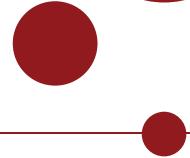




Master of Computer Science



The Social Effect of Virtual Body Representations on the Observer

Socially-Driven Physical Illusions in a VR Tug-of-War Game

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September 2019

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1 Abstract

2 Introduction

Virtual reality's (VR) immersive capabilities have been successfully applied in fields such as entertainment, military training and phobia management to enhance and complement real-world human experiences. Bowman and McMahan examine some of these successful VR ventures and suggest their aspired fidelity to real life is what sets them apart [1]. In long term, the goal of many VR researchers and enthusiasts seems to be engaging as many of the human senses as possible to replicate real life sensory experience with high accuracy.

VR has been shown to alter people's perceptions and bring about realistic physical and behavioral reactions to situations that are virtual and fabricated. For example, virtual environments (VEs) can decrease the perception of pain [2], aid phobia treatment [3] and activate stereotypical social responses ([4]). Research exploring physiological effects of VR has mostly concentrated on responses to fear inducing stimuli, such as phobias. From spiders [5] to fear of heights [6], virtual objects have determined significant physiological changes such as increased heart rate or skin conductance. In these cases, people reacted implicitly to VEs in congruence with their real-world experience. What is more, in case of [6], haptic feedback, such as the inclusion of a physical, wooden ledge for a virtual pit greatly increased presence.

With its roots in the *rubber hand illusion* [7], many researchers have turned to body ownership to explain physical and behavior changes caused by VR. Christou and Michael explore the effects of avatars on performance. They created a game in which users would deflect incoming objects while embodying a human or, stronger, alien avatar. Users had fewer misses and males used more force in the alien condition. Social influence is also a powerful drive for peoples behaviour change. Many experiments done by Slater [8, 9] and Yee together with Bailenson [10] shed light on the *transcending* power of virtual reality. Dubbed as an *empathy machine*¹ by the media, people can assume various personas in virtual environments, and experience what used to be a thought exercise in a tangible way [11].

Compounding the transformative power of VR and social influence of virtual humans, we present a proof of concept experiment to explore the capabilities of VR as an illusion generating machine. We leverage the power of social VR and design a competitive virtual reality rope-pulling game. In our experiment, we manipulate the appearance of virtual humans to make them appear stronger or weaker. We aim to give participants the illusion that the rope is being pulled back harder by

¹<https://www.wired.com/brandlab/2015/11/is-virtual-reality-the-ultimate-empathy-machine/>

stronger opponents. Equivalently, we expect people to feel the rope being pulled less by weaker opponents. If participants assume these expectations, we hypothesize they will also perceive pulling harder for strong opponents and less for weaker ones. Finally, we measure their actual force pull to check if their expectation has determined a physical reaction.

Our main interest lies in exploring how far virtual reality can go in making the implausible probable and material. Through our experiment, we hope to shed light on best practices to achieve and sustain such illusions in order to give users extraordinary VR experiences.

Our results show most participants detected variations in pulling. However the way in which they pulled is not consistent with our hypotheses, despite qualitative feedback. In what follows we give an overview of our findings, explain the limitations of our study and give advice about using physical objects in VR to generate illusions. It appears physical illusions seem feasible even in a low-fidelity environments. However, we posit that some degree of behavioral and physical realism is desired, especially to sustain these perceptual overrides. If physical illusions can occur with such a simple setup, generating complex illusions is limited only by the creativity of the designer.

3 Related Work

3.1 Body Ownership

The rubber hand illusion[7](RHI) is an experiment in psychology to demonstrate the formation of body ownership through congruent visual and tactile stimulation. Usually, a rubber hand is placed where a participant’s hand should be, and both hands are stroked or tapped in a synchronized manner. The illusion created by the synchronized tactile and visual feedback generates a feeling of ownership of the fake arm for the participant. This illusion has been successfully replicated in mixed [12] and virtual reality [13], where researchers have also used avatars to generate feelings of ownership over virtual bodies. Slater and colleagues explore in an extensive body of work the parameters and effects of this illusion [14]. They introduce the term, *sense of embodiment* to capture the broader experience of embodiment in VR, which has three distinguishable levels: body-ownership, agency and self-location [15]. To evaluate the occurrence of RHI, researchers usually measure the perceived location of participants’ hands and use questionnaires for subjective data. When movements are synchronized and the illusion occurs, usually there is a displacement of the perceived location closer to the rubber hand called *proprioceptive drift*. [16].

In an experiment combining embodied cognition and body ownership, Bailey,

Bailenson and Casasanto [17] explore *space-valence associations* as a result of mirroring participants' hand movements. They conclude that multiple senses have to be engaged in order to obtain an effect.

The effects of appearance have also been studied with respect to ownership illusions. Lin and Jorg investigate the influence of six different hand models on ownership [18]. In two experiments, participants played a game in which they had to block white spheres and experienced a threat scenario where a knife slashed their hand in the VE. They note that all these hands generated ownership for at least some participants, with various levels of strength. However the effect was strongest for the realistic model and weakest for a *non-anthropomorphic* bloc. However, the most realistic hands do not always receive the highest ratings. In their study Argelaguet et. al [19] evaluate ownership and agency for hands in 3 different realism condition that offer different degrees of freedom. They found that the most realistic hand with the most accurate tracking was rated highest in ownership. Conversely, agency was stronger for less realistic hands. They conclude that the difference in ratings occurred because the highly realistic hand was often mismatched with the actual hand. This was not the case for the less realistic hands providing fewer degrees of freedom.

3.2 Social VR

The threshold model of social influence put forward by Blascovich [20] implies that digital actors, who are perceived to be human (have high agency) will have more influence than their computer counterparts. Both perceived agency and agency have been shown to play a role in social influence especially for tasks such as persuasion [21, 22]. We use the term *avatar* to refer to a user's own digital and embodied representation in virtual reality and the term *agent* for computer-driven digital entities.

People have been shown to respond socially to computers even when they are not necessarily embodied in avatars, known as the Computers As Social Actors paradigm [23]. In a virtual reprise of a well known social-psychological study - Milgram's obedience experiment - Slater et al. observed that people had realistic responses when shocking a virtual learner [9]. This occurred despite knowing their activities had no real effect.

Digital self representations have far-reaching implications from altering a user's own behavior in the virtual world to shaping perceptions in reality. *The Proteus Effect*, postulated by Yee and Bailenson, refers to how users change their own behavior conforming to the perceived behavior of their digital representation [24]. They observed that users in more attractive avatars got closer to confederates and showed more self disclosure than participants with less attractive avatars. Similarly, in a negotiation task about monetary splits, people with taller avatars were

more confident and made more splits in their favor, while owners of shorter avatars were more likely to accept unfair deals.

The Proteus Effect is framed around self-perception theory [25] in a context in which users are deindividuated [26]. In such cases users rely more on identity cues and behave in a way which conforms with the stereotypes of their virtually displayed body. An alternate explanation is provided by Peña and colleagues. They suggest priming as an underlying cause of the Proteus Effect and raise concerns about users role playing in their new identities [27]. They measure participant's awareness about the true scope of the study and use clothing as means for priming. Avatars were shown from a third person perspective in a 3D distributed desktop virtual environment. In their first experiments, participants were given a negotiation task to solve in groups of 3 either, having all white or black robes. Results showed that participants in black presented more aggressive intent and lower group cohesion than those in white. In their second experiment, participants had either a KKK, doctor or transparent avatar and were tasked with writing 2 stories. Those employing a KKK type avatar wrote more aggressive stories compared with the other groups.

To decouple the effects of priming and embodiment, Yee and Bailenson ran a study in which users were given an attractive or unattractive avatar in an immersive virtual environment (IVE) [28]. Inside the environment, they were looking at themselves in a mirror or they saw a playback of someone from before. Participants interacted with a confederate of the opposite gender who was blind to the condition, and then completed a dating website task.

They found that virtual embodiment resulted in more behavior change with users. In the attractive condition people chose more attractive dates and got closer to the confederates. In the opposite condition, users were more likely to increase their height in the dating profile.

Extending their work on the Proteus effect, Yee, Bailenson and colleagues found that in online communities an avatar's appearance was a predictor of performance. Furthermore changes in behavior lasted outside of IVEs with participants given tall avatars having more aggressive negotiations with confederates [10]. Further, they investigated this effect in a conversation between 2 opposite-gendered participants in a distributed medium [29]. The avatars the male participants saw varied from attractive to attractive or no appearance. Females saw their avatar in a congruent condition. The findings, however, were inconsistent with the Proteus effect. Females who had an unattractive avatar were reported to behave more friendly, affectionate and intimate. The authors explain these findings through the behavioral compensation effect [30].

However, this phenomenon does not always benefit the user. In similar experiments, women having highly sexualized avatars objectified themselves more [31], embodiment in black avatars increased implicit racial bias [32]. Users were also

more prone to persuasion by avatars that mimicked them [33] or consistently gazed towards them [34]. More recently, virtual social exclusion had similar negative effects with real-world exclusion leading to less prosocial behavior outside of VR [35].

In a series of experiments, Slater et. al put forward the idea of body semantics to explain how body ownership illusions can generate behavior and attitudes in users [8]. Some examples are reducing implicit racial bias for owners of black avatars or affecting perception of object sizes in the case of child avatars. Furthermore, the effects of reduced racial bias were observed for at least a week outside VR [36]. This paradigm differs from the Proteus Effect by attributing this change of behavior to the generation of the body ownership illusion. While people have mostly experienced positive outcomes due to the empathy driven by embodiment, highly stereotypical contexts may have opposite outcomes.

Virtual reality has shown its potential as an efficient tool in framing social and psychological studies. However, most research is focused on behavior and attitude changes stemming from one's own avatar. Few studies examine physical changes determined by the appearance of another's avatar. Avatar appearance can also alter physical performance. Peña, Khan and Alexopoulos investigate avatar and opponent body size in a Nintendo Wii tennis exergame and explain their findings through social comparison theory and priming [37]. They found that participants with obese avatars had less physical activities than those in normal avatars and showed that this effect was mediated by the appearance of their opponents. When the opponent had a more obese avatar, participants performed less. In the same experiment with women, they found participants made the most effort when both avatars were normal and the appearance of obesity decreased performance [38]. In a series of experiment for health and behavior change in virtual environments, Fox and Bailenson observed that participants made more exercise when their avatar lost or gained weight according to their movements [39]. Similar with this research, we look at whether participants will use more force when faced with a stronger opponent than with a weaker opponent. We implement a rope-pulling game in virtual reality and allow participants to see their hands on the rope. However, we do not vary their body representation.

3.3 VR Illusions

The illusions that enables the feeling of presence have been extensively studied in literature. *Presence* has many dimensions ranging from location, simply *being there*, to various aspects of computer-mediated communication such as social presence or co-presence — *being there together* [40]. For IVEs, Slater and colleagues propose a separation of presence in *Place Illusion* for location-related presence, and *Plausibility Illusion* to denote the perceptual override that occurs

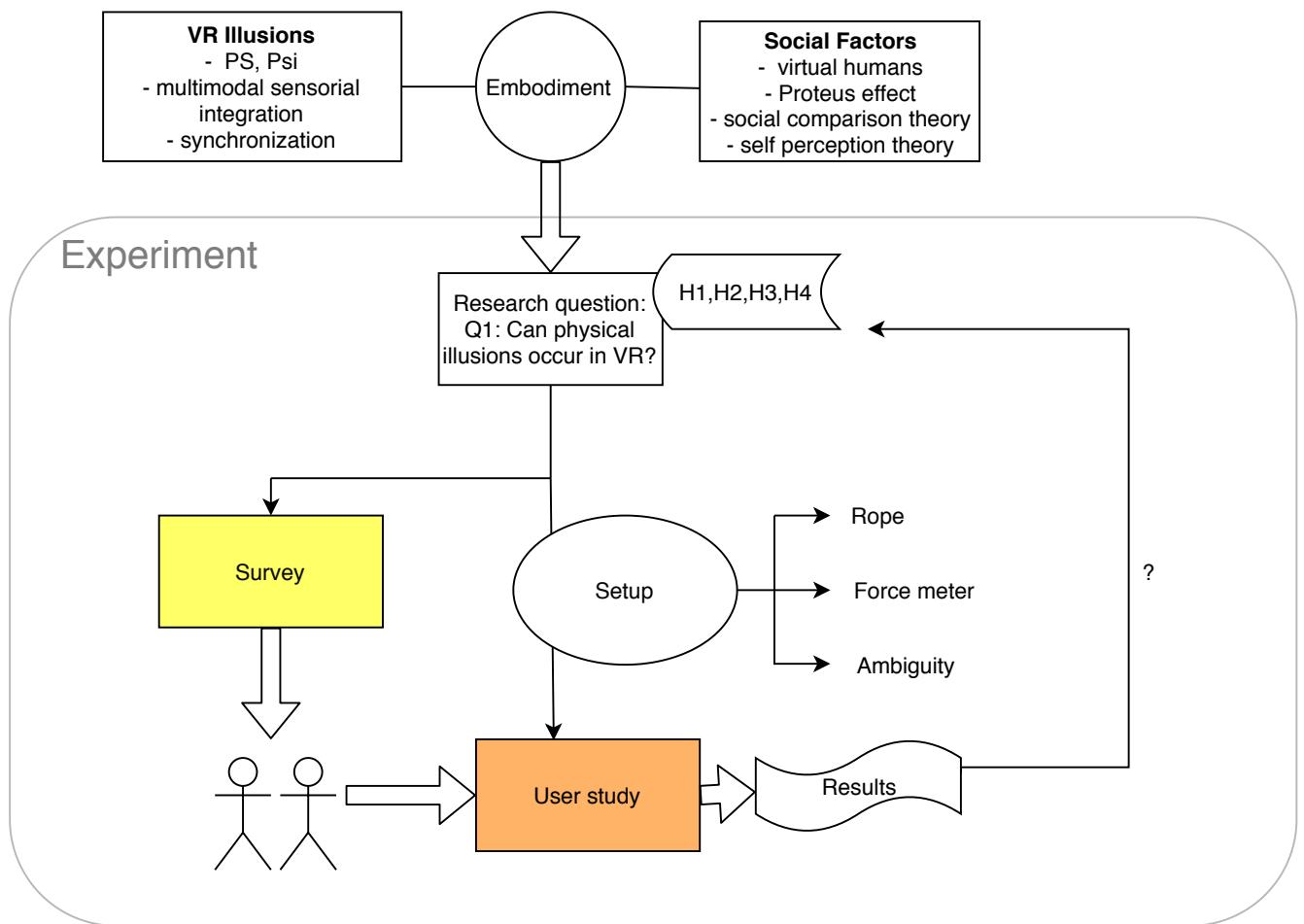
when users perceive what they know cannot occur. He defines *sensorimotor contingencies (SCs)* as actions users perform in order to achieve perceptual clarity. Some examples are as bending to see below, or touching a virtual object and receiving haptic feedback. He contends these VR illusions occur *as a function* of possible SC. The author defines plausibility illusion as “*the illusion that what is apparently happening is really happening (even though you know for sure that it is not)*” [41]. He emphasizes being the target of events is an important element in producing this illusion. On one hand, motor and visual synchronicity are essential to produce place illusion. Additionally, Slater posits that a correlation between a user’s sensations and events they have not caused is important to bring about plausibility illusions (Psi). In his experiments, the author notes that Psi also occurs in low physical realism conditions, such as in the reprise of the obedience experiment [9]. To illustrate this illusion, most of the examples refer to interactions between virtual humans, such as reacting to the gaze of avatars. However, he also mentions people’s realistic responses to a virtual pit, despite their knowledge there are no such objects in real life [42]. Commercial VR applications are able to reproduce this illusion with relative easy ². When haptic feedback is added to, the response is even more realistic, with significantly increased heart rate [6]. We identify three key elements in Slater’s framework: synchronicity, correlation and realism. The body is, of course, the main focal point of these illusions. The author emphasises that these illusions take place against reasoning when people have knowledge of the actual environment. However, their reactions to the environment seem to be automatic. As such, some level of perceptual override takes place in order to generate these illusions. We posit, however, that these illusions can occur even in ambiguous settings, where participants do not have knowledge of their actual environment. Considering the powerful, and mostly undocumented effect of haptic feedback for VR illusions, we introduce a new category of illusions, namely physical illusions. In this paper we aim to investigate their feasibility in immersive virtual environments. By physical illusions, we mean the subjective haptic or motor feedback, which is not congruent with the magnitude of the external force. The illusion could, we speculate, occur even in the lack of any haptic feedback. This is a subcategory of a broader range of more complex illusions we believe can take place in VR. These illusion occur when users have no knowledge of the actual environment and/or actually believe that virtual reality reflects an objective reality, when that is not the case. We refer to them as complex illusions.

We believe more work is necessary to explore the perceptual limits of people in virtual environments. Most research has focused on determining changes in at-

²https://store.steampowered.com/app/517160/Richies_Plank_Experience/

titudes, physical performance or a mix of the two. Work that explores changes in physical states mostly relates to fear-induced stimuli. While we explore the feasibility of physical illusions, in future work we aim to implement applications to simulate complex illusion. This, however, is outside the scope of our current research.

4 Methodology



H1: Participants will perceive changes in rope-pulling force across opponents.

H2: Participants will use more force for stronger-looking opponents.

H3: Participants will report pulling harder for stronger-looking opponents.

H4: Participants will find stronger-looking opponents more challenging

Figure 1: Methodology overview.

The experiment has two parts: a survey and a user study. We run a survey in order to determine perceptions of strength and intimidation in avatar design. We measure perceived strength and intimidation for avatars and vary the appearance based on a weighted score of these two measures. We choose the avatars for the experiment based on the survey results. Please see section 7 for more details about the survey and choice of avatars.

4.1 Research Aims

The aim of our experiment is two-fold. Firstly we explore the feasibility of generating physical illusions in virtual reality (**Q1**). To do this, we implement a VR tug-of-war game and vary the appearance of participants' opponents. Our independent variable is the appearance of the opponent. Each opponent will randomly be assigned a condition of this variable, from weak-looking to strong-looking. We determine the appearance perception in a survey (see 7.4) and the number of conditions through piloting (see 8.2). We investigate if participants perceive any change in rope-pulling from one trial to another. We formalize our first hypothesis:

H1: *Participants will perceive changes in rope-pulling force across opponents.*

To measure any perceived changes in rope pull, we introduce a dependent variable, **challenge**. We ask participants to rate how challenging each rope-pull was after the respective trial. We do not give any indication for a standard to be applied for this rating. We leave it to the participant to interpret what *challenging* means. Additionally, we introduce **perceived pull** as a subjective measure of how much participants thought they pulled. We measure both variables on a 5-point Likert scale. For each condition, we also take objective measurements of actual pull. We use a force meter to detect the maximum force each participant pulled per trial. This constitutes the the third dependent variable, **force**. We expect users to react to the appearance of their opponent and pull harder for stronger-looking opponents. We formalize the hypotheses of these variables:

H2: *Participants will use more force for stronger-looking opponents.*

H3: *Participants will report pulling harder for stronger-looking opponents.*

H4: *Participants will find stronger-looking opponents more challenging.*

For H2, we use the maximum pull per trial as a measure of *more force*. We

do not make it explicit that participants are competing with an agent. We set up the rope pulling game in an ambiguous manner, such that participants do not see the pulling mechanism. Ultimately, we are interested in the feasibility of generating very implausible illusions in VR. Giving the impression that another human player is pulling the rope is one example of such an illusion that can be generated with this setup.

4.2 Study Design

To investigate the actual variation in force determined by the avatars, we run a user study in which participants play a tug-of-war game. The study has a within-subjects design varying the appearance of the opponent avatar in terms of strength and intimidation. We use a 5 point scale from weak to strong-looking. Our independent variable is the appearance of the opponent’s avatar. We have 3 additional dependent variables, challenge, pull and force. Through mixed methods, we also measure presence in the virtual environment, co-presence with the opponents and body ownership of the participant. This design reflects the holistic approach of our research methods. We endeavour to collect quantitative objective data, subjective experiences and qualitative feedback. We believe this approach is necessary to accurately and consistently frame of our results. Having multiple perspectives allows for at least a minimal validation of our conclusions. We hope that our data will be mirrored in participants’ feedback. Furthermore, qualitative data can be used to explain unexpected quantitative variations.

We frame our research in the context of a competitive strength task between a user and a perceived agent in virtual reality. A competitive set up allows participants to face their opponents directly in a physical task. Furthermore, it constitutes a realistic interaction for a game setup. Players are told they are testing a rope pulling VR game and they are asked for feedback and suggestions to improve the game. Their task is to face several different *opponents* in VR, compete at pulling a rope and win. The player is able to see their hands in the virtual environment holding the rope. They are instructed to keep their hands on the rope at all times. Since their fingers are not animated and the grip is fixed on the rope, letting go of the rope might result in breaks of presence and ownership. We do not mention the nature of the opponent as we would like to investigate what assumptions participants have. We do not make the aim of our research transparent, to avoid any possible biases, such as the observer expectancy effect, or induce powerful demand characteristics.

