the zombie hand (because it appeared he was wounded)." It seems that all participants who experienced the RHI were also able to experience the VHI. Of the three participants who were omitted as they did not experience the RHI, only one rated the VHI consistently low throughout the entire study: "I didn't feel anything. I mean, I knew I was playing a video game the whole time."

6.3 Discussion

In summary, participants' ratings were significantly lower for the block model compared to every other model in seven of the nine questions. We can therefore confirm our hypothesis that participants felt that the VHI was weaker when using the wooden block model than when using any other model. Furthermore, participants' ratings were significantly higher for four of the questions when the realistic human model was used compared to some of the other models, not taking the block model into account. We conclude out of this result that participants did have a preference for the high realism of that model. The other models can be ranked in between with some differences, such as the zombie model rated less than the toony and very toony models in two questions. However, those differences would need to be investigated further. We also found that appearance does not affect agency. For the three omitted participants, it is unclear if they were not prone to the RHI or needed longer than two minutes for the illusion to take effect: only one of them did not experience the VHI at all. Our observations that the VHI occurs for more participants than the RHI supports Ma and Hommel [2015b]'s findings that being able to control the model is more convincing than seeing and 'feeling' an immobile model being touched.

7 Conclusion

We investigated the effect of hand model appearance on the VHI. The first study, using a between-subjects design, yielded no significant differences for the core statements. Yet, the VHI was felt for all models to some extent. The second experiment, using a within-subjects design, had significant differences.

Our findings suggest that there are large differences between participants leading to a large error variance, but in direct comparison, anthropomorphic models lead to a stronger illusion and a realistic human model leads to the strongest effects. Appearance does not affect agency, and the illusion can happen for all models. Even a wooden block that was used instead of a hand lead to comments that showed an effect of illusion for some of the participants.

Our results on ownership are overall consistent with all studies mentioned in Table 1, but our results on agency contrast to Argelaguet et al. [2016]'s findings that agency is stronger for less realistic virtual hands. Based on the comments of some participants, the illusion might have been reduced in some cases as the hand and especially finger motions were not captured perfectly at all times despite restricting the area in which the spheres arrive. Yet, this and experiencing all the models in direct comparison do not seem to deter participants from feeling like they control any sort of hand.

Another explanation for the VHI effects in the second experiment could be that participants gauge danger in virtual surroundings by context:"That robot hand...Maybe I would have felt something [from the knife] if [the hand] looked more real; there was blood so it didn't." One participant commented that the human-looking hand models did not move as well as the robot hand, and one participant said, "there's more of a suspension of disbelief [for the robot and zombie hands] so I feel like it's more real. I picked at [the hand model] the more it looked [like a human hand]." These comments suggest that the participants are more critical of models nearing their own hands. However, the human hand still rated the highest across participants in general for the VHI, suggesting that such an aesthetic is not detrimental to immersion. Further investigation will be needed to fully understand the illusion in virtual environments and the effect of realism on it. How would BOIs be influenced by more realistic environments or nearby interactive characters?

Our results and the large variances between participants' ratings

Table 3: *Questionnaire and results of our second study. Corresponding concepts in bold belong to core statements designed to test if the virtual hand illusion is occurring; they are either direct ownership questions or implications or signs of ownership. Friedman tests were used to detect significant differences, which were found for all statements except for Q-B2. The mean and standard deviation over all models is provided when no significant differences were found. Results are reported based on Wilcoxon tests.*

Questionnaire Item	Corresponding Concept	Friedman test	Mean, Standard Deviation	Results
Q-B1: I had the sensation that I felt the ball touch my hand in the same location where the virtual hand on the screen was in contact with it.	**Location-related similarity**	$\chi^2(5) = 17,78$	H = (5.50, 1,09); Z = (4.42, 1.83) T = (5.00, 1.54); R = (5.08, 1.44) V = (4.92, 1.51); B = (2.92, 1.78)	H, T, V, Z, R >B
Q-B2: The movements of the virtual hand on the screen were caused by myself.	**Agency**	$\chi^2(5) = 7,58$	(6.06, 0.95)	
Q-B3: It sometimes seemed my own hand was located on the screen.	**Location-related similarity**	$\chi^2(5) = 24,33$	H = (5.67, 1.07); Z = (4.67, 1.50) T = (5.00, 0.74); R = (5.33, 1.37) V = (4.75, 1.14); B = (2.91, 1.68)	H, T, V, Z, R >B
Q-B4: The virtual hand on the screen began to resemble my own hand in terms of shape, skin tone, freckles, or some other usual feature.	Visual similarity	$\chi^2(5) = 36,19$	H = (5.33, 1.72); Z = (3.17, 1.19) T = (4.67, 1.37); R = (3.08, 2.07) V = (4.33, 1.44); B = (1.67, 1.23)	H, V, T >R, Z >B
Q-B5: Sometimes I felt as if the virtual hand on the screen was my own hand.	**Ownership**	$\chi^2(5) = 23,29$	H = (5.42, 1.16); Z = (3.83, 1.40) T = (5.08, 1.16); R = (4.67, 1.56) V = (4.75, 1.36); B = (2.67, 1.92)	H, T, V, Z, R >B; H, T, V >Z
Q-B6: Sometimes it seemed as if what I was feeling was caused by the ball that I was seeing on the screen.	**Intersensory interactions**	$\chi^2(5) = 10,28$	H = (5.16, 1.19); Z = (4.33, 1.67) T = (4.91, 1.24); R = (4.92, 1.44) V = (4.67, 1.15); B = (3.91, 1.73)	H >B
Q-B7: During the experiment there were moments in which it seemed that my own hand was catching the ball.	**Ownership**	$\chi^2(5) = 27,51$	H = (5.83, 0.83); Z = (4.42, 1.62) T = (5.08, 1.08); R = (4.92, 1.62) V = (4.58,1.16); B = (3.08, 1.68)	H, T, V, Z, R >B; H >V, Z, B
Q-B8: I thought the virtual hand on the screen looked realistic.	Realism	$\chi^2(5) = 27,62$	H = (6.00, 1.48); Z = (4.67, 1.23) T = (4.91, 1.24); R = (4.08, 2.23) V = (4.25, 1.76); B = (1.67, 1.44)	H, T, V, Z, R >B; H >V, Z, R, B
Q-B9. I was so immersed in the virtual reality, it seemed real.	Immersion	$\chi^2(5) = 24,60$	H = (5.58, 1.08); Z = (4.83, 1.53) T = (5.00, 1.20); R = (4.92, 1.73) V = (4.67, 1.30); B = (3.33, 1.83)	H, T, V, Z, R >B