For the game, participants use VR gloves and hold a real, physical rope that corresponds to the virtual rope. Rope-pull time will be adjusted through piloting. The present set up is a low fidelity version of the user study. The opponents do not respond to participants’ pull, and there is no force activating on the rope. We use

a spring and an elastic band to give some resistance when participants pull. To maintain the appearance of realism, we use animations, game physics and sound. We pay particular attention to timing and synchronization in the design of the game. As noted in [15], congruence between visuomotor actions gives rise to agency and ownership is determined by synchronized haptic and/or visual feedback. We combine and leverage these synchronicities to match the expected outcome of peoples actions. Such *sorimotor contingencies* [41] allows us to create a context viable for giving rise to VR physical illusions. We use spring resistance to give participants some motor sensations. After all, the rope moving towards them is something they expect to happen in a rope-pulling game. Realistic interactions that allow visual and sensorial synchronization seem to contribute to the formation of these illusions [41]. The ambiguous source of the motor feedback and its magnitude is what participants will have to discern.

Participants see a countdown accompanied by sounds for each visual element being displayed. They are told to start pulling when they see *start*, and stop pulling when they see *stop*. When participants start pulling, they also see their opponent pulling and feel the resistance increase on the rope as they go on. Through this flow of events we synchronize, visual, audio and haptic feedback in order to give users the impression of agency and realism. With this low fidelity set up, we explore whether participants perceived any changes in the rope pull. In a high fidelity set up, we would use motors to pull the rope to generate the illusion that another human player is pulling.

5 Implementation

The tug-of-war game was implemented in Unity3D and integrated with VR through SteamVR. Auditory feedback was provided for the countdown before the rope-pulling in order to increase the appearance of a gaming situation. Sounds were provided from the laptop speakers which was located behind the black curtains. To give users a sense of depth and maintain performance, we use mixed lighting methods³.

The avatars of the players were designed from the Morph Character System (MCS) female and male humanoid avatars⁴. The models were edited in Autodesk Maya⁵ to remove parts of the mesh so that only the upper torso and arms were displayed. The original skin material was replaced with a custom design with less detailing to remove any uncanny valley effects [43].

In the game players could see their left and right hand holding the rope, which

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³<https://docs.unity3d.com/Manual/LightMode-Mixed.html>

⁴<https://connect.unity.com/p/morph-3d-morph-character-system-mcs>

⁵<https://www.autodesk.com/products/maya/overview>

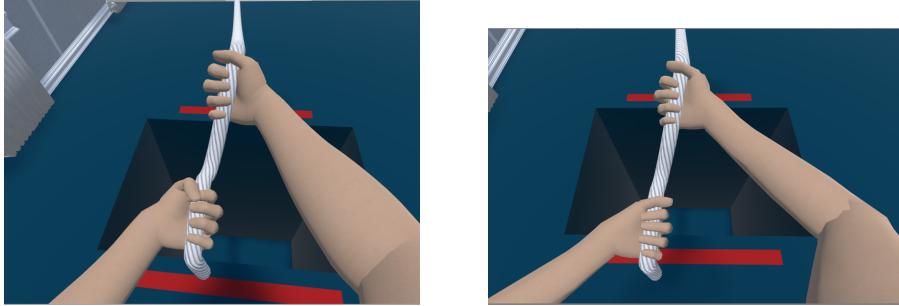


Figure 2: First person view of male (left) and female (right) arms.

comprised their embodied avatar (seen in figure 2). The virtual grip of the hands on the rope was taken from a real hand grip of the rope using the HI5 gloves. The finger movement was disabled as the gloves were easily magnetized by the set up and would malfunction shortly after the beginning of the experiment. To prevent loss of ownership from random finger movements, players were told to maintain the same grip on the rope at all times during the experiment. Before starting, users would undergo the calibration of the gloves provided with the HI5 glove set up to maintain accurate hand orientation and position. Despite calibration efforts and manual adjustment trials, the undesirable finger movement and often inaccurate hand orientation and position proved to be the most difficult set back of this project. This was most challenging when integrating the gloves within an inverse kinematics VR algorithm to display user arm movement in a natural manner.

We used Final IK VR⁶ to display naturalistic avatar body movements. The positions of reference for the algorithm were the left and right hand trackers, together with the headset position. This implementation does not always congruently display the position of the virtual arm and user arm. It is, however, an acceptable trade-off due to the lack of manual elbow tracking and full body tracking. Furthermore, due to the haptic sensation from actually holding a rope and the competitive aspect of the game, users were mainly focusing their attention away from their hands and on their opponent. The virtual rope was implemented using the Obi Rope asset⁷. Its settings were adjusted manually to simulate real rope movements through a trial-and-error approach. Please refer to appendix A for the chosen rope settings. The rope texture was modeled to the real rope users were holding.

Between rope-pulls we display a vertical panel with questions 3. We used TextMesh Pro⁸ for the font, to allow for better readability considering the reso-

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⁶<https://assetstore.unity.com/packages/tools/animation/final-ik-14290>

⁷<https://assetstore.unity.com/packages/tools/physics/obi-rope-55579>

⁸<https://assetstore.unity.com/packages/essentials/beta-projects/textmesh-pro-84126>

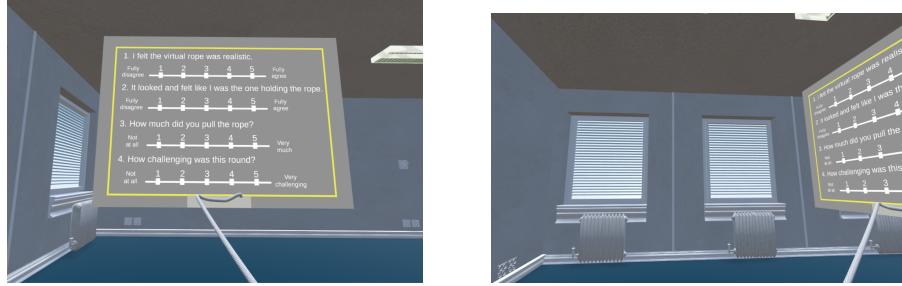


Figure 3: Panel with questions in VR, side and left view.

lution of the headset. Between trials participants always hold the rope in their hands. In order to still display the rope when agents do not hold it, we place it on the panel as if hanging there. To allow for natural transitions between experiment states, we use a black out animation lasting one section. This animation fades to black then fades back into the room scene. During this time we spawn the questionnaire panel or the opponents.

We designed the experiment scene to be as close as possible to room where the experiment was taking place. This was done to ease the transition between the virtual and the real world and to sustain high immersion.

Every second the state of the experiment is logged in a file. Please see Appendix subsection 11.1 for a detailed explanation of what is logged. Among others, we log users' the gaze target. This is implemented with a Raycast⁹ originating at the center of the headset. Gaze targets are detected as objects with colliders. Since UMA's and some special parts of the setting (such as the hole) cannot have coliders, we added transparent panels with colliders on top of these objects.

6 Agent Design

The virtual agents were created in Unity using the Unity Multipurpose Avatar 2 (UMA) asset¹⁰ and o3n UMA Races¹¹. We chose this library because the UMA character system has a high degree of avatar customization allowing avatar generation with relative ease. Programmers are able to vary body part sizes and, among many others, ear and brow rotations.

The manipulations described below serve to provide users with a more dynamic experience and make their opponents appear more life-like. We aim to create high behavior realism in order to make up for the lack of perceived agency.

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⁹<https://docs.unity3d.com/ScriptReference/Physics.Raycast.html>

¹⁰<https://assetstore.unity.com/packages/3d/characters/uma-2-unity-multipurpose-avatar-35611>

¹¹<https://assetstore.unity.com/packages/3d/characters/humanoids/o3n-male-and-female-uma-races-102187>

This serves the purpose of eliciting more realistic responses from people in accordance with the threshold model of social influence [20]. We place UMAs close enough to participants so they notice the changes in expression and other animation changes.

6.1 UMA Dna

We varied perceived strength in the design of the agents and used UMA DNA settings to generate a distribution of agents varying from strong looking to average and weak looking. UMA Dna represents a dictionary used to customize Unity multipurpose avatars (UMAs). Appearance can be changed on a scale of 0 to 1, with higher values being used to make adjustments more salient. A downside of this character system is that the magnitude of these features does not vary linearly and can differ between races and genders. For example, female muscle size cannot be increased on the same scale as male muscle size. Due to this, male agents have higher perceived strength. This can also be observed in the results of our survey in the next chapter. Another example is that increasing lower muscle mass for women inflated the leg muscles in an unnatural way. Furthermore, there were color differences due to mesh materials and texture.

UMAs in the strong conditions generally had strength-signaling Dna parts closer to 1. Their values decreased to 0.5 for agents in the normal conditions and below 0.5 for agents in the weak condition. We considered the default 0.5 Dna values as average. We manually adjusted these values through trial and error to give UMAs the most human-like appearance and prevent them from looking exceedingly uncanny.

6.2 Strength Cues

As strength cues we used muscle tone and fitness, together with adjusted facial proportion as seen in [44]. Skin, eye and hair color, together with outfit designs were kept as constant as possible between races and genders. For the upper body clothing, the agents had a sleeveless shirt to increase the visibility of the arm muscles. With respect to facial manipulations, we varied facial width and jaw size which are known to be associated with testosterone in men [45]. We decreased the size of the lips and eyes in the strong conditions to increase face-width ratio. While height and age are the best predictors for female perceived strength [46], we applied the same variations to the female avatars. We do not adjust height for the agents displayed in the survey images, however we manipulate height in the actual experiment, increasing height for agents in the strong condition.

As strength is closely related to dominance and aggression, we added variables meant to increase intimidation such as tattoos, military hairstyles and ma-

nipulated outfit colors. As in previous Proteus effect literature and associated body of work related to social psychology [10, 27], we used black clothing to elicit more aggressive attitude perceptions. Agents in strong conditions had black upper-body clothing, those in medium conditions had gray and for weak agents we used white. While male tattoos are dominantly viewed, female tattoos generate mixed responses from observers [47]. As with previous research [29], agents were gender matched to avoid any tensions or similarity biases that would arise from cross-gendered evaluations. Please see Appendix B for the agent settings and pictures chosen for the surveys, and the final settings chosen in the experiment.

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6.3 Animations

In addition, we use the UMA Expression Player to even out neutral facial expressions between races and genders. Please refer to appendix X for the neutral expression settings.. The Expression Player was also used at the moment the UMAs were pulling the rope to give the impression that the opponents were exerting themselves or seemed angry. Their facial expressions were exaggerated to be more visible to participants in VR. Additionally, we use the blinking mechanism provided by the UMA Expression Player to make the avatars blink throughout the trials. We interpolate¹² between the changes in facial expression in order to blend them in a natural way.

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tings

We use the Mecanim animation system provided by Unity for animation layering and blending. At the start of each trial the opponents are shown with the rope in their hands in an idle posture animation, with their hands moving in the air and their chest moving as if breathing. This animation overlays all other animations and plays throughout the trial. We use the *MORRO MOTION* Idle MoCap for this purpose¹³. After a 3-second countdown, UMAs are triggered with a rope-pulling animation. This animation is derived from the rope pulling animation on Mixamo¹⁴. When UMAs reach their maximum-exertion posture, a tugged animation is triggered showing the agents moving their hands back and forth as if the rope was being pulled from them. For the remaining pull time, the UMAs maintain maximum pull posture. This serves the purpose of giving users the impression that their opponents react to the rope being pulled. From the end of the countdown, the rope-pulling lasts 10 seconds. At the beginning of each trial participants have 20 seconds before the countdown starts. This is to allow users to inspect their opponent and look around the room if desired. After the rope pulling ends, there is a 10 second delay before the screen fades to black and the question panel is

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pic
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¹²<https://docs.unity3d.com/ScriptReference/Vector3.Lerp.html>

¹³<https://assetstore.unity.com/packages/3d/animations/idle-mocap-28345>

¹⁴<https://www.mixamo.com>

presented.

7 Survey

Through the survey, we aim to make an informed choice when selecting the final agents for the experiment. We provide a range designs that elicit realistic perceptions of intimidation and strength.

7.1 Survey Questions

Participants were told we were interested to see how people perceive traits of avatars based on their design and looks. The goal of evaluating strength and intimidation was not made completely transparent to avoid any possible bias. We gathered demographic data like gender and age. For each avatar, participants had to answer the following questions on a 5-point Likert scale, from 1 — *Strongly disagree* to 5 — *Strongly agree*:

1. This avatar looks attractive.
2. This avatar looks strong.
3. This avatar looks intelligent.
4. This avatar looks intimidating.

We are not interested in measuring intelligence, however it serves the purpose of distracting participants from the specific goal of the survey. Our main interests are strength and intimidation, as these variables may have the effect of changing user performance. Attractiveness is tangentially related because of the Halo Effect [48], whereby participants could be determined to assign more positive traits to the avatars. A further consideration with respect to the survey responses is agency. Since social responses can vary with agency [22], when answering the scale on intimidation, thumbnails of virtual humans may elicit lower responses than actual people.

7.2 Agent Design Coding

The agents were chosen through stratified sampling to display various levels of strength on a scale from *weak* to *very strong*. In total 36 agents were designed, 18 female and 18 male. The design procedure and implementation for these agents is described in chapter 6. Section 12.9 contains an enumeration of the images that users had to rate in this survey and represents the designed look of the agents' upper body. In section 12.5 we present tables containing a mapping of a unique

ID for female (10) and male avatars (11) to an agent design and its respective condition. We use this ID to reference the agent ratings in the following chapters.

7.3 Participants and Design

To measure perceived strength in our agent designs, we ran a survey with 31 participants (15 female), aged 21-60 (mean 25.5). Participants were recruited from the university and through snowball sampling. The survey was gender matched and each participant rated 18 avatar thumbnails on a 5-point Likert scale measuring perceived strength, attractiveness, intelligence and intimidation. The order of the agent thumbnails was the same for all participants, but they were randomly selected from an initial ordered set. The survey took 10 to 15 minutes to complete.

7.4 Results and Discussion

Please see section 12.9 for a complete overview of all ratings given to all agents and their respective thumbnail. Tables 12, 13 from section 12.6 show the mean ratings given female and males. The tables are ordered ascending according to the **Weighted** column.

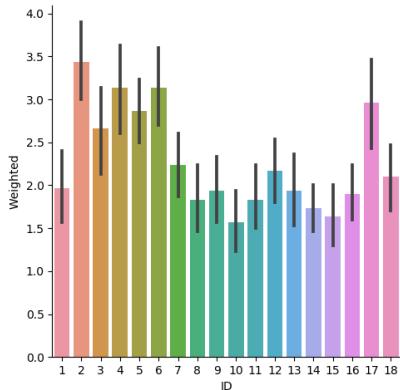


Figure 4: Female avatars
weighted ratings.

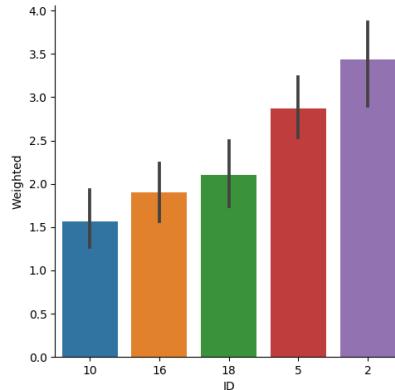


Figure 5: Chosen female avatars
weighted ratings.

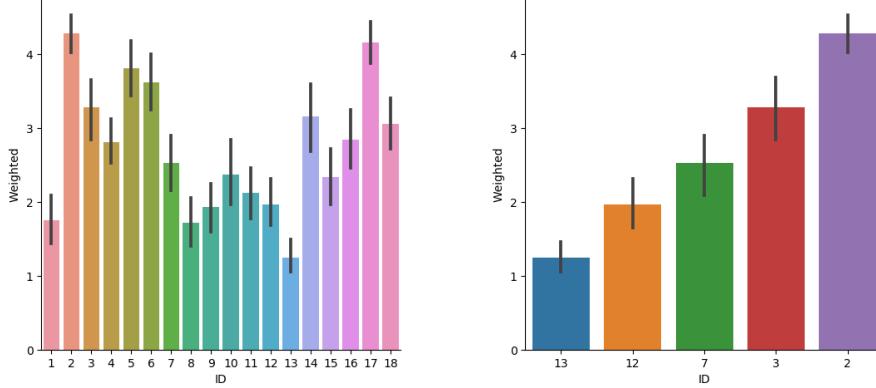


Figure 6: Male avatars weighted ratings.

Figure 7: Chosen male avatars weighted ratings.

To determine the final avatars for the user study, we compounded the strength and intimidation rating and computed a final weighted score according to the following formula: $0.5strength + 0.5intimidation$. This value can be found in the **Weighted** column. As a reference for the other chapters, the chosen UMAs are marked in the table in the **UMA** column. The first part of the column value represents a unique identifier for the UMA design and the second part is the condition shorthand, where C1 denotes the weak condition, C2 average and C3 strong. The unique identifier is shown on the x axis in the above table as ID. Users generally found UMA designs unattractive. Female ratings for intimidation and strength were lower than male ones.

As expected, female ratings were overall lower than male ratings. This is a limitation of the UMA DNA ranges and difference in character enhancements magnitude between genders and races. Female upper and lower body muscle mass could be increased less than for males. Males had more defined muscle, while for female muscle tone decreased with muscle mass. Other downsides of increasing body mass for females was that leg muscles grew non-uniformly and appeared unnatural. Some other disadvantages are mentioned in the previous chapter. We consider the Morph Character System (MCS) as an alternative to UMA, however support for current Unity versions has been discontinued for this library.

7.5 Conclusion and Improvements

For more control over avatar variation, we can consider a custom design for the avatars using a 3D modelling tools. UMA has the advantage of providing a simplified and fast method of generating many avatars with some degree of control over the body-related changes. Conversely, 3D tools are have a high learning curve and can be difficult for inexperienced users. To allow the same magnitude of change

for all body modifications, we would ideally implement a VR character creator with a simple user interface. With respect to appearance modification, other body enhancements such as piercings can be considered.

8 User Study

Before starting the experiment we had a series of pilots to determine rope-pull quality, force measuring feasibility and opponent realism. We also collected feedback about rope-pulling duration and animation styles.

8.1 Initial Design

For the piloting, we had a gender-matched, within-group experimental design. Initially, the game consisted of three of rope-pulls with questions in-between. We had the same technical set up as mentioned in section 8.5. The rope was tied to a box with a force meter and some elastic bands were placed between them to give the impression of resistance. The box was set on a table to prevent damage to the force meter from being dropped. This would additionally prevent participants from feeling a weight on the box between rope-pulls. The VR room was made as similar as possible to the experiment room. There were two rounds of piloting. For this, we recruited participants from the university campus. Each round resulted in several modifications to the original design of the experiment and implementation of the game. We detail these changes below.

8.2 Piloting

For the first piloting session we had 2 participants, 1 female, aged 23-25. Participants had observations with respect to the way their opponents were holding the rope, mentioning that one looked like it was “holding a rod” in their hand. They also mentioned the distinction between the avatars’ strength was too obvious and showed high awareness of the experimental purpose. Animation wise, initially opponents pulled the rope at the start of the countdown and resumed initial position at the end of the trial. One participant mentioned that they “expect her to react when [...] pulling”. After this session, we decided to increase the number of rope-pulls to five and add 3 additional agents to represent low-average, upper-average and average strength. With this, we wanted to remove any clear impression of strength separation between the agents. We redesigned the grips the opponents had on the rope and added two fixed points on the opponents’ thumbs and pinky finger to make the grip seem more natural.

Additionally, we added a tug animation after the agents start pulling the rope,

and overlayed an idle breathing and moving animation throughout the trials. The sequence and design of these animations are further explained in section 6.3. Regarding the rope set up, we noticed the force meter was placed inadequately inside the box and participants would rotate it when pulling. This could affect their perception of the forces acting on the rope and it was undesirable. We subsequently used a bigger box and place the force meter and camera in the middle to balance the weight remove rotations. Furthermore we noticed the elastic bands were stretching and breaking and for the final experiment we used a spring and an elastic rope.

A second pilot was ran with 2 males participant, aged 28. Seeing the rope being pulled back, one participant mentioned that the agents’ “[the opponents] reacting to me is nice”. From this session the participant asked if they are pulling on a box. We noticed the sound of the box hitting the table was drawing their attention to the rope setup. To remove this we placed a blanket on the table to dampen any sounds from the rope or other attachments. The participant also mentioned that they wished it took longer and so we increased rope-pulling duration to 10 seconds from 6 seconds. We also increased the time spent looking at avatars before starting the countdown to 20 seconds from 10 seconds. One participant also mentioned that “[starting he competition] felt too sudden” and would like “more time to adjust and look at hands, take in the surroundings.” As a consequence of this, we made an additional scene that participants would see before starting the actual game. This was the questionnaires part between rope-pulls. Participants would first see the panel of questions, their hands and the rope for 1 minute before starting the competition.

Additionally, we noticed that participants were pulling the rope too hard and moving the set up, if allowed to use their legs. The first set of pilots were not allowed to use their legs and the second one was allowed. This was problematic because, upon noticing that they are pulling too hard, participants would restrain themselves and the first trial would have a higher force distribution than the rest. We decided to tell participants not to move their legs, if they can. To test if the elastic addition to the rope makes any difference, we asked a participant from the last pilot to play the game two times, one with a rope and elastic resistance, and one with the rope tied to the meter directly. The participant mentioned that it is “much better” with the elastic band because it gives the impression of “some resistance”. We believe this impression is so strong due to the timing between the visual and tactile stimuli. Participants see their opponents pulling and feel resistance at the same time.

Other miscellaneous set up decisions were taken:

- For the glove calibration, we changed the instruction panel to appear in front of the users, so they would not need to turn around to calibrate the

gloves. This change was needed because participants were turning around and moving away from the preset experimental location and interfering with the base stations;

- We placed the desks in the room away from the rope-pulling location;
- We relocated the laptop containing the post-experimental survey away from the base stations;
- We relocated the base stations and placed them higher, as we noticed taller participants would get between them and cause loss tracking issues;
- We placed papers with directions to the experiment room around the experiment location.

8.3 Experimenter Instructions

Throughout the piloting sessions, many of the difficulties of running this study were revealed. The most challenging task would be synchronizing data capturing with starting the game and giving all necessary information to participants. If VR set up errors occurred, such as base station loss of sync or tracker issues, the experimenter would need to ad-lib until starting data capturing, resume experimental procedure and repeat important instructions. We incorporate all this knowledge in an *Instruction Sheet* the experimenter must follow to give participants the same experience of the study. This sheet can be seen in section 12.3. Additionally, participants were required to sign a consent form (presented in section 12.4) which broadly described the experimental setup, method and purpose. In it, we ask for their consent to store recordings and other experimental data in an anonymized form. Both forms were modified from their initial structure as a result of piloting. The purpose of evaluating strength of pull based on avatar appearance was not mentioned in the consent form. Instead, broader terms such as *virtual reality interactions* were used.

8.4 Experiment Design

To investigate whether an agents' appearance can increase people's strength, we ran a study where participants played tug-of-war with an agent opponent in VR. We elaborate on our research aims and methodology in section 4. We had a gender-matched, within-group experimental design for the user study. We independently vary the agent's appearance on a 5-point scale from weak-looking to strong-looking. Participants played five trials of rope-pulling with the five avatars chosen from the survey. The avatars were meant to display various degrees of strength and intimidation, compounded in a final weighted score. We chose the

weakest and strongest male and female avatars. For the remaining three, we chose avatars in a low-average, average and high-average strength condition. Further details about the avatars chosen for the experiment are presented in section 7.4. For each trial, we measure the maximum pull force in kilograms for each participant, which constitutes our dependent numeric variable. We further measure perceived pull and perceived challenge on a 5-point Likert scale, with constitute our two ordinal dependent variables.

Participants completed a post-experimental survey, gave feedback for each rope-pulling trial in-game and had a short chat with the experimenter at the end. All subjective questions were answered on a 5-point Likert scale.

Between each rope-pull, participants rated four statements about the previous round on a 5-point Likert scale. They were presented with a panel of these questions in VR, and were asked to read the questions out-loud and give their answer to the experimenter. These questions are the following:

- **Q1:** I felt the virtual rope was realistic. Rating: 1 (*Fully disagree*), to 5 (*Fully agree*);
- **Q2:** It looked and felt like I was the one holding the rope. Rating: 1 (*Fully disagree*), to 5 (*Fully agree*);
- **Q3:** How much did you pull the rope? Rating: 1 (*Not at all*), to 5 (*Very much*);
- **Q3:** How challenging was this round? Rating: 1 (*Not at all*), to 5 (*Very challenging*).

Q1 refers to rope realism, Q2 captures rope agency, Q3 refers to perceived pull and Q4 refers to challenge. We will use these terms to refer to the categories of these questions in the results section. Q3 and Q4 are two dependent variables. We present results of Q1 and Q2, however their main purpose was to give participants the impression we are evaluating rope performance.

For the post-experimental survey, we measured participants' subjective experience on three levels: body ownership, presence and co-presence measures. To measure presence, we retained 5 items from the igroup presence questionnaire (IPQ):¹⁵

- **Q1:** How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)? Rating: 1 (*Not aware at all*), to 5 (*Extremely aware*);

¹⁵<http://www.igroup.org/pq/ipq/index.php>

- **Q2:** How real did the virtual world seem to you? Rating: 1 (*Not real at all*) to 5 (*Completely real*);
- **Q3:** How much did your experience in the virtual environment seem consistent with your real-world experience ? Rating: 1 (*Not consistent*) to 5 (*Very consistent*);
- **Q4:** I felt present in the virtual space. Rating: 1 (*Fully disagree*) to 5 (*Fully agree*);
- **Q5:** In the computer generated world I had a sense of “being there”. Rating: 1 (*Not at all*) to 5 (*Very much*).

The IPQ questionnaire measures presence on three levels: spacial presence, involvement and experienced realism. From our retained questions, Q1 refers to involvement, Q2 and Q3 capture realism, Q4 spacial presence and Q5 refers to general presence.

The survey items for body ownership were taken from [19]. For our study, we replaced the term *hand* with *arm*, and changed the 7-point rating scale to a 5-point one. The following questions were retained:

- **Q1:** I felt as if the virtual arm moved just like I wanted it to, as if it was obeying my will. Rating: 1 (*Fully disagree*), to 5 (*Fully agree*);
- **Q2:** I expected the virtual arm to react in the same way as my own arm. Rating: 1 (*Fully disagree*), to 5 (*Fully agree*);
- **Q3:** I felt that the interaction with the environment was realistic. Rating: 1 (*Fully disagree*), to 5 (*Fully agree*);
- **Q4:** I felt like I controlled the virtual arm. Rating: 1 (*Fully disagree*), to 5 (*Fully agree*);
- **Q5:** I felt as if the virtual arm was part of my body. Rating: 1 (*Fully disagree*), to 5 (*Fully agree*);
- **Q6:** I felt as if the virtual arm was someone else’s. Rating: 1 (*Fully disagree*), to 5 (*Fully agree*).

With respect to co-presence/social presence, we retained three questions from [49], changed their scale to a 5-point one and replaced the term *interaction partner* with *opponents*. They questions are:

- **Q1:** My opponents were intensely involved in our interaction. Rating: 1 (*Fully disagree*), to 5 (*Fully agree*);
- **Q2:** To what extent did you feel able to assess your opponents’ reactions?. Rating: 1 (*I was unable*), to 5 (*Their reactions were clear*);

- **Q3:** To what extent was this like you were in the same room with your opponents? Rating: 1 (*Did not feel in the same room*), to 5 (*Felt completely in the same room*).

Additionally, the participants had to rate the appearance of the avatars on the same scale as in the initial appearance survey. We did this in order to verify our assumptions with respect to the hypothesis, that the opponents users faced were indeed perceived as strong/intimidating. These questions were in the final part of the post-experimental survey:

1. This avatar looks attractive.
2. This avatar looks strong.
3. This avatar looks intelligent.
4. This avatar looks intimidating.

The avatars were randomized for each participant at the start of the experiment. This study was ran alongside another study by researchers within the department. We made a common call for participants to take part in a *VR Games Study*. Their task was to assess to virtual reality games and give researchers feedback about their experience. The two games were Tug-of-war VR and Whack-a-mole VR. At the end of the experiment, participants had a short recorded chat with the experimenter. Participants were asked to give feedback for the games and, in addition, we checked their awareness about the true purpose of the experiment.

8.5 Setup and Measurements

For the experiment we used a Predator Helios 300 Acer laptop with an Nvidia GeForce GTX 1060, VRREADY graphics card. VE immersion was achieved by using a HTC Vive headset with a resolution of 2160x1200 and a refresh rate of 90Hz. Players' hand movements were tracked by the Noitom HI5 Vive tracker gloves¹⁶. The glove uses a wrist-mounted Vive tracker to generate users' presumed hand position. In addition to the subjective measures presented in the previous section, we gather quantitative datam namely the maximum pulled force for each rope-pull. We measure the force of participants' pulling through a digital force meter with a seven-segment display. The force meter was fastened inside a box and placed on a table. We recorded the force by filming the digital display with a webcam, Intel RealSense VF0800 Developer Kit Digital Depth Camera¹⁷. To hide the measuring mechanism, participants pulled a rope between two black

¹⁶<https://hi5vr手套.com/>

¹⁷<https://www.intelrealsense.com>



Figure 8: Participants' view of the setup.

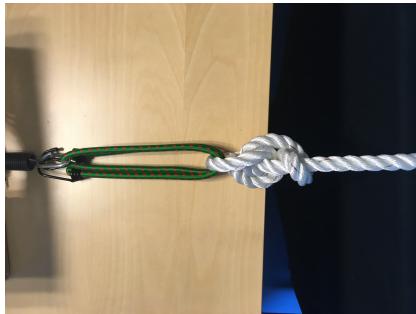


Figure 9: Rope and spring tied to the meter.



Figure 10: Box with force meter and camera.

sheets which hid the whole set up of the experiment. This setup is shown in figure 8.

The force meter was placed on a table and it was tied to a heavy piece of furniture. To dampen the sound of the box hitting the table, a piece of cloth was placed under the box. Various amortizing materials were placed inside the box to absorb sound and prevent the force meter from being damaged. The rope was tied to an elastic cable connected to a strong spring. The spring was connected to the force meter. The elastic band offered less resistance and, as participants pulled, the spring increased resistance. This spring mechanism was designed to increase realism and offer users some resistance in order to give the impression of a force acting on the rope. The box and spring mechanism can be see in figures 9 and 10.

8.6 Procedure

We greeted participants and briefly explained the broad purpose of the study. After that, we gave them two consent forms to fill in and further explained details and constraints of the tug-of-war game. Before giving participants the VR headset and gloves, they filled in a short survey with demographic data. The experimental

procedure is fully explained in section 12.3.

Before starting the game, we calibrated the gloves for participants' hands. For each rope-pulling trial, participants were told to start pulling after the end of the countdown, when they see *Start*, and keep pulling until they see *Stop*. They also received audio feedback for the countdown. Participants were told to follow two constraints: always keep their hands on the rope and try pulling the rope without moving their legs. Between rope-pulls, participants answered the questions on the quiz panel (figure 3) from within the VE. After 5 rope-pulls, the game ends and participants are asked to fill in the post-experimental survey. The survey questions of the avatar appearances were gender-matched. Before participants left, we collected feedback about the game and then debriefed users about the true scope of the study.

For each trial, users pulled the rope for 10 seconds. Before that, they were in the VE with their opponent for 20 seconds. After the pulling ended, they remained in the same VR state for an additional 10 seconds. During this time, users could inspect the appearance of the avatars. Only after that, participants were shown the quiz panel. Transition between the game states (rope-pulling and quiz panel) was realized through a black splash screen. When the screen faded to black, the objects in the room changed. The screen fades back when the changes are complete. We did this in order to maintain a natural state of the room and prevent breaks in presence and immersion. Further details about the implementation are presented in section 5.

8.7 Participants

In order to give the appearance of a gaming study, we designed a poster to recruit people for the experiment. We placed this poster (12.10) around the university campus and used it for recruiting messages. For the user study, we recruited a total of 28 participants (17 female) from the university campus and local Facebook groups. They were between 21 and 34 years old ($M = 24.42, SD = 3.06$). Participants were unable to take part in the study if they previously completed the avatar appearance survey. We discarded the results of 2 participants (1 female) due to invalid data. Of the remaining ones, 9 participants had never used VR before and 16 had never played real-life tug-of-war. Participants were rewarded with a gift valued at 100 danish krone for taking part in the whole study.



Figure 11: Participants playing tug-of-war VR .

8.8 Results and Discussion

The results were manually logged by the experimenter. To measure the maximum force, we looked at the force meter data from the end of the countdown, at the beginning of the *Start* message, until the end of the *Stop* message. All force data presented is measured in kilograms. In the plots below, we present data in terms of ordering and condition. By ordering, we mean the order in which participants saw the appearances, labeled as *Trial*. By condition we mean the condition of the opponent participants faced, labeled as *Condition*. Trial 1 refers to the first trial of rope-pulling participants performed, out of a total of five. Trial 2 refers to the second one and so on. The condition captures the independent variable and represents a numerical mapping from 1 to 5 to the appearance variable, increasing by strength/intimidation. Condition 1 refers to the weakest-looking chosen avatars according to the weighted score (see 5,7) and condition 5 refers to the strongest looking avatars. We also display our results by gender.

Considering the large amount of information presented, we structure the results section as follows:

1. For each subsection we start with a short paragraph describing the main findings, if applicable;
2. We give an overview of the results;
3. We discuss the results with respect to related work and speculate on our respective findings;
4. At the end, we present a summary of all our findings and discuss implications.

8.8.1 Conditions per Trial

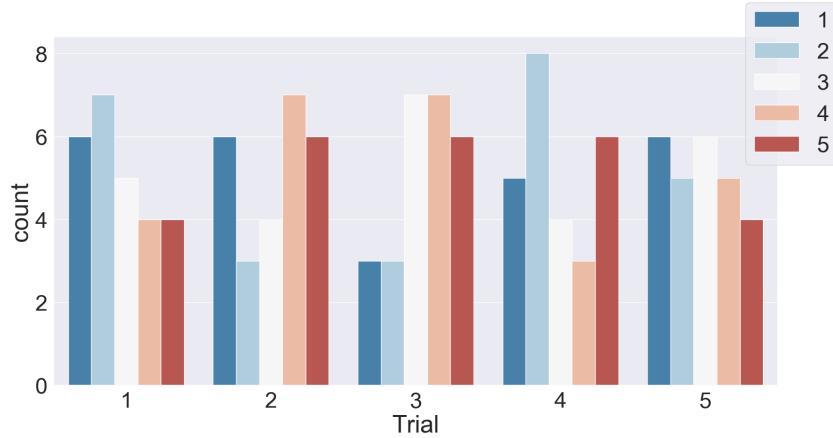


Figure 12: Number of conditions per trial.

In the above pictures we show the distribution of each condition for each trial. Since the conditions were randomized, there may be an effect of over-representation. The fifth trial seems to be the most balanced, representation wise. We had more female participants and thus more female avatars were evaluated. For an overview of the distribution of conditions per trial for males and females please section 12.2 figures 34 and 33.

8.8.2 Appearance Ratings

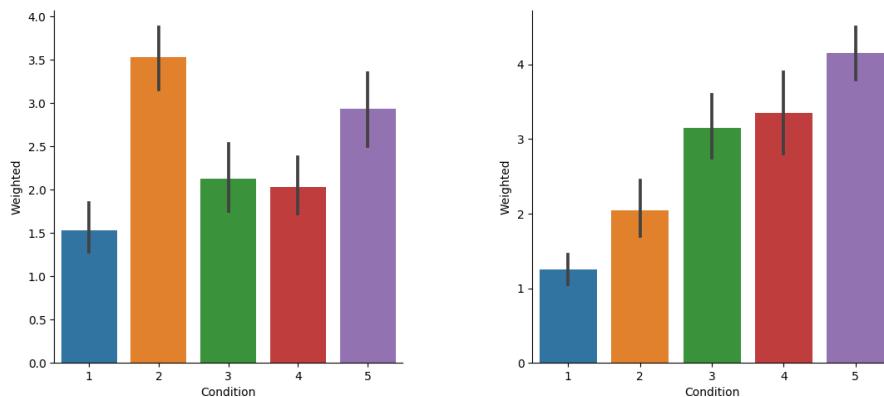


Figure 13: Weighted ratings by condition for the opponent avatars in the user study. Error bars show 95% confidence interval.

Results

Participants rated the appearance of same-gender avatars on attractiveness, intimidation, intelligence and strength. In the above figures we present the weighed results of those ratings for female (13a) and male (13b) avatars. The weighted value is computed as: $weighted = 0.5strength + 0.5intimidation$. Male participants rated the avatars as expected, increasing in intimidation and strength by condition. For females, the avatar in condition 2 (low-average) was rated as highest in intimidation and strength, while the avatar in condition 5 (strong) came second. All ratings for these avatars and their thumbnails can be found in section 12.8.

Discussion

The ratings for female avatars for the VR tug-of-war game were inconsistent with our results from the survey. There were several limitations when designing the female agents (detailed in section 6) which lead to females being perceived overall as less strong and intimidating, even in the survey. One difference between the 2 studies is that participants playing tug-of-war could see the full body of the avatar in VR. On the other hand, participants filling in the survey only saw their thumbnails. Furthermore, due to the resolution of the headset, participants in VR saw the avatars with less clarity and texturing. One participant mentioned that she would have liked to see females having more hair. This aesthetic preference appears to have put off participants instead of making strength cues more salient.

8.8.3 Qualitative Feedback

Our observations and qualitative feedback show that people experienced various degrees of physical illusions. Participants initial comments suggest that the illusions were stronger in the first few trials. As the game went on, they seemed to become aware that there is no force acting on the rope. Realism was often quoted as a reason for the breaks in illusion. With respect to this, participants suggested improving the animations and making their opponents react to their pull. The virtual rope was seen as highly realistic and holding the rope seemed to contribute to this belief.

Results

In total, 4 participants showed high awareness of the purpose of the experiment (“how people react when they see different people in front of them”— P22). Among them, a few made comments about their own behavior, which seemed to support our research question (“for the people that looked stronger I had to pull more”— P2).

Participants generally seemed to have an expectancy that the stronger the avatar

looks, the more they should pull (“if you expect a stronger person you will pull stronger”—P14). P16 mentions “I felt like the body shape was according to how to pull. [I was] pulling more strong for someone bigger and less for someone smaller”. In the case of P26, they mention intimidation: “I was expecting I would feel the need to pull harder because the characters were more intimidating from their look”.

With respect to the challenges, some participants clearly state feeling a distinction: “[for one avatar] felt like it was easier”—P19, “felt actually pulling like there was another person on the other side”—P16. Furthermore, our qualitative feedback suggests the illusions were breaking as trials went on. In the case of P13, her feedback in the first trial was that: “It’s weird - I can feel something pulling”. Eventually, in the post-experimental interview she mentions that “sometimes they were pulling without me feeling”. P4 remarks: “the machine did not make much effort pulling back” and that “[it] was not consistent with the guys [referring to opponents]”. However, in the end they state: “[it] lost realism when I realized it isn’t pulling back”. P15 remarks feeling a difference in the first trials, but not in the last ones — “didn’t see a difference in challenge in the last 2 ones”. P9 comments: “I can tell the difference between the challenges”. However, by the end they conclude referring to the opponents that it “didn’t feel like they were pulling”. One participants adds that the appearances made him think about his own abilities: “I think it was the same strength but, in a way, since you are not prepared for that, maybe you feel weak” (P18).

Some participants were unsure if they had felt any difference and used ambiguous language to suggest they felt little to no variation: “can’t tell if there was a difference or not in pulling”—P15, “more or less the same strength”—P24, “did not feel that much of a difference in enemies”—P28. P8 then adds that it seemed like they were “receiving same amount as putting into it”. They admit feeling “resistance”, however it was “difficult to tell”. Acknowledging some perception incongruities, P25 says that: “I wasn’t sure if I should feel the pressure, but I could see them pulling so you created that impression a bit”.

Others mentioned not feeling any difference throughout the experiment: “didn’t feel physical challenge of a counterattack” (P17), “feels like it’s the same challenge” (P12). Often, participants referred to lack of realism when pointing out downsides of the game: “when I was trying to pull harder, [I] didn’t have my body being pulled”—P17. They were mostly disappointed that their opponents were not reacting properly to their pull: “always leaned back no matter how much I pulled”—P23, “if you pull harder you expect them to come closer, lose balance or pull harder”—P14. They suggested “make[ing] the other avatar move or fall” (P7) or adding sounds: “avatars made it look more unreal, it looked silent; make them talk with some sounds” (P16). When their expectations about the game were not met, the realism of the experience decreases (“didn’t feel real because they were

not pulling stronger when they looked stronger”—P9). Some participants noticed that the avatars were animated in the same way, which also had an impact: “avatars doing the same, kind of the same move, doesn’t feel realistic”—P11. Additionally, users desired their opponents to be more *expressive* (P27). Beyond avatar design, a participant mentions that “being able to also move your feet would be good” (P11). One participant disliked that the textures and shading in the game were not detailed enough (P6). In their opinion, these design enhancements were required to generate a realistic setting.