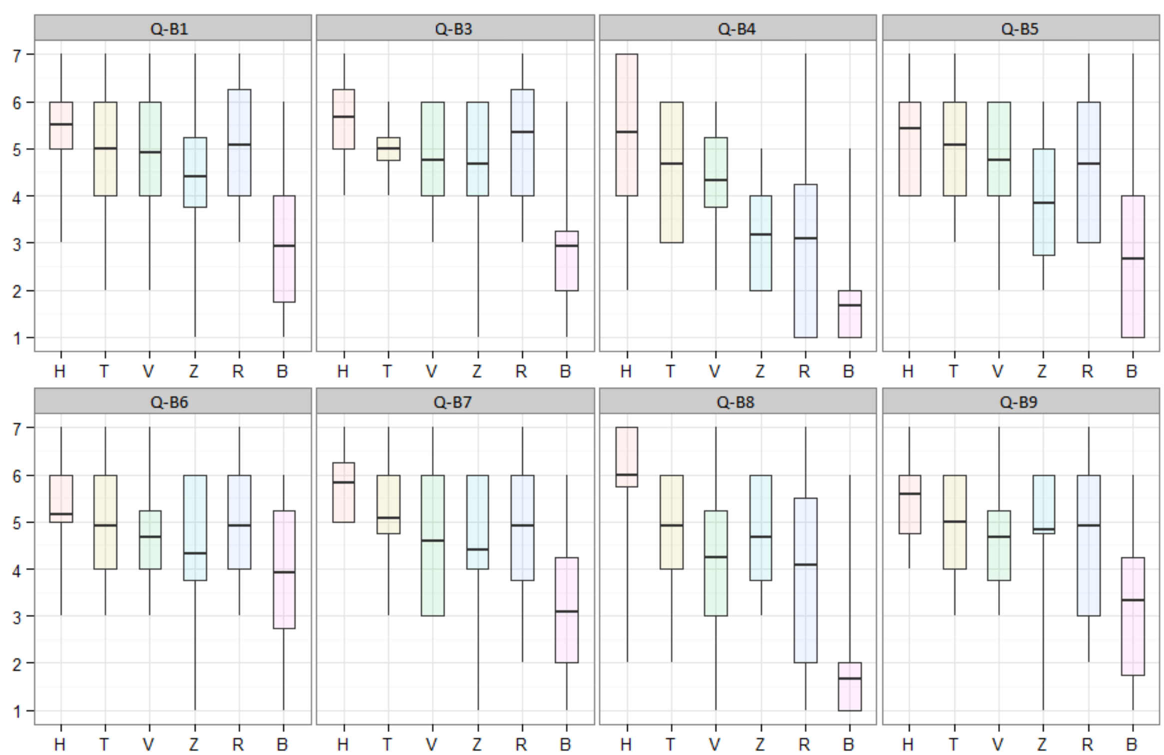

Figure 6: *Boxplots of the questionnaire results with significant effects. H stands for the human or realistic model, T is for toony, V for very toony, Z for zombie, R for robot, and B for wooden block. The full questions can be seen in Table 3. The boxes indicate inter-quartile ranges and the bars show the range of the ratings.*

are consistent with prior research, which has shown that the VHI is only convincing for some participants. An interesting next step would be to investigate the reasons behind this observation. Are some people more prone to the illusion? Does the length of the induction phase influence the results? Would the elimination of lag and non-accurate tracking increase the effects? Future work will need to address these questions.

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