In contrast, there were some participants who found the experience highly realistic “Felt real like really against an opponent” (P1). The rope was often mentioned as a good source of realism for the game: “Felt more real because I was holding something”—P9. The haptic feedback seemed to make the virtual rope even more real, one participant mentioning: “I didn’t look as much at my hands as I thought [...] I could feel the rope”. P16 remarks: “I played VR before, but never like pulling an object and seeing it in VR [...] It helps that you feel the rope and see the rope”. Few mentioned any downsides of the rope (“rope was too elastic”—P15).

Participants did not generally make comments about their arms. Some noticed inaccuracies in their avatars: “Arms seemed off when I looked straight at them”—P4. For example, P1 had a highly realistic experience (“I really had a feeling like I was in that room”), but mentions the arms *twisted around*, and “everything else felt more responsive than the arms”. // We also noted that sometimes participants dynamically changed their standards for the challenge ratings: “I’m getting tired more so I will give it a 5”—P11. P10 mentions that he begins to give 5 challenge ratings because of lack of feedback: “I feel like I’m not making any progress; they are not moving at all”.

Discussion

Overall, from their feedback and our observations, participants seemed to use the system in unexpected ways. Their comments suggest that they tested the way in which opponents pulled. In one example, P23 acknowledges straying from experimenter instructions to test their assumption. After the game, P23 mentions that when they saw a *strong guy* they *expected* them to pull harder, so they pulled less to feel it. When logging the results of the force meter and during the game we also noticed participants were pulling the rope in various ways. They were instructed to pull the rope and keep pulling until they see *Stop*, however many users tugged at the rope, pushed it back and forth instead of keeping it at maximum exertion. Moreover, other participants seemed to be affected by the novelty of the experience. P10 was surprised that they actually had to pull the rope and realized this only after the trial began, when the experimenter remarked they should pull the rope. The first trial had other design problems. Three participants used their legs

initially and pulled too hard, moving the equipment. They realized they could not pull so hard and restricted themselves in the following trials. Other participants also displayed this restraining behavior and reluctance to pull hard.

8.8.4 Force Meter Data (H2)

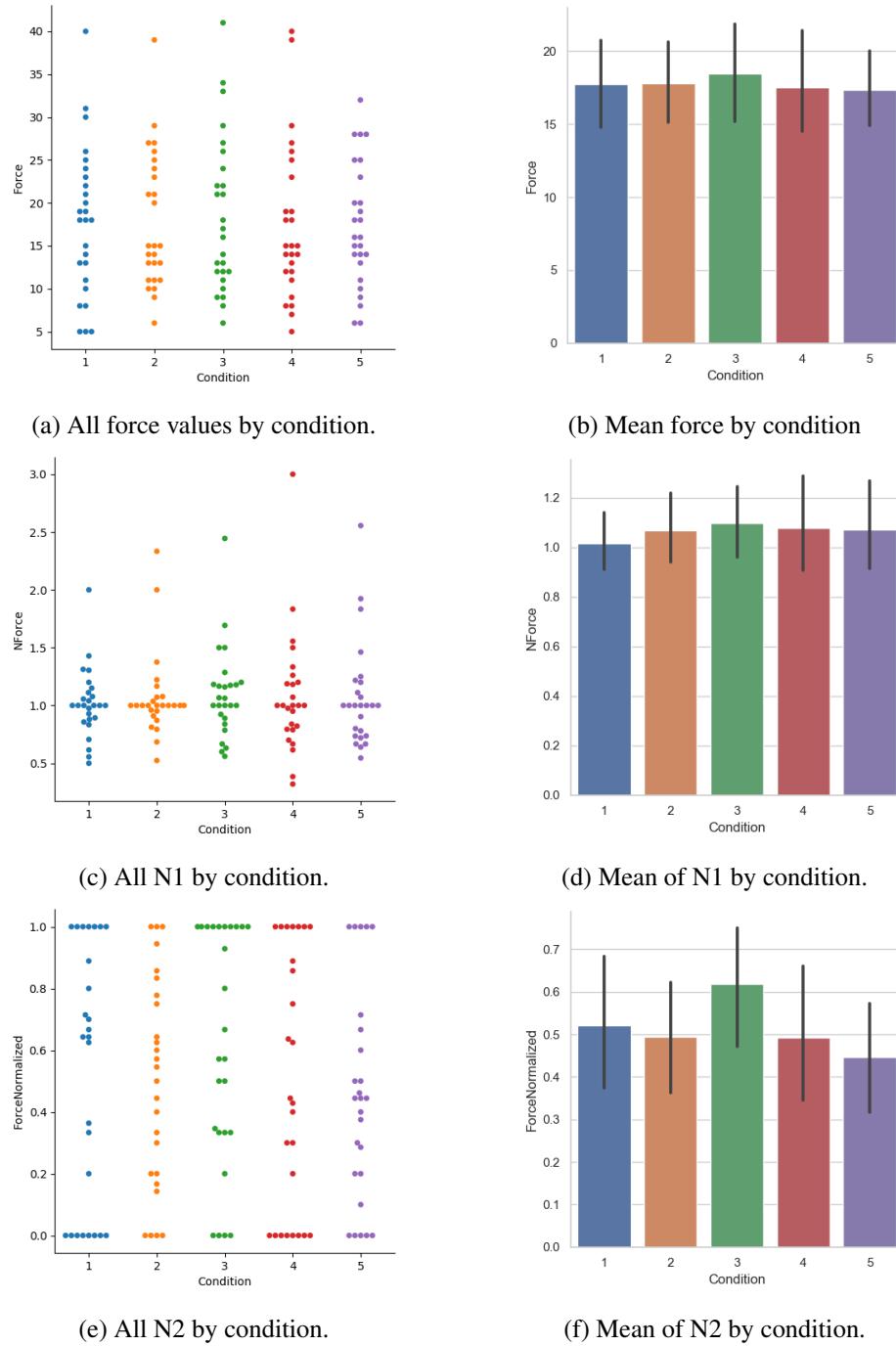


Figure 14: All force (kg) values by condition. Error bars show 95% confidence interval.

Despite positive qualitative feedback, there were inconsistencies in how strong participants pulled. We expected some variability because users interacted with the system in unforeseen ways. These quantitative results, however, do not appear to support H2.

Results

In the above figures we show an overview of all the data measured from the force meter, namely the maximum force pulled for each trial (kg). We normalize this data in two ways, N1 and N2. In the case of N1, for each participant we subtract from all trials the value in the first trial. For N2, we normalize values between 0 and 1 with min-max normalization. We take the minimum and maximum for each participant from all their respective trials. The normalization formulas are as follows:

$$N1_i^p = X_i^p - X_1^p, i \in \{1, 2, 3, 4, 5\}, i \text{ trial number, } p \in PIDS$$

$$N1 = \{N1_i^p | i \in \{1, 2, 3, 4, 5\}, i \text{ trial number, } p \in PIDS\}$$

$$N2_i^p = \frac{X_i^p - X_{min}^p}{x_{max}^p - x_{min}^p}, i \in \{1, 2, 3, 4, 5\}, i \text{ trial number, } p \in PIDS$$

$$N2 = \{N2_i^p | i \in \{1, 2, 3, 4, 5\}, i \text{ trial number, } p \in PIDS\}$$

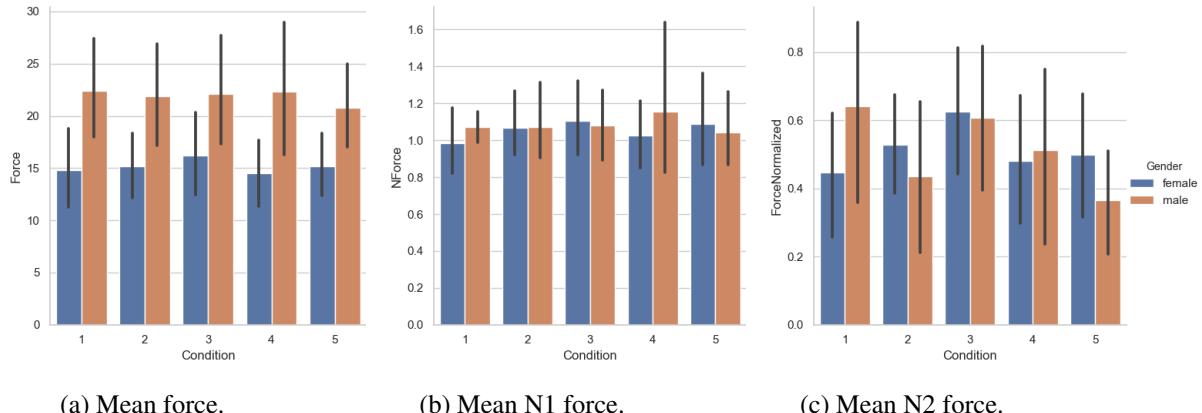
The force meter measurements do not seem to support our hypothesis, that the stronger avatar looks the harder people would pull (H2). The differences between trials are not very significant and the error bars vary. The data shows participants pulled slightly more in the third condition (average). In the tables below we present mean and standard deviation per trial and condition. For all force data we have: $M = 17.76153$, $SD = 8.29289$. From the tables below, there appears to be more variation by condition than by trial. Also, participants seemed to pull the strongest in the second trial and for condition 3 (average-looking).

Cond	Mean	SD
1	17.73076	8.70658
2	17.76923	7.88064
3	18.461538	9.06523
4	17.5	9.06090
5	17.34615	7.20523

Table 1: Mean force and standard deviation by condition.

Trial	Mean	SD
1	17.69230	8.75794
2	18.65384	8.42350
3	17.88461	8.19427
4	17.19230	8.37147
5	17.38461	8.28529

Table 2: Mean force and standard deviation by trial.

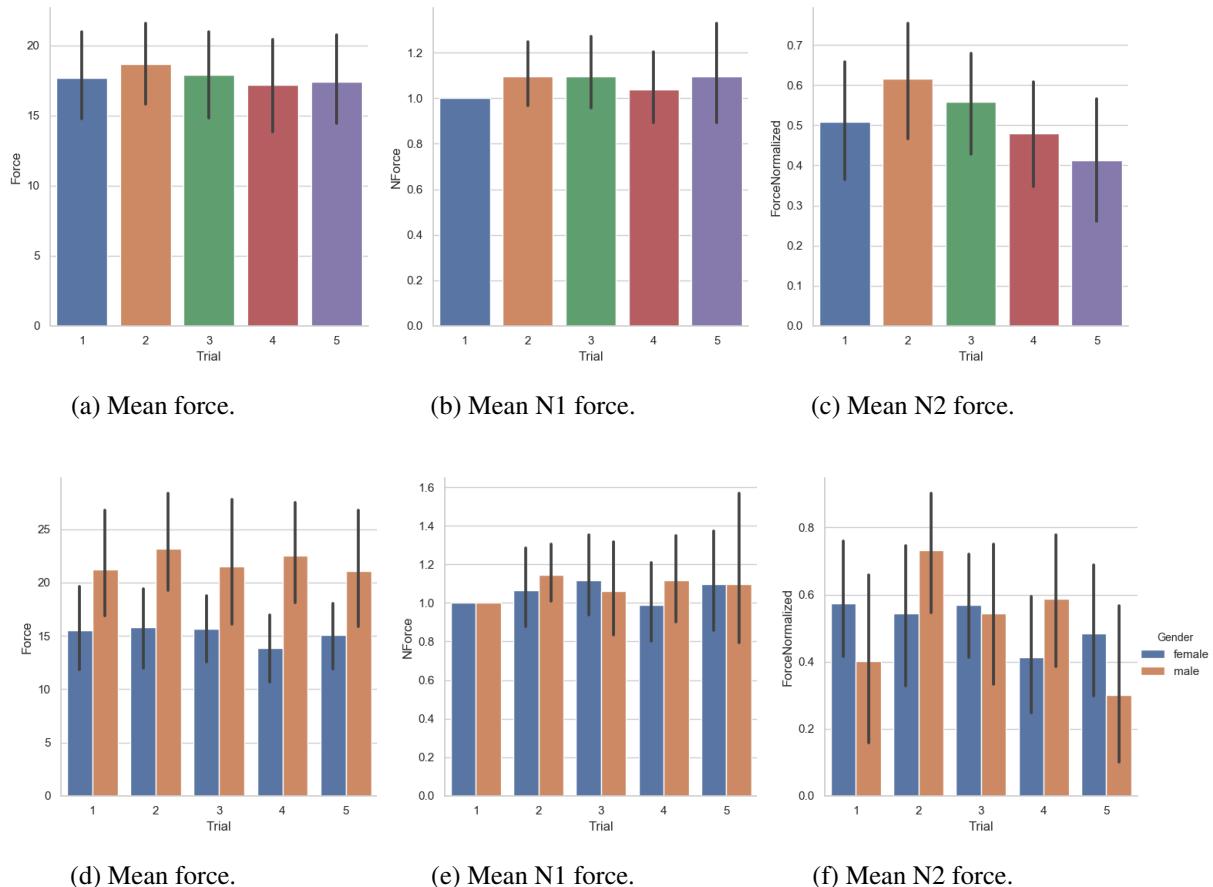


(a) Mean force.

(b) Mean N1 force.

(c) Mean N2 force.

Figure 15: Mean force, N1 , N2 by condition and by gender. Lines on bars denote confidence intervals.



(a) Mean force.

(b) Mean N1 force.

(c) Mean N2 force.

(d) Mean force.

(e) Mean N1 force.

(f) Mean N2 force.

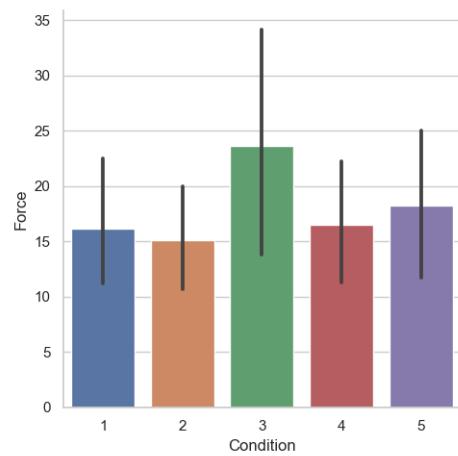
Figure 16: Mean force, N1, N2 by trial, and by gender in the second row. Error bars show 95% confidence interval.

From figures displayed in 15 we can see males pulled more than females. Additionally, the error bars seem to be overall bigger for males than females. Error bars are biggest for N2 due to the normalization procedure, as minimum values are considered 0 and maximum values 1. Male participants seem to have the biggest error bars in condition 4.

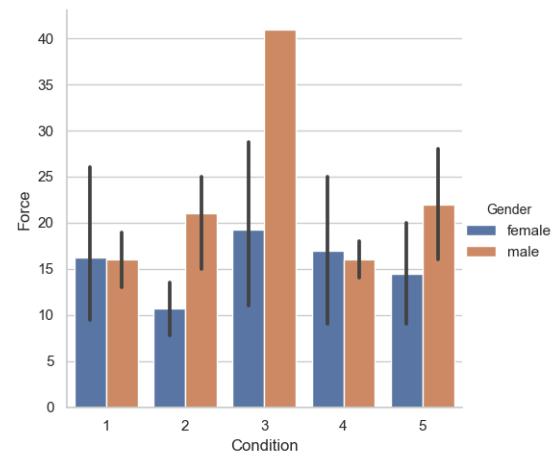
In figure 16 we display our results by trial. Both males and females seemed to have pulled harder in the second trial. We look at the distributions of avatars per trial in order to determine if the effect is due to order or representation. Figure 12 shows that in the third trial there were the most avatars in condition 3. The high pulling values would, therefore, more likely occur because of condition than trial order, as participants seemed to pull hardest for the average condition.

While an effect of ordering seems to be less strong than appearance, we observed some design issues for the first trial. Participants reacted in various ways due to the novelty of the experience or the setup. As such, we isolate the first trial to look for discernible differences.

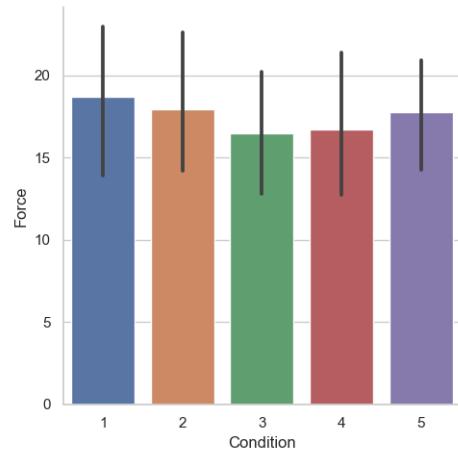
We examine our results considering only the first trial in figures 17a and 17b. In figures 17c and 17d we look at our results excepting the first trial. We notice there are 2 trends between these force pulls. In the first trial, womens' pull on the rope increases until the third condition, then decreases. They pull the least in condition 2, which was the avatar rated most strong and intimidating by women participants (see 13a). There is only one data point for males in the average condition, which seems to be an outlier of very high force. It would explain the high value for condition 3 for all participants in figure 17a. Males' pull increases again for the last condition. When we consider trials 2,3,4 and 5 there is also an increase in pull for women in condition 5. Overall it looks like the first trial has an uptick in the force for the average condition, something not present when considering only the last 3 trials.



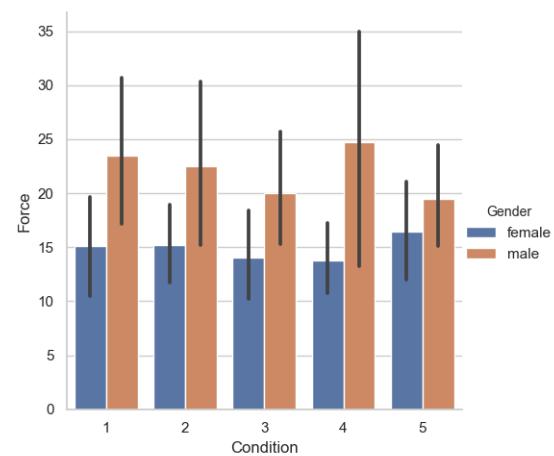
(a) Mean force in 1st trial.



(b) Mean force in first trial gendered.



(c) Mean force in all trials except first one.



(d) Mean force in all trials except the first one gendered.

Figure 17: Mean force by condition and by gender, taken for the first and first 3 trials. Error bars show 95% confidence interval.

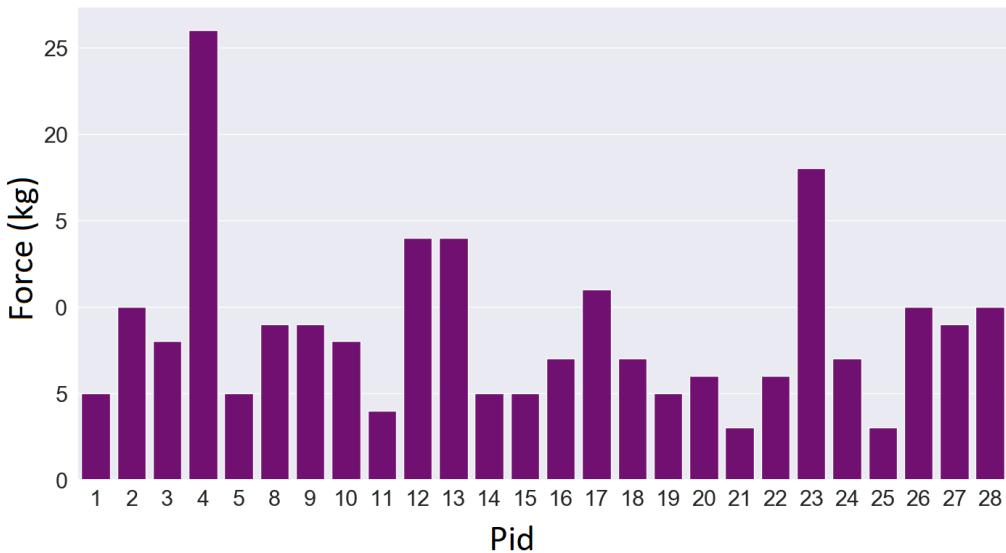


Figure 18: Maximum force difference per participant.

Participants did not appear to use force in accordance with our hypotheses (H2). However, our data shows some users varied their pull very much. We explore the maximum differences in pulling for each participant in figure 18. On average, the difference was: $M = 8.61538, SD = 4.94995$. However, there are several outliers. The maximum pull difference was for participant 4 — 26 kg of force. With our hypothesis, we presumed there would be differences in pulling, however such large differences suggest participants were not simply reacting to their opponent. Rather, some other factors seem to have influenced their pull strategies. Qualitative feedback offers some insight into this behavior. These large variations support our observations that participants tested the application. They behaved in an unexpected way in order to test their own assumptions about the opponents, not always respecting the instructions of the experimenter.

Discussion

From qualitative feedback we also noticed that, as participants carry on with the rope-pulling, the illusion that the rope is being pulled eventually breaks. This suggests there might be a trend of lower force across trials. Figure 16 shows some indication of a downwards trend for mean force and N2. Another explanation could be that participants simply felt tired and pulled less. A correlation between performance and realism should be explored in future research. Keeping the number of trials at a minimum to avoid fatigue should be considered a priority.

Nass et al. put forward the social response theory known as *Computers Are Social Actors* (CASA). Their observations have shown that people treat computers

as social actors [23]. Essentially, it means that people conform to social rules throughout their interactions and behave towards a computer as they would towards another human. Furthermore, people seem to mindlessly apply these social rules and other expectations in this context. Some examples are: attributing social categories as gender stereotypes, increased reciprocity in response to assistance, self disclosure reciprocity. We can explain our participants' expectations in terms of the CASA paradigm. People expect strong people to pull harder in real life, so this expectation was projected onto virtual humans and its associated force *mechanism*. It seems clear from our feedback that people assumed there was a machine, and only one, which provided the force and the virtual humans were meant to be representations of this force.

Another reason why we expected participants to pull harder was due to the priming effect of avatars' appearances, similar with [27]. Aggressive cues were meant to activate peoples' aggressive behavior and enable them to pull stronger. Considering the interplay between these psychological effects, we expected a similar outcome for our experiment, that people would pull stronger for strong avatars. Our results, however, our results are inconclusive. They capture the variability of human behavior.

Social comparison theory posits people judge their qualities with respect to the perceived attributes of others. Peña and colleagues frame their results for exergames performance in terms of this theory and note that weight did not solely have a significant effect, but rather the observed differences were a result of an interplay between avatars' and agents appearance' [37]. Some qualitative feedback suggests participants were comparing themselves to the opponents, especially relative to size. Thus, assuming they would pull less with less stronger looking avatars would be in conformity with this theory. We considered that participants could be intimidated by the strong avatars and thus pull less due to inhibition. From qualitative feedback, avatars did not seem to generate enough realism for participants to react in this manner. Participants remarked being spurred into action by strong appearances, as opposed to being put off.

From a Protean perspective, participants' avatars were bigger than the weaker opponents. This could explain why users tended to pull stronger in the weakest conditions. By the self-perception paradigm, users would see themselves stronger and as such perform stronger. An issue with adopting a Protean perspective for this research is that participants did not see themselves in a virtual mirror before the game, as with usual Proteus Effect studies [33]. Furthermore, they did not appear to look at their arms nearly as much as they looked at their opponents, as shown in figure 28. However, we postulate that the novelty of the experience and ambiguity determined participants to act in a way that is not natural. After all, playing tug-of-war with a virtual person in a virtual environment is not a natural, commonplace experience. Furthermore, participants also mentioned restraining

themselves in various ways, by keeping their legs still or being careful not to pull too hard. These actions might determine high cognitive load preventing a natural social response. Despite this, the general consensus among researchers seems to be that VR can generate realistic reactions and is ideal to study psychological and social behavior without endangering participants [39].

The large force variations make our measurements unreliable to support hypothesis H2. This is especially true for some participants with a very big difference in pull. If users have different motivations for pulling stronger than simply reacting to their opponent, we cannot make a reliable case for our research aims. Moreover, testing the application suggests that participants did not follow the instructions provided by the experimenter. We do not know what effect this could have on their perceived pull value, but we speculate participants could have over-compensated in cases in which they pulled much less. We believe there is a reasonable doubt to be shed over the measures for H2 and H3. We cannot and should not prevent participants from using our systems in playful and unexpected ways. This behavior is documented for other new technologies such as conversational agents [?]. For a question-answering system, Liao et al. document similar playful and curiosity-driven behavior. Approximately 85% of users asked the system questions outside the scope of its advertised purpose [?]. For games or VR experiences meant to give rise to VR illusions, we suggest extensive piloting in order to establish users' expectations. This would allow for more realistic interactions with the system and reduce the number of breaks in presence or plausibility.

8.8.5 Perceived Pull and Challenge

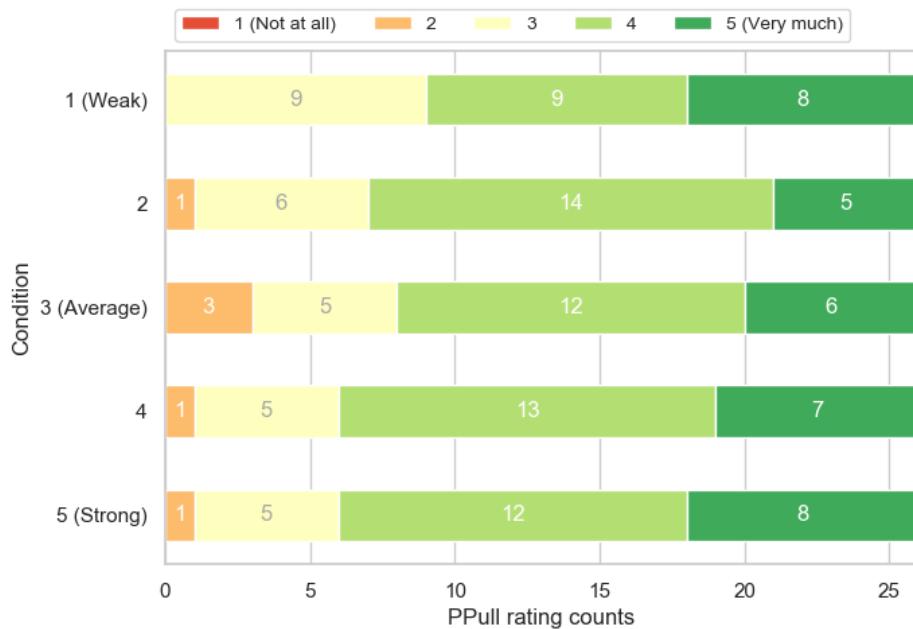


Figure 19: Count of perceived pull ratings by condition.

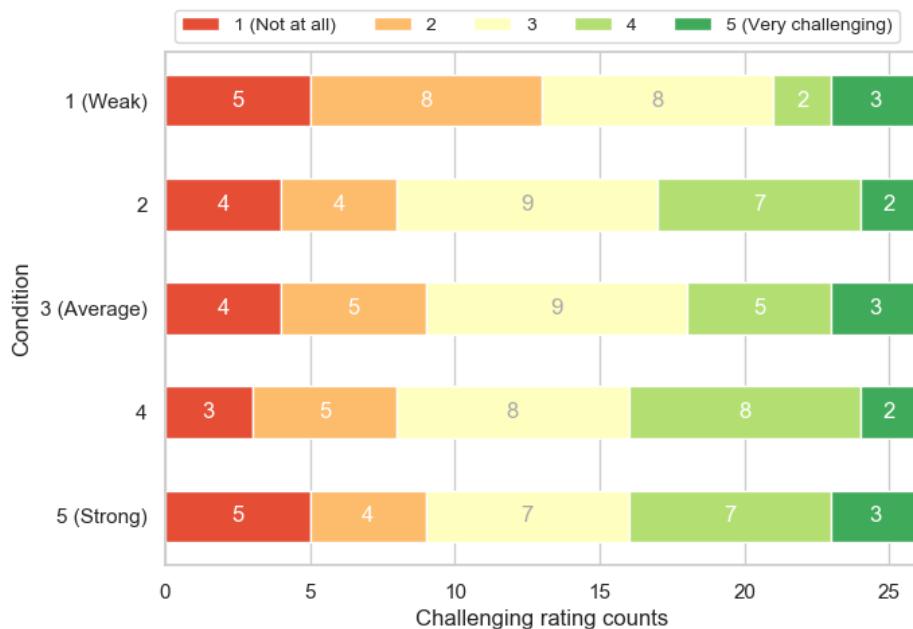


Figure 20: Count of challenge ratings by condition.

The majority of participants seemed to rate opponents with different challenges, which gives support to H1. Their reported values do not seem to coincide with our assumptions from H2 and H3.

Results

Above in figures 19 and 20 we present an overview for the ratings given to Q3 and Q4 between rope-pulls, namely challenge and perceived pull (see 8.4).

- **Q3:** How much did you pull the rope? Rating: 1 (*Not at all*), to 5 (*Very much*);
- **Q3:** How challenging was this round? Rating: 1 (*Not at all*), to 5 (*Very challenging*).

To see the total ratings for these metrics per participants, please refer to section 12.7, for perceived pull (35) and challenge (36).

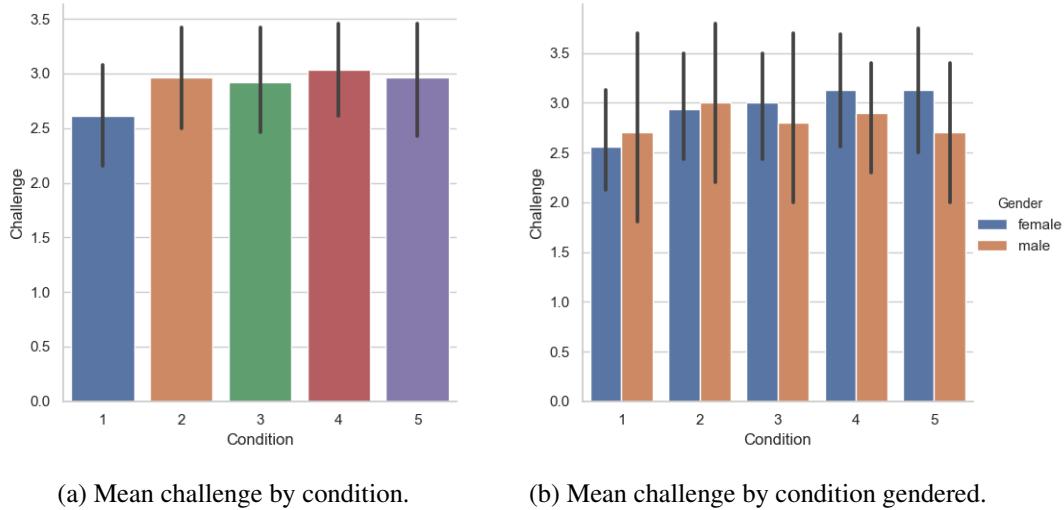


Figure 21: Mean challenge by condition, and by gender. Error bars show 95% confidence interval.

Most participants did give different ratings across trials, despite the rope having the same resistance ($M = 2.9$, $SD = 1.21265$), which appears to support **H1**. In tables 3 and 4 we display the means and standard deviation of challenge ratings by condition and trial respectively. Figure 21 shows mean challenge given by participants for each condition. In womens' case, it would appear to support our hypothesis, however women rated condition 2 as being strongest. Males had a downward trend when rating challenge. However, the confidence intervals for some condition indicate large variation. We can see in table 3 that condition 5 had the highest standard deviation. Participants also mentioned being unsure about

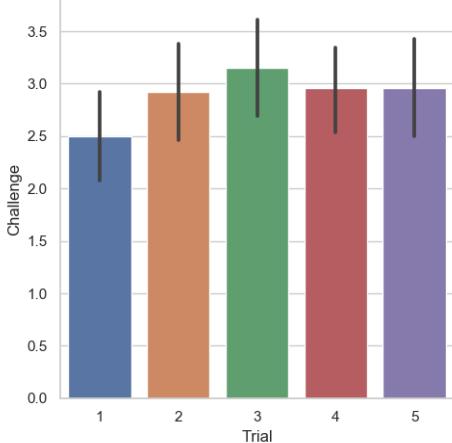
the feedback of the rope. The variation in the challenge rating seem to reflect participants' uncertainty.

Cond	Mean	SD
1	2.61538	1.23537
2	2.96153	1.18256
3	2.92307	1.23038
4	3.03846	1.14824
5	2.96153	1.31090

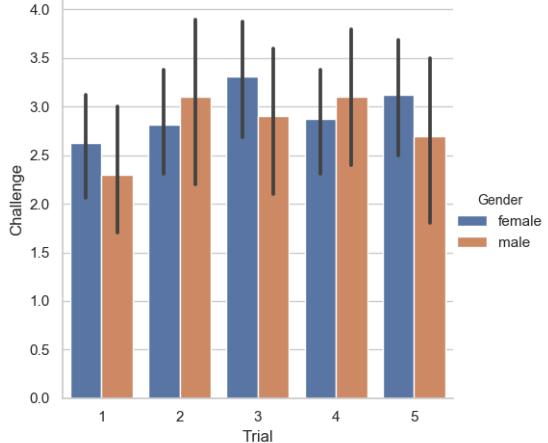
Table 3: Mean challenge and standard deviation by condition.

Trial	Mean	SD
1	2.5	1.1401
2	2.92307	1.23038
3	3.15384	1.28661
4	2.96153	1.11286
5	2.96153	1.28002

Table 4: Mean challenge and standard deviation by trial.



(a) Mean challenge by trial.



(b) Mean challenge by trial gendered.

Figure 22: Mean challenge by trial, and by gender. Error bars show 95% confidence interval.

Figure 21 shows mean challenge ratings by trial. We can see the challenge increase until the second trial for males, and until the third trial for females. Results seem to vary more by trial which could support our observation that appearance had a stronger effect than ordering. We inspect the results for the first trial only in figure 23 below. These results seem to vary with the first condition being rated more challenging overall by males and females. The challenge ratings for the first trial seem to follow a similar trend as the force values. We note that in the first trial there were more avatars in condition 1 and 2 which could suggest an effect of over-representation.

We observed that participants did not use the same standard for the challenging rating. Furthermore, some changed their assumptions dynamically during the

game, based on visual feedback or their internal state. We detail these observations in section 8.8.3. A limitation is that we did not gather the assumptions participants had about this rating, however we noted their voluntary comments.

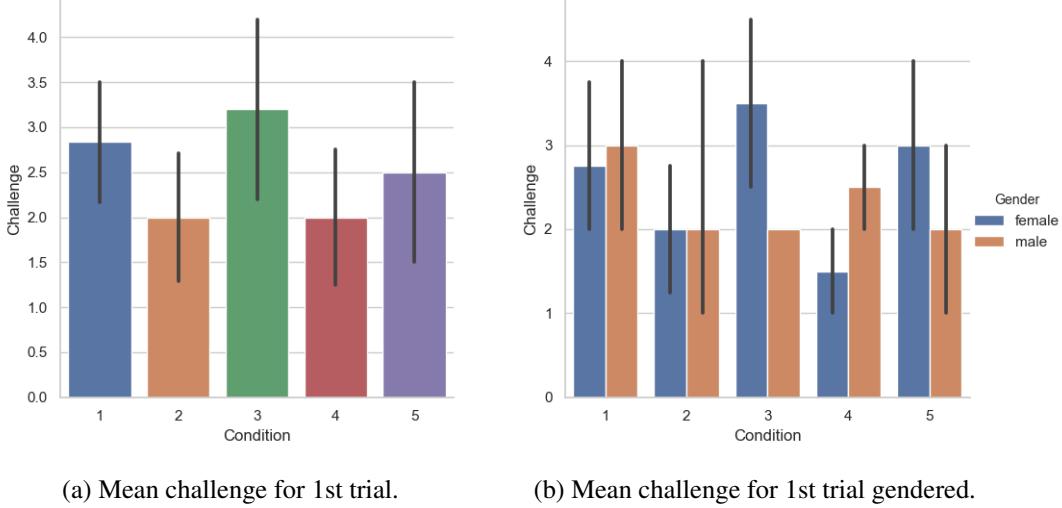


Figure 23: Mean challenge by condition, and by gender for first trial. Error bars show 95% confidence interval.

The majority of participants also reported pulling differently, despite competing in a game to pull the strongest ($M = 3.93846$, $SD = 0.82362$). In tables 5 and 6 we show the mean perceived pulls by condition and trial. Participants seemed to pull stronger in the last conditions, despite rating them less challenging. It appears they were also more consistent with their answers in this metric, as standard deviation for is less for perceived pulls.

Cond	Mean	SD
1	3.96153	0.82368
2	3.88461	0.76560
3	3.80769	0.9389
4	4.0	0.8
5	4.03846	0.8236

Table 5: Mean perceived pull and standard deviation by condition.

Trial	Mean	SD
1	3.73076	0.82741
2	4.15384	0.6748
3	3.76923	0.99227
4	3.92307	0.7961
5	4.11538	0.76560

Table 6: Mean perceived pull and standard deviation by trial.

In figure 24, below, we show mean perceived pull values by condition and trial. By condition there seems to be a trend for the perceived pull. Namely that it seems to decrease until the average condition then increase again. This trend

could support our hypothesis, namely that participants believed they pulled more for stronger-looking avatars.

The challenges and perceived pulls show two different trends. While challenges seem to peak at the average condition and look similar to the actual force, perceived pulls appear to decrease at condition 3.

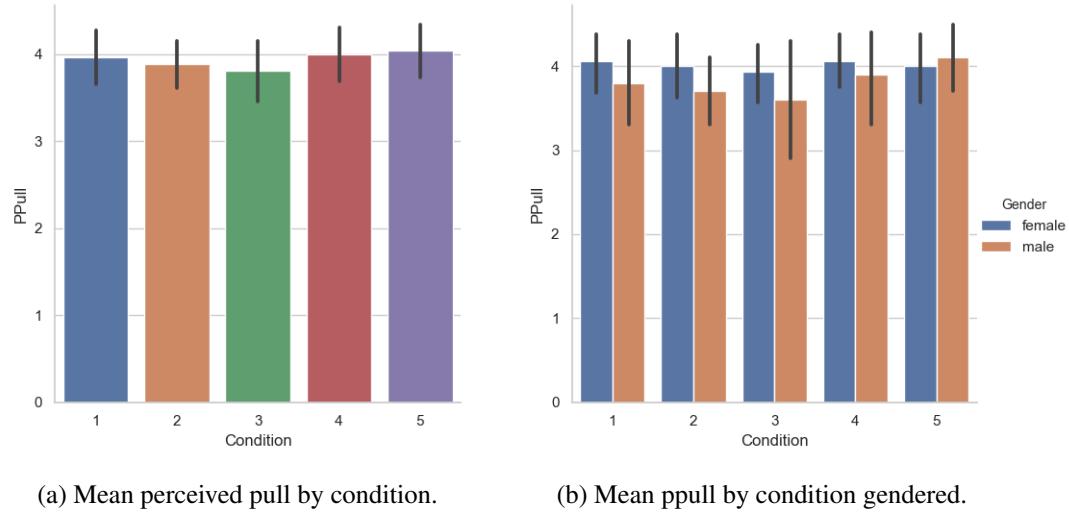


Figure 24: Mean perceived pull by condition, and by gender. Lines on bars denote confidence intervals.

In figure 25 we show the mean perceived pull by trials. Seems participants thought they pulled strongest in the second and last trials. Overall, they reported less perceived strength for the first trial.

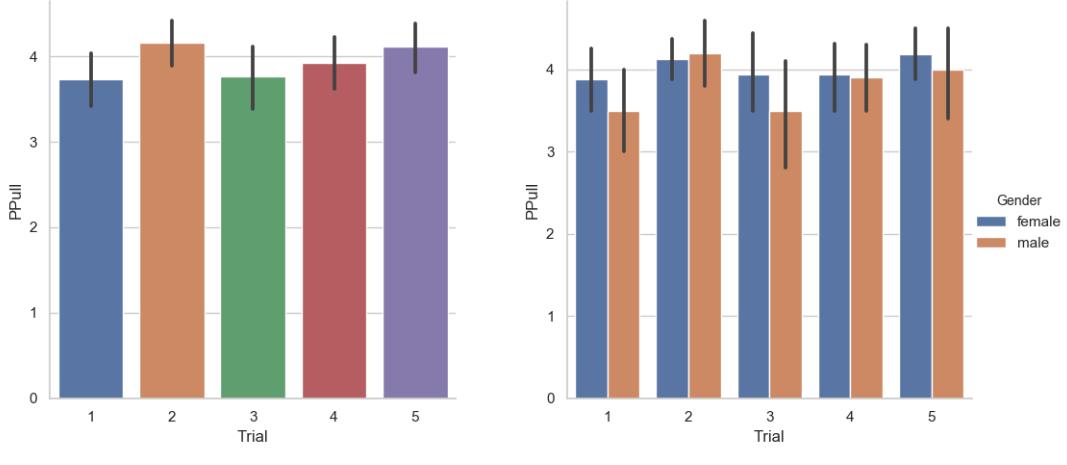


Figure 25: Mean perceived pull by trial, and by gender. Error bars show 95% confidence interval.

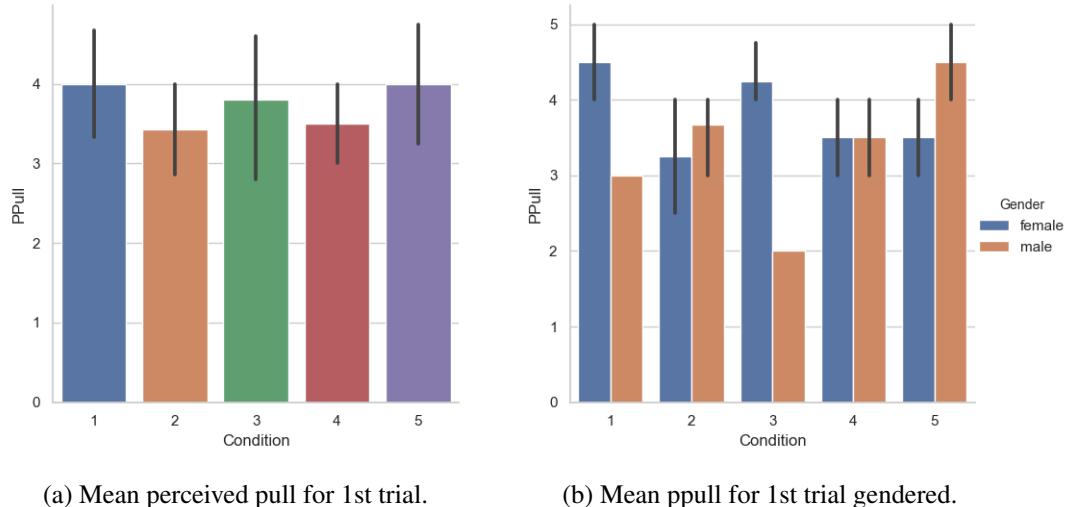


Figure 26: Mean perceived pull by condition, and by gender for first trial. Error bars show 95% confidence interval.

We also look at the perceived pulls only for the first trial in figure 26. Again, they seem to differ from the overall trend, but appear similar to the reported challenges for the first trial. However, there is only one data point for males in condition 1 and 3.

Discussion

It seems that the results do not show support for hypotheses H3 and H4. As we have highlighted throughout this section, participants behaved in unexpected ways, tested their opponents and The trends they show, however, lead us to believe that H3 and H4 should not be dismissed. So far, perceived pulls seem to conform the most with our hypothesis.

Our observations that the illusion seemed to break as the game went on would lead us to believe participants behaved more realistically in the first few trials. This lead us to look at the isolated results. Force, perceived pull and challenge measurements do not seem to show a consistent trend. What is interesting, however, is that isolating results only for the first trial seems to paint the same picture of the data. Condition 3 seems to be the highest rated and measures, and the extremities (condition 1 and 5) show a slight increase.

As values for perceived pull and challenge appear to increase for the last conditions, it seems less likely participants would be intimidated by the opponents into pulling less. We also suggest, based on our feedback, that the behavior of the agents was not realistic enough to determine such a response. Participants noticed their opponents did not react in sync with their pulling. Increasing realism could determine participants to respond more naturally. However, increasing behavior realism in virtual humans could give rise to uncanniness and provoke aversion [50, 51].

To produce VR illusions, it seems essential for users to be at the center of events and observe synchronized visual and motor cues [14]. We designed an experience meant to provide visual and haptic synchronization. That is, when users pull the rope they feel resistance and see the avatars tug at the rope. However, we did not account for several *sensorimotor contingencies*. We may borrow this terminology to express the actions of our participants:

- they pulled the rope and expected the avatars to look like they are being pulled back, a result of their motor actions;
- they let go of the rope and expected to still feel resistance, in congruence with the visual feedback.

Most feedback about challenge centered around the fact that opponents were not reacting to users. That is, their sense of agency was being called into question. We believe that failure to provide these affordances lead to the breakdown of our illusion. Our experiment suggests that sustaining the illusion depends on its credibility and conformity to expectations [41]. Indeed, breaching a fundamental assumption about the affordance of an abject could place doubt on the entire context. If opponents do not pull back, then users may question the competitive nature of the game itself.

8.8.6 Rope Agency and Realism

Below we briefly present the results of the ratings for rope realism and agency (see Q1, Q2 in 8.4). While we are partially interested in these results, they serve to confirm our qualitative feedback that participants were generally a *fan* of the rope. They rated rope agency highly ($M = 4.63846$, $SD = 0.59720$), despite noticing inaccuracies in their hands representation. The same applies to rope realism ($M = 4.51538$, $SD = 0.58713$), in figure 27. In general, participants found the rope to behave as a real rope.

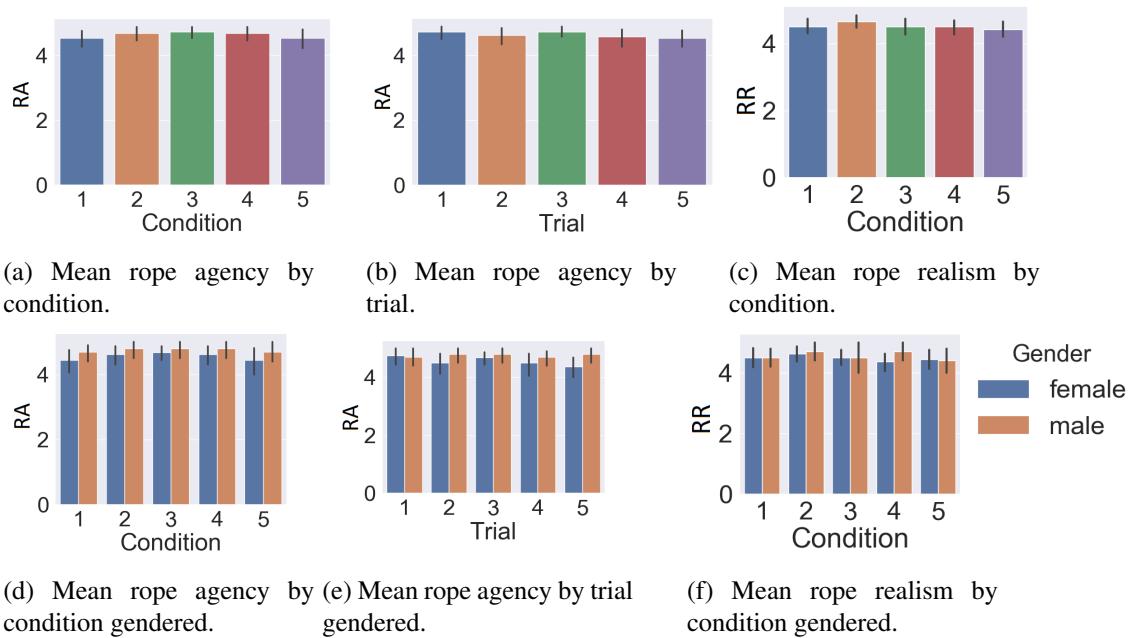


Figure 27: Mean rope agency and rope realism by condition, trial, and by gender. Error bars show 95% confidence interval.

Discussion

For males it suggests by the challenges they were intimidated.

8.8.7 Post-experimental Survey Results

In the following, error bars show standard deviation.

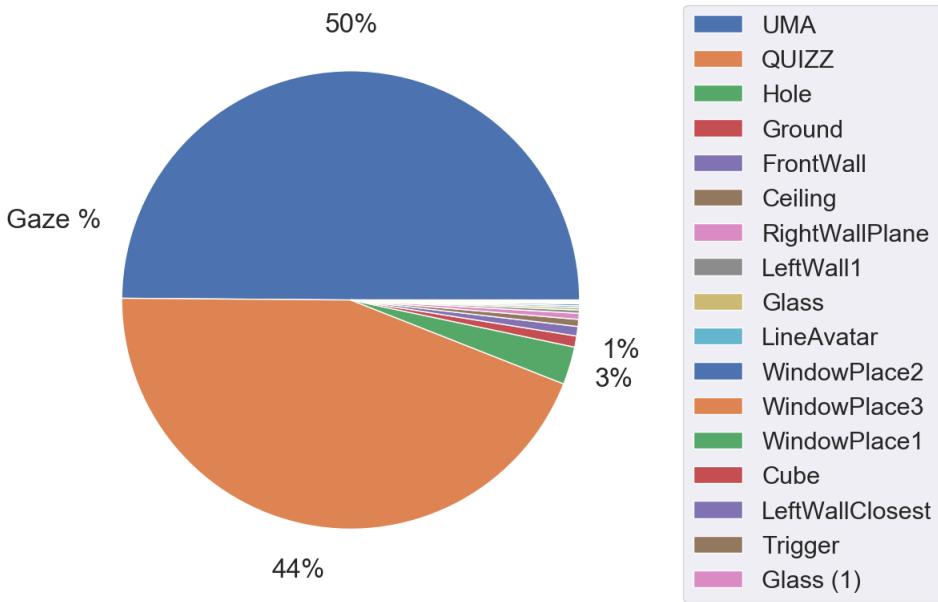
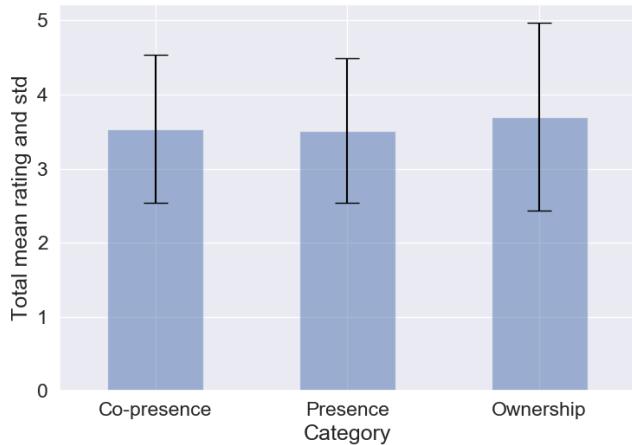


Figure 28: Percent participants gazed at objects during the whole experiment duration.

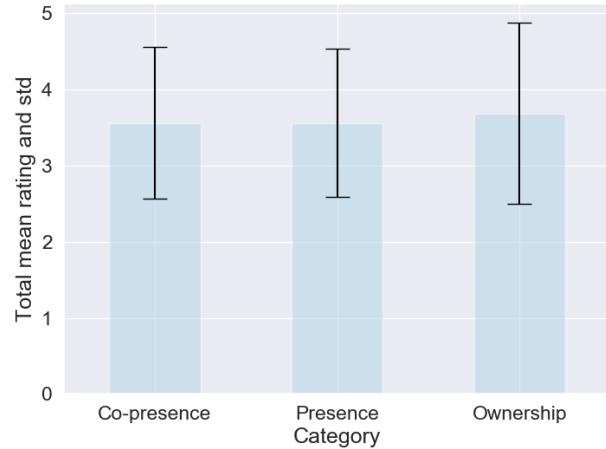
We did not have eye tracking, however we used the midpoint of the headset to estimate what objects participants were looking at. From figure 28 it can be seen that participants mostly gazed at their opponents. The second most gazed object is the quiz panel (*QUIZZ*), which is expected as participants were answering the questions written on it. The arms were not tagged with a separate ID due to implementation. However, the object behind the hands was logged which would most likely be the *Hole* or the *Ground*. This is a rough estimation, however it is supported by qualitative data, the ratings for rope realism and rope ownership, which were generally very high despite inaccuracies in arm tracking.

In figures 29a below, we present all mean ratings for the co-presence ($M = 3.53842$, $SD = 0.99604$), presence ($M = 3.51538$, $SD = 0.97849$) and arm ownership ($M = 3.69871$, $SD = 1.26804$) ratings. In figures 29b and 29c we show the ratings for females and males respectively. Despite feedback that avatars were not expressive enough from several participants, co-presence mean does not differ significantly from the other categories. Among them, participants varied the most rating arm ownership. In what follows we give an overview of the post-experimental survey data by question. Please see tables 8, 7 and 9 for

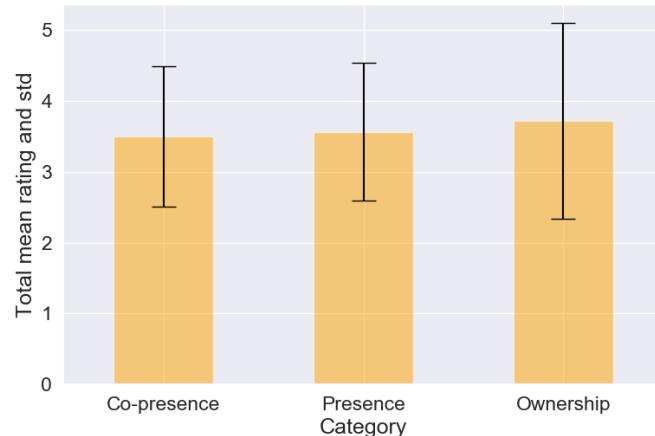
mean, median and standard deviation values for presence, co-presence and arm ownership.



(a) Total mean ratings.

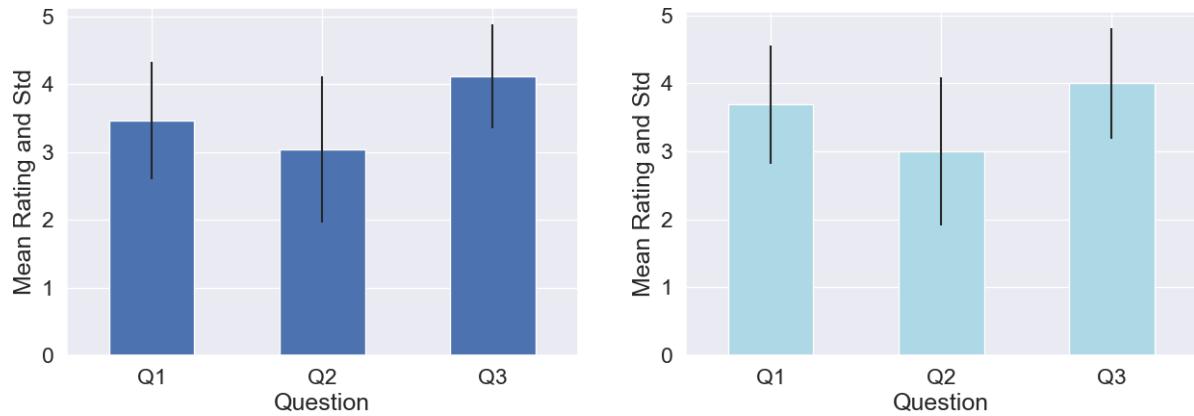


(b) Females mean ratings.

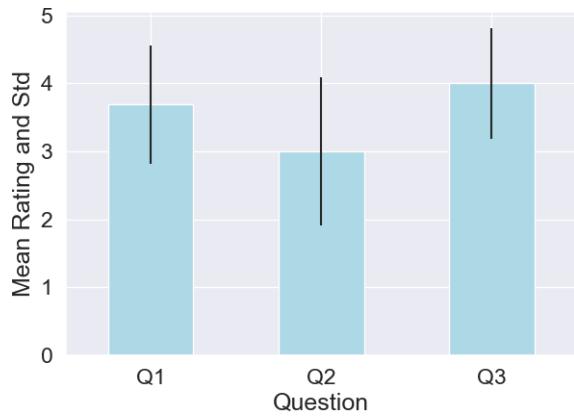


(c) Males mean ratings.

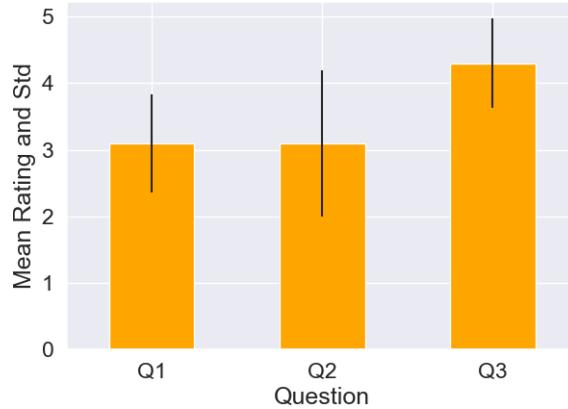
Figure 29: Total mean co-presence, presence and ownership ratings by gender. Error bars show standard deviation.



(a) Total mean ratings.



(b) Females mean ratings.

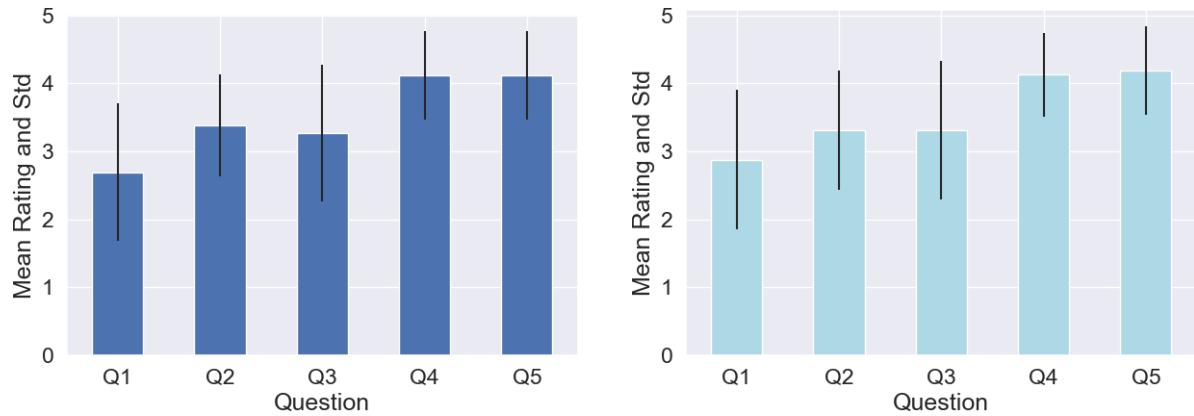


(c) Males mean ratings.

Figure 30: **Co-presence** ratings, by mean and gender. Error bars show standard deviation.

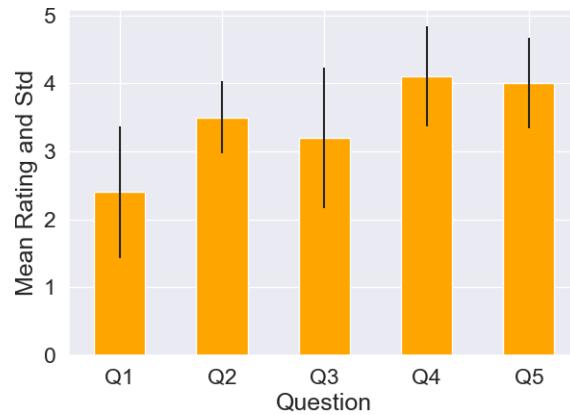
Q	Mean	SD	Med
1	3.46153	0.85933	4
2	3.03846	1.07631	3
3	4.11538	0.76560	4

Table 7: Mean co-presence, standard deviation and median by question.



(a) Total mean ratings.

(b) Females mean ratings.



(c) Males mean ratings.

Figure 31: **Presence** ratings, by mean and gender. Error bars show standard deviation.

Q	Mean	SD	Med
1	2.69230	1.01071	3
2	3.38461	0.75243	3
3	3.26923	1.00230	3
4	4.11538	0.65280	4
5	4.11538	0.65280	4

Table 8: Mean presence, standard deviation and median by question.

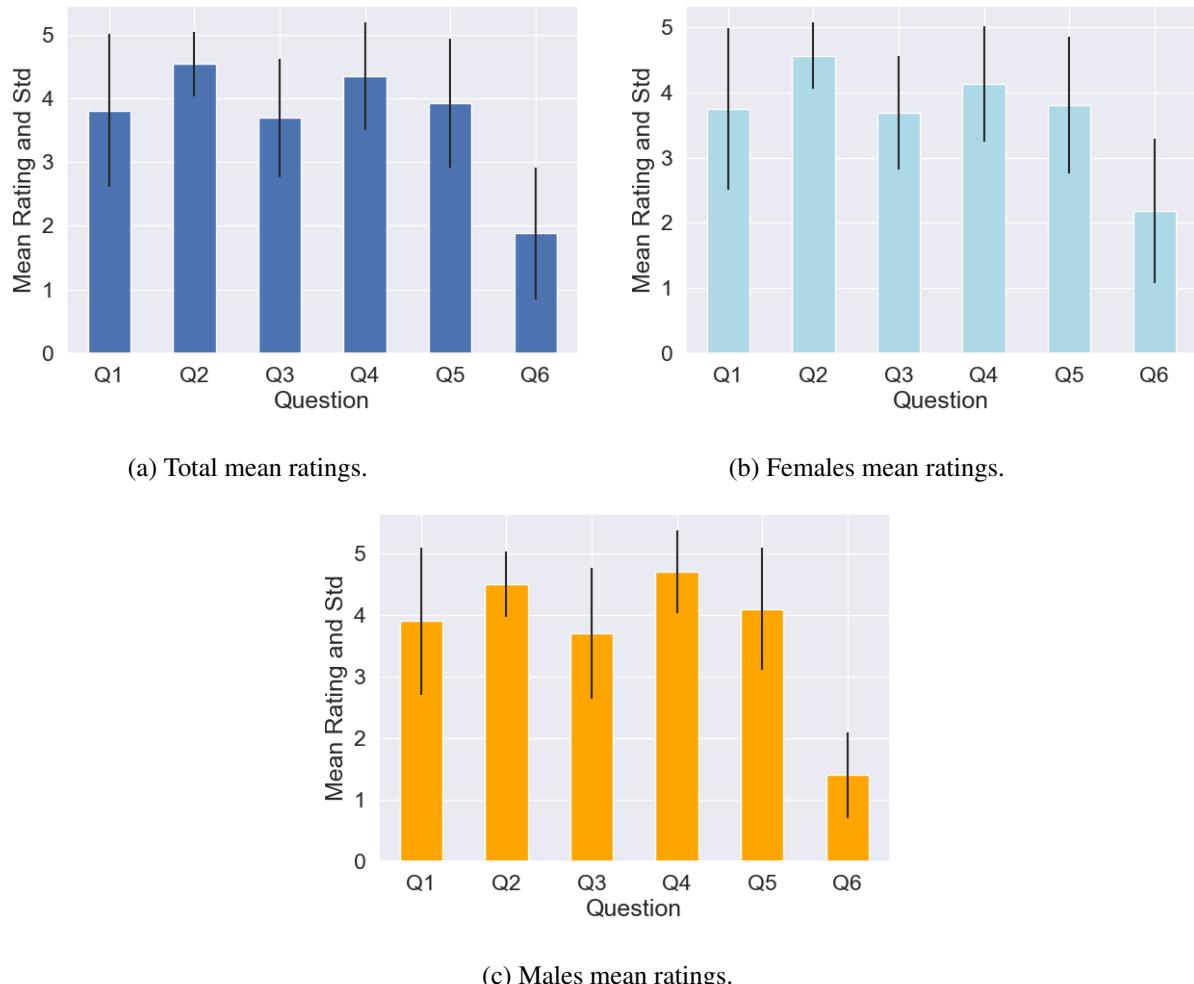


Figure 32: **Arm ownership** ratings, by mean and gender. Error bars show standard deviation.

Ownership ratings are generally high and support participants' feedback. The illusion of holding the rope was strongly supported by the haptic feedback. Participants did not generally look at their hands, however.

Q	Mean	SD	Med
1	3.80769	1.20064	4
2	4.53846	0.50839	5
3	3.69230	0.92819	4
4	4.34615	0.84580	5
5	3.92307	1.01678	4
6	1.88461	1.03254	2

Table 9: Mean arm ownership, standard deviation and median by question.

8.9 Summary

9 Limitations

DRAFT - spring absorbs force a participant stretched the spring too much and it was replaced

- force meter accuracy for the digital display - person error prone? -resolution and realism all had same movements but varying so many things would allow less control over the independent variables research wise, it would be difficult to establish causation,// -ppl unsure about pulling the first round and there is some effect// - force got maxim for whatever minimum amount of time other strategies can be used to measure with a force meter that is not digital - like the average value across all that time, the longest value for how many seconds. etc. - there could be some effect that people held medium values for longer idk -challenge - what is challenging what they rated with if they rated it by looks then it is bad. MMaking it implicit and explicit has advantages and disadvantages. For example cognitive load focusing only on the pull ...

-change ratings allow and mention some did some not

0-The downside of this is that some participants mentioned they experience cognitive load as they were trying not to move their legs during the pulls. They were focusing on that instead of focusing on pulling as hard as they can. To solve this, we can use a set up in which the ropes are tied to walling.

-participants misbehave pilot pilot to design the experiment against misuse
- low resolution of vr headset i recommend something to make people stay closer to the avatars and allow them to see them better

Another issue is that participants will need to form a baseline opinion of what is a strong-looking avatar. As such, ordering might have too big an effect on the results of the experiment. Their assumption about the designs of the avatars could change.

10 Conclusion

DRAFT

Referring to stronger avatars Okay... I should pull stronger, it's a natural response. P13 - seems like a natural response, however the context was not something familiar and it determined people to have exploratory actions like testing the environment or hesitating.etc

Illusions are feasible, seem to be mitigated by realism and decay in time because of sensory adaptation. meet expectations to sustain illusion like Slater said [41]. Users interacting with the system might have a playful attitude, probe and

test the environment. Provide contingencies for unexpected participant behavior. Otherwise, breaks in realism and ownership can decay the illusion. High behavior and physical realism might not be accessory but it provides limits in which it can occur [41]. Most important to afford realistic interaction with the haptic object people interact with. The social aspect of the technology seemed to be the focal point of the interaction. Participant had expectations that were not met about the interaction with the avatar which seemed to place doubts about the realism of the system in their minds. Either way, useful to provide as few boundaries for the interaction as possible. We posit it might be useful to include some haptic feedback in order to generate more body ownership when degrees of freedom of the actual body or realism cannot be matched. We also expect people behaved differently because of the novel situation that they were in. They showed reluctance to pull the rope. A demonstration by the experimenter with physical actions can be useful to clarify the instructions.

11 Future Work

DRAFT

For this instance of the experiment, we do not manipulate avatar appearance. In VR, people will be able to see their arms holding the rope. However, we acknowledge the significant effect of embodiment [citations] and postulate that a physical transformation of the self, coupled with an appropriate context, would generate a better illusion.

Discuss and reason about social effects in VR with respect to possible applicabilities in the industry and for future research.

12 Appendix

12.1 Logging Table

Timestamp	Date and time of log entry.
Condition	Condition of avatar:weak (c3), average (c2), strong (c1).
SplashScreen	State of black screen
HeadX	item 22
HeadY	item 22
HeadZ	item 22
HeadRX	item 22
HeadRY	item 22
HeadRZ	item 22
RightHandx	item 22
RightHandy	item 22
RightHandz	item 22
RightHandRX	item 22
RightHandRY	item 22
RightHandRZ	item 22
LeftHandx	item 22
LeftHandy	item 22
LeftHandz	item 22
LeftHandRX	item 22
LeftHandRY	item 22
LeftHandRZ	item 22
Action	item 22
GazeTarget	item 22

12.2 Additional Quantitative Data

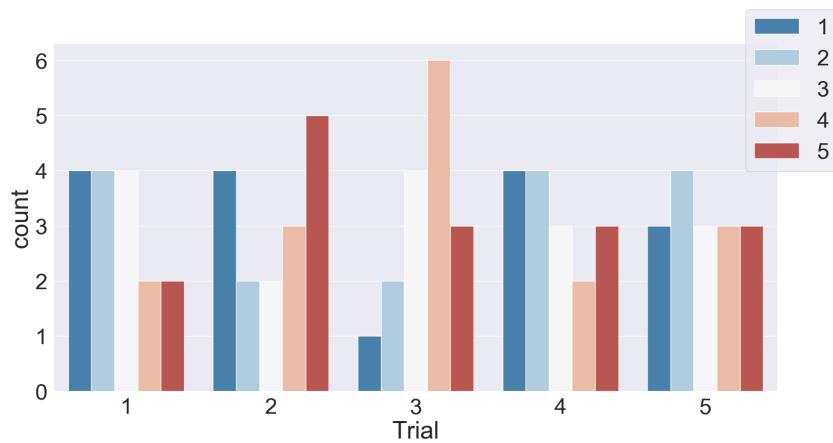


Figure 33: Number of conditions per trial for females.

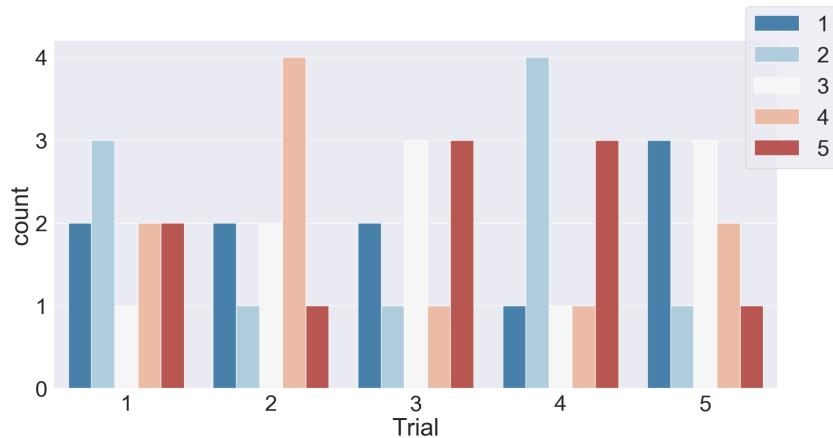


Figure 34: Number of conditions per trial for males.

12.3 Instruction Sheet

Instruction sheet for experimenter for VR games study

1. Describe the games to users at arrival

We made 2 virtual reality games - a virtual reality tug-of-war game and a whack-a-mole game! We are interested in providing users with the best gaming VR experience and we need your feedback for the games we designed.

Tug of war, if you have not played it, is a game in which you pull a rope with an opponent and the one that pulls stronger wins! For whack a mole you see a mole come up and you have to slap it with your right hand and hold your hand straight like this [show participant].

First, for each game we must calibrate these gloves for your hands and then we can start playing. There will be a screen in front of you and you will have to follow some hand movements. I will walk you through the instructions.

We first play tug of war and then 4 minutes of whack a mole! After each game, I will kindly ask you to fill in a short survey about your experience and other design aspects. Before you leave, I will ask you for any feedback or suggested improvements you might have about each game. For full disclosure, our conversations during the experiment will be recorded. All data I record will be transcribed and anonymized. Only I have access to the code.

But before you I continue the instructions could you please have a look at these two consent forms. There is a place for your name and signature at the end. I will be here and you can ask me any questions while you read.

2. Tug-of-War Instructions

For tug of war, your task is to play the game and compete at pulling the rope! You will pull the rope 5 times and you can use both hands for that. You must put your right hand in front of the left hand on the rope and hold it like this [show]. I will give you the rope in your hands once we finish calibrating the gloves. Before I place the gloves on your hands could you please fill in this page from the survey with your information [Show participant survey on laptop page and tell them to click next after inputting their data. The next page will not be filled in. Tell them you will shortly explain what that is. After they fill in the questions start putting the gloves on their hands and continue explaining.]

In the game you will see your opponent and a countdown will begin. When you see START you should start pulling the rope and keep pulling until you see stop, When you see stop you should stop pulling the rope and the round will be over.

After each rope-pull, there will be a set of questions in VR on a panel and I will kindly ask you to read the questions out loud and tell me your answer. I will record your answers in this survey on the laptop, there [show].

You have to remember 2 things:

1. Try pulling the rope without moving your feet.
2. Keep your hands on the rope at all times, even when you are reading questions between rope-pulls.

3. Setup and runtime instructions

At all times:

1. Keep trackers of gloves charged
2. Keep batteries in charging port
3. Gloves demagnetized daily/several times per day
4. Always let participants know what you want to do. (eg. I will turn off the game now).
5. Always let participants know if you want to move them or adjust any parts of the VR setup such as the headset or gloves, especially if it involves touching them.

Before participant arrival:

1. Wipe headset
2. Close windows in experiment room
3. Check all devices are tracked
4. Put laptop speakers on the correct output
5. Start survey
6. Adds participant ID and click next
7. Replace batteries on gloves if needed
8. Demagnetize gloves if needed
9. Turn on trackers of gloves
10. Turn on gloves
11. Make sure trackers are synced with steam (they have a green light)
12. Turn on both unity projects
13. Start force meter
14. Turn on camera
15. Turn on OBS
16. Make sure Windows picks the correct webcam, the one over the force meter

17. Start Unity and open both games
18. Place Camera and Unity Game view side by side to capture them with OBS.

At start experiment

1. Greet participant.
2. Explain intro story
3. Give participant both consent forms to sign
4. Participant is invited to complete data with gender and age
5. Do you have any questions? You can ask me anything throughout the experiment.
6. Give participants gloves
7. Give participant headset protector
8. Give participants headset
9. Do glove calibration
10. Tell participants you will give them the rope in their hands now
11. Give participant rope in hands
12. Tell them to grab the rope with right hand in front of left
13. Tell participant First I will show you the VR setup. I would like you to look around for a minute, tell me if everything is clear, if you can see your hands, the rope, and if the words on the panel are clear.
14. Start PreTrial scene.
15. Stop scene.
16. START FORCE METER (if it turned off)
17. START RECORDING OBS
18. START RECORDING CAMERA
19. START GAME in Experiment scene
20. Tell participant: *Now I will start the game and you will be facing your opponents. Remember to start pulling when you see START and stop pulling when you see stop. Don't forget, always keep your hands on the rope.*
21. Remind participants of constraints at trial 3
22. At 4th rope pull, tell participant there are 2 more rounds.

23. For question-answering, tell participant whenever you are ready to take their answers and after each answer tell them some word of acknowledgement that you got their answer (eg. ok, Alright). Refrain from using overly positive adjectives like great, to prevent encouraging them to give positive answers.

4. End instructions

Note that the experiment instructions for the whack-a-mole game are nor presented as they are out of the scope for this research. Participants always played tug-of-war first, completed its related survey, then played whack-a-mole and completed its related survey.

Take a pen, paper and write participant feedback during the interview.

1. Thank the participant.
2. I would like to ask you now if you have any suggestions to improve the first game, the tug-of-war game? What was your impression?
3. What about the whack-a-mole game? Do you have any thoughts about that game?
4. Thank you for the feedback. One last question before you go. Could explain to me, in your own words what this experiment was about? Based on what you saw and what I explained.

At the end of each day do the logging:

1. Log participant feedback in document on Google Drive.
2. Move logs in experiment folder for both games and commit to Git.
3. Rename recorded videos with participant id and upload them to Google Drive.

12.4 Consent form

Informed Consent Form for Volunteer Participants This informed consent form is for volunteer participants to take part in an experiment about playing tug of war in virtual reality with different players. This research is done by a student following a master's degree in Computer Science at the University of Copenhagen, Denmark as part of their Master Thesis. This research is under the supervision of professors Henning Pohl and Kasper Hornbæk from the University of Copenhagen.

This Informed Consent Form has two parts:

- Information Sheet (to share information about the research with you, the volunteer participant)
- Certificate of Consent (for giving your consent if you agree to take part)

PART I: Information Sheet Introduction I am Andreea-Anamaria Muresan, a student at the University of Copenhagen, and I am doing a master thesis about interactions in virtual reality.

I would like to invite you to be part of this research. In this document, you can find detailed information about the project. Before you decide, you can talk to anyone you feel comfortable with about the research. If there are words that you do not understand please ask me about them and I will take time to explain. If you have questions later, you can ask me or even pose your query to the project supervisors.

Purpose of the research and type of manipulation The purpose of this research is to evaluate a rope-pulling game in virtual reality. In this evaluation, we look at the quality of the virtual rope, the design of the players and measure body ownership and presence in the virtual world.

Participant selection You have been invited to this study because you satisfy the following requirements: you are representative of a group of users who may use virtual reality.

Voluntary Participation

Your participation in this research is entirely voluntary. It is your choice whether to participate or not. You can change your mind later and stop participating even if you agreed earlier.

Procedures and Protocol

Throughout this experiment you will be asked to:

1. Play tug-of-war,
2. Complete a verbal questionnaire after each rope-pull,
3. Fill in a survey after finishing the game,
4. Have a short chat before you leave and tell us your opinion about the game and how we can improve it. Our conversations will be recorded and anonymized.

At the beginning of each round, you will hear and see a countdown. You must start pulling when you see **Start** and you must stop pulling once you see **Stop**. Please try to:

1. Grab the rope with your right hand in front of the left hand.
2. Keep your hands on the rope at all times.
3. Do not move your hands on the rope once you grab it.
4. Try pulling the rope with your upper body and arms. Try keeping your feet in the same starting position.

Duration

The experiment is expected to last between 20 and 30 minutes.

Risks and Benefits

We anticipate no risks from participating in the experiment. If you participate in the experiment you will help the student conducting the experiment complete their Master Thesis successfully as well as gain experience running, designing experiments and interacting with participants.

Reimbursements You will not be given any money or gifts to take part in this research.

Confidentiality

The data we collect from you will be made anonymous; your name will be replaced with a number known only to the person running and designing the experiment.

Sharing the Results

If you are interested, you may leave us your email or contact us at a later stage to learn about the outcomes of the study. No confidential information will be shared.

Right to Refuse or Withdraw

You do not have to take part in this research if you do not wish to do so. You may also stop participating in the research at any time you choose. It is your choice and all your rights will be respected.

Who to Contact

If you have any questions about the study at a later stage, please contact the student investigator at the following email addresses: Andreea-Anamaria Muresan: zph748@alumni.ku.dk

You can ask me any questions about any part of the research study if you wish. Do you have any questions so far?

PART II: Certificate of Consent

I have read the foregoing information. I have had the opportunity to ask questions about it and any questions that I asked have been answered to my satisfaction. Below I mark that I consent voluntarily to participate as a participant in this research.

Print Name of Participant:

Signature of Participant:

Date (Day/Month/Year):

Statement by the researcher/person taking consent

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

Print Name of person taking the consent:

Signature of person taking the consent:

Date (Day/Month/Year):

12.5 Coding Tables

ID	Name	Condition
1	F5_C3	Weak
2	F4_C1	Strong
3	F1_C2	Average
4	F6_C1	Strong
5	F1_C1	Strong
6	F3_C1	Strong
7	F5_C1	Strong
8	F5_C2	Average
9	F1_C3	Weak
10	F4_C3	Weak
11	F2_C3	Weak
12	F6_C2	Average
13	F6_C3	Weak
14	F4_C2	Average
15	F3_C3	Weak
16	F2_C2	Average
17	F2_C1	Strong
18	F3_C2	Average

Table 10: Female avatar designs coding.

ID	Name	Condition
1	M6_C3	Weak
2	M5_C1	Strong
3	M1_C2	Average
4	M7_C1	Strong
5	M1_C1	Strong
6	M3_C1	Strong
7	M6_C1	Strong
8	M6_C2	Average
9	M1_C3	Weak
10	M5_C3	Weak
11	M2_C3	Weak
12	M7_C2	Average
13	M7_C3	Weak
14	M5_C2	Average
15	M3_C3	Weak
16	M2_C2	Average
17	M2_C1	Strong
18	M3_C2	Average

Table 11: Male avatar designs coding.

12.6 Survey Mean Ratings

ID	Attractive	Intelligent	Intimidating	Strong	Weighted	UMA
10	1.93333	2.66667	1.66667	1.46667	1.56667	f4 c3
15	1.73334	2.46667	1.73334	1.53334	1.63334	
14	1.93334	2.8	2	1.4666	1.73333	
8	2.46667	2.8	1.8	1.86667	1.83333	
11	2.33333	3	1.6	2.06667	1.83333	
16	2.86667	3	1.73333	2.06667	1.9	f2 c2
9	1.8	2.6	2.2	1.66667	1.93333	
13	2.06667	2.66667	1.93333	1.93333	1.93333	
1	2	2.33333	1.86667	2.06667	1.96667	
18	2.26667	2.6	2.2	2	2.1	f3 c2
12	2.4	2.66667	2.06667	2.26667	2.16667	
7	1.8	2.13333	2.13333	2.33333	2.23333	
3	2	2.8	2.66667	2.66667	2.66667	
5	1.53333	2.2	2.73333	3	2.86667	f1 c1
17	1.6	2.2	2.86667	3.06667	2.96667	
4	1.73333	2.33333	3	3.26667	3.13333	
6	1.66667	2.4	2.73333	3.53333	3.13333	
2	1.46667	2.2	3.4	3.46667	3.43333	f4 c1

Table 12: Female mean ratings.

ID	Attractive	Intelligent	Intimidating	Strong	Weighted	UMA
13	2.625	3.0625	1.25	1.25	1.25	m7 c3
8	2.5	2.6875	1.5625	1.875	1.71875	
1	2.1875	2.4375	2.125	1.375	1.75	
9	1.25	1.625	2.125	1.75	1.9375	
12	3.5	3.3125	1.5625	2.375	1.96875	m7 c2
11	1.8125	2.3125	2	2.25	2.125	
15	1.8125	2.1875	2.125	2.5625	2.34375	
10	2	2.375	2.3125	2.4375	2.375	
7	1.75	2.8125	2.3125	2.75	2.53125	m6 c1
4	2.375	2.5625	2.3125	3.3125	2.8125	
16	2.0625	2.25	2.375	3.3125	2.84375	
18	2.625	2.625	2.5625	3.5625	3.0625	
14	2.3125	2.5	2.75	3.5625	3.15625	
3	1.375	1.9375	3.5	3.0625	3.28125	m1 c2
6	2.5625	2.5625	3.0625	4.1875	3.625	
5	1.5625	2.3125	3.5625	4.0625	3.8125	
17	2.25	2.125	3.625	4.6875	4.15625	
2	1.9375	2	3.8125	4.75	4.28125	m5 c1

Table 13: Male mean ratings.

12.7 All Challenge and PPull Ratings

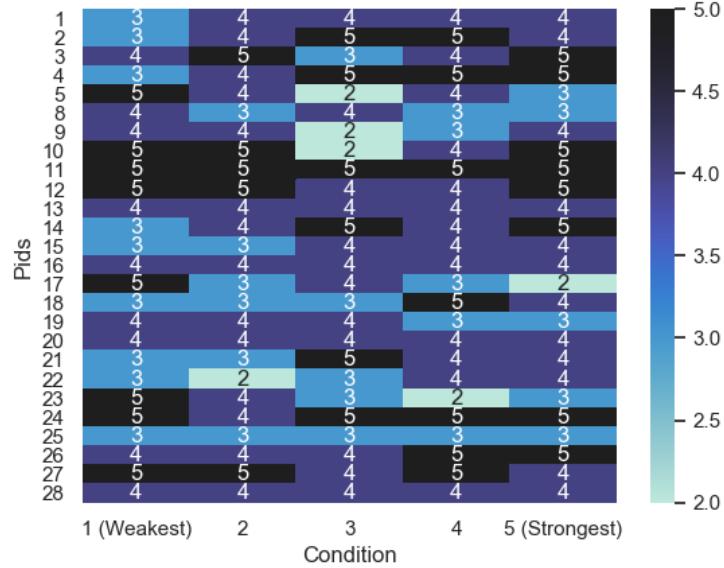


Figure 35: Perceived pull ratings by condition per user coded as user Id.

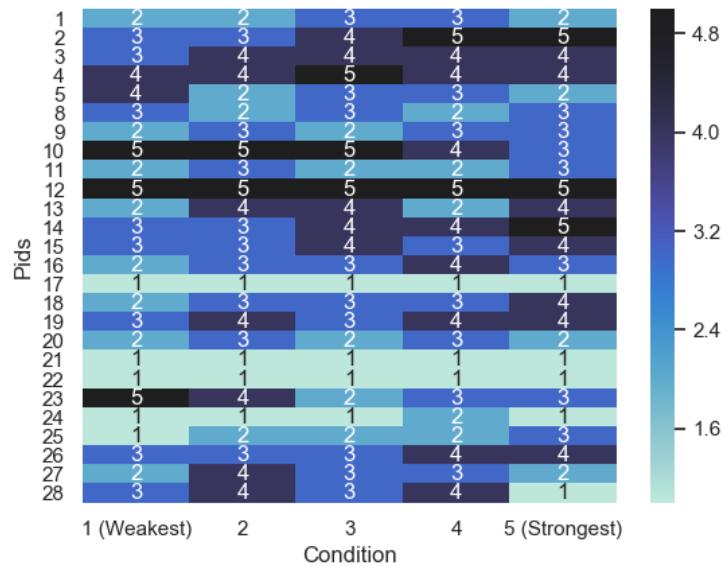


Figure 36: Challenge ratings by condition per user coded as user Id.

12.8 User Study Thumbnails and Ratings

12.8.1 Females



Figure 37: Female in condition 1 (weakest) thumbnail and ratings.



Figure 38: Female in condition 2 (low-average) thumbnail and ratings.

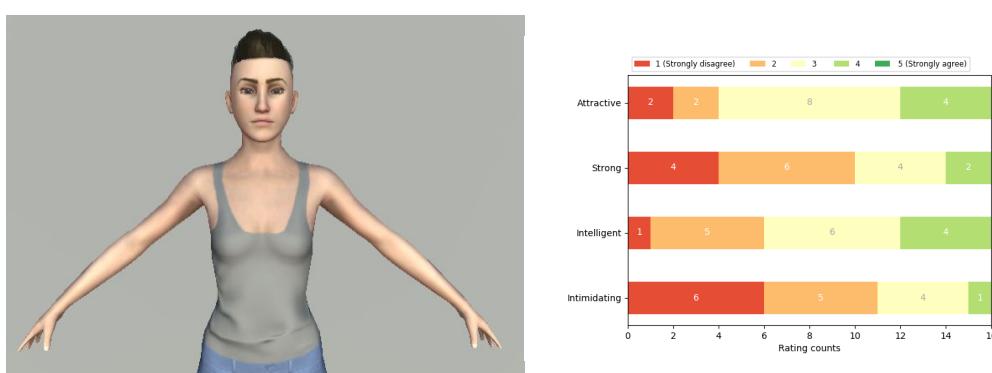


Figure 39: Female in condition 3 (average) thumbnail and ratings.

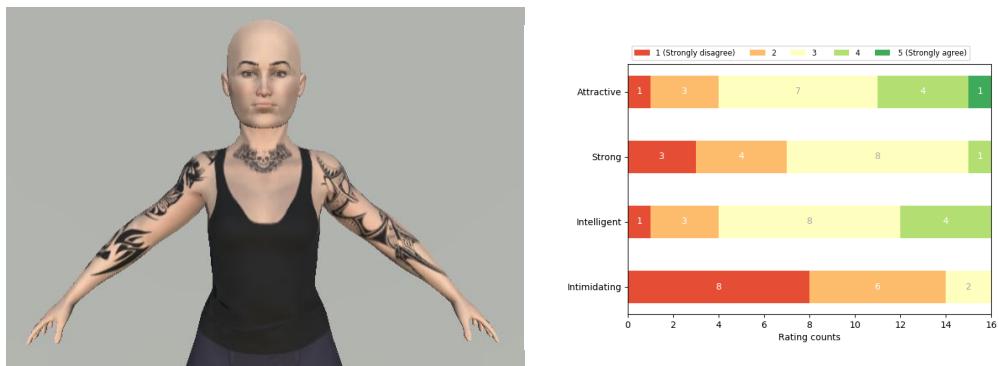


Figure 40: Female in condition 4 (high-average) thumbnail and ratings.



Figure 41: Female in condition 5 (strong) thumbnail and ratings.

12.8.2 Males

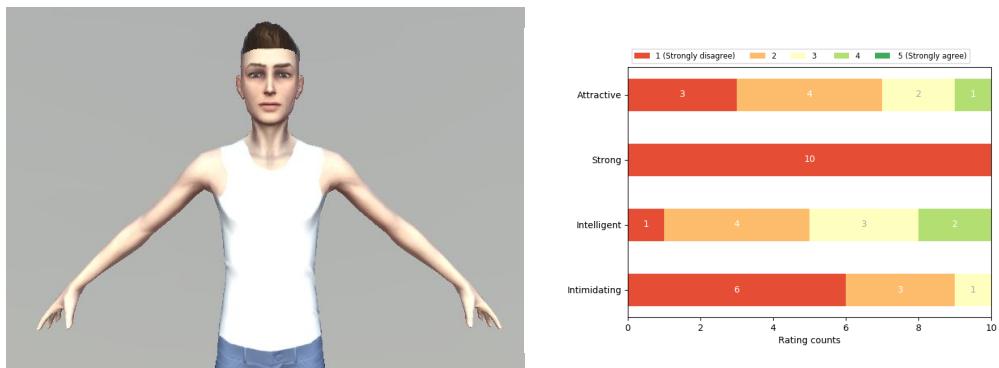


Figure 42: Male in condition 1 (weakest) thumbnail and ratings.



Figure 43: Male in condition 2 (low-average) thumbnail and ratings.



Figure 44: Male in condition 4 (average) thumbnail and ratings.



Figure 45: Male in condition 4 (high-average) thumbnail and ratings.

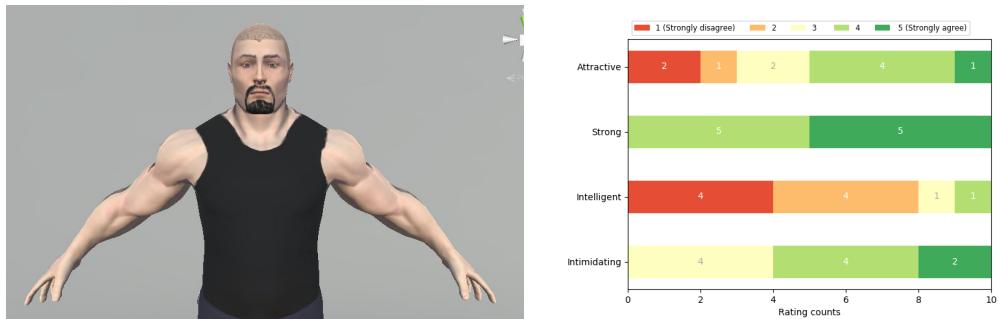


Figure 46: Male in condition 5 (strong) thumbnail and ratings.

12.9 Survey Thumbnails and Ratings

12.9.1 Females

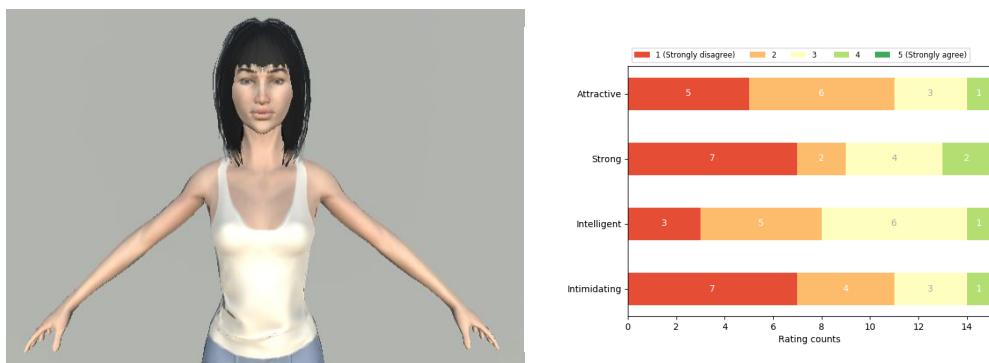


Figure 47: Female 1 thumbnail and ratings.

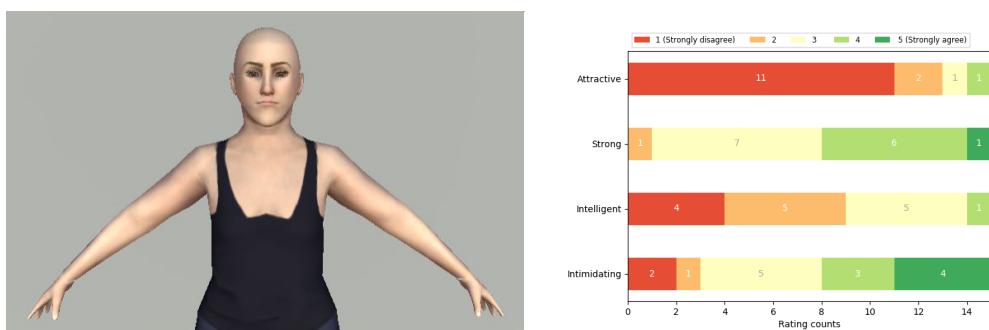


Figure 48: Female 2 thumbnail and ratings.



Figure 49: Female 3 thumbnail and ratings.



Figure 50: Female 4 thumbnail and ratings.

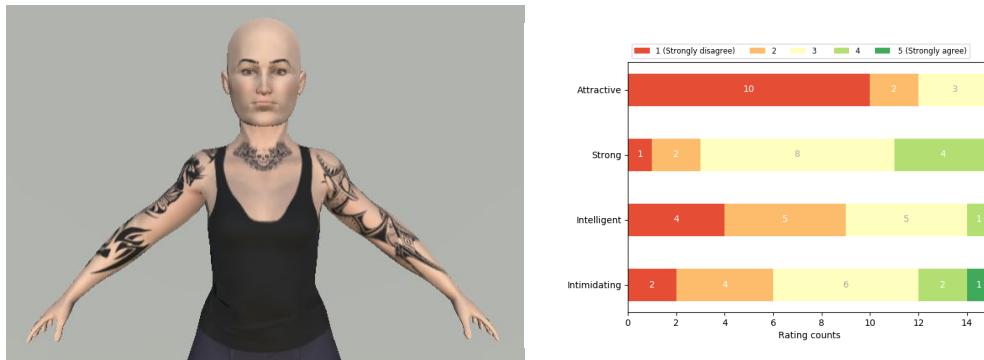


Figure 51: Female 5 thumbnail and ratings.

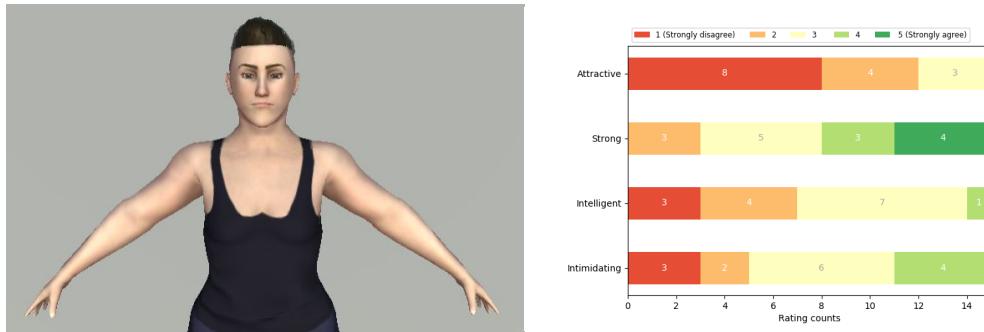


Figure 52: Female 6 thumbnail and ratings.



Figure 53: Female 7 thumbnail and ratings.

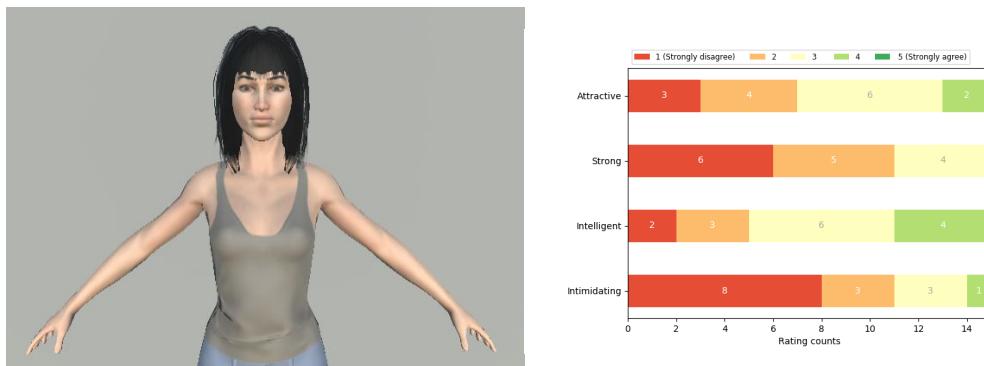


Figure 54: Female 8 thumbnail and ratings.

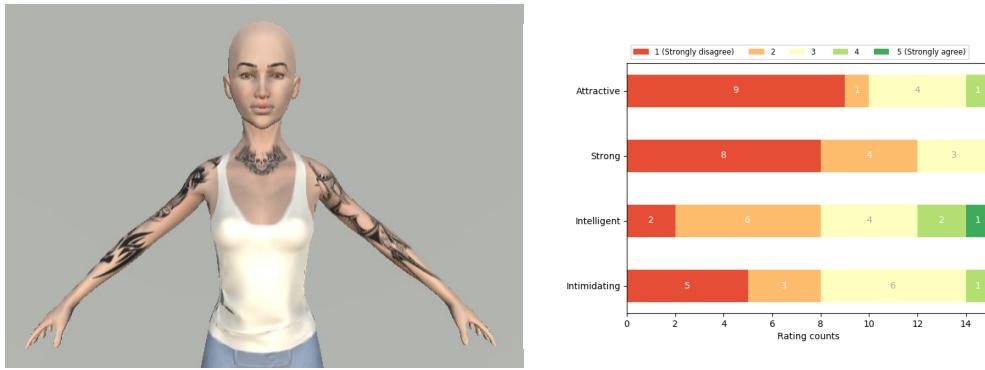


Figure 55: Female 9 thumbnail and ratings.

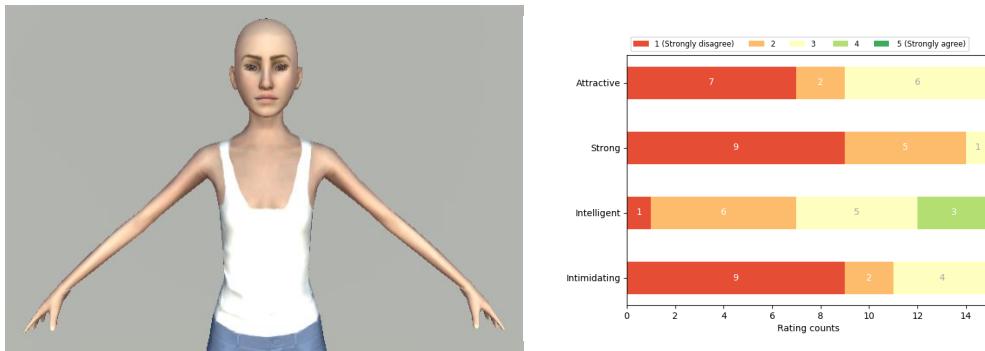


Figure 56: Female 10 thumbnail and ratings.



Figure 57: Female 11 thumbnail and ratings.



Figure 58: Female 12 thumbnail and ratings.

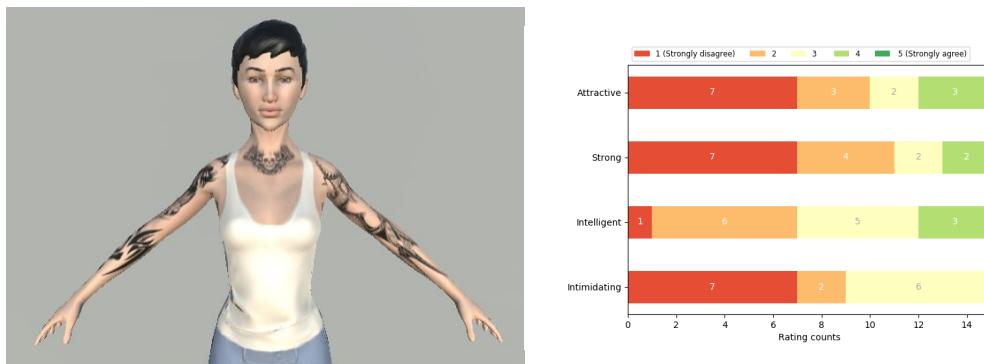


Figure 59: Female 13 thumbnail and ratings.

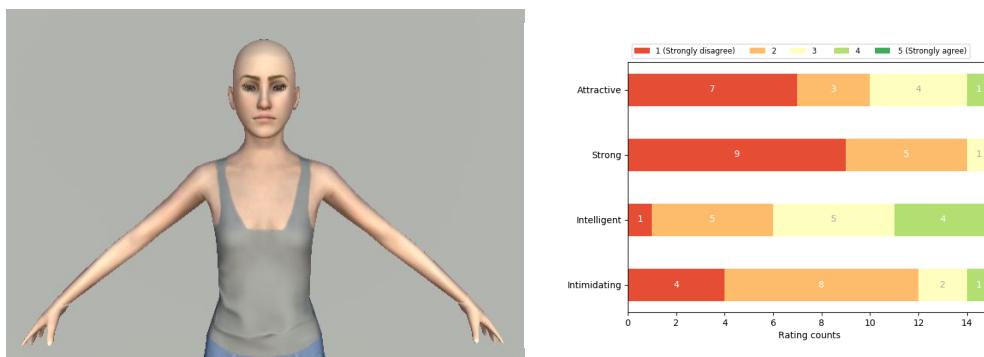


Figure 60: Female 14 thumbnail and ratings.



Figure 61: Female 15 thumbnail and ratings.

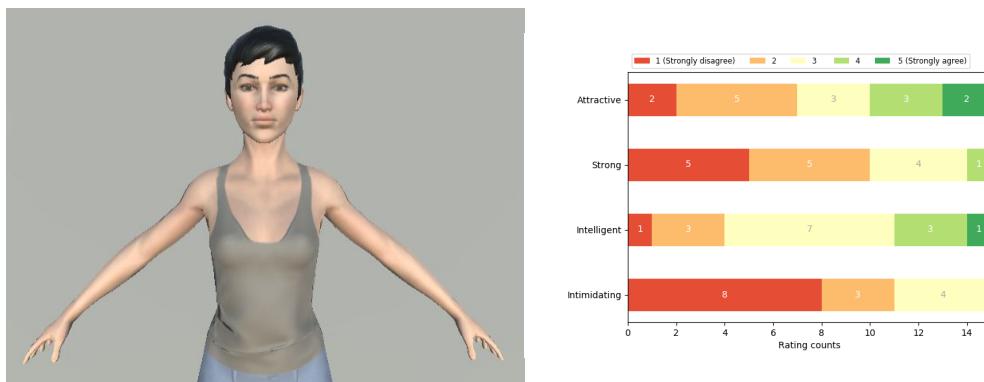


Figure 62: Female 16 thumbnail and ratings.



Figure 63: Female 17 thumbnail and ratings.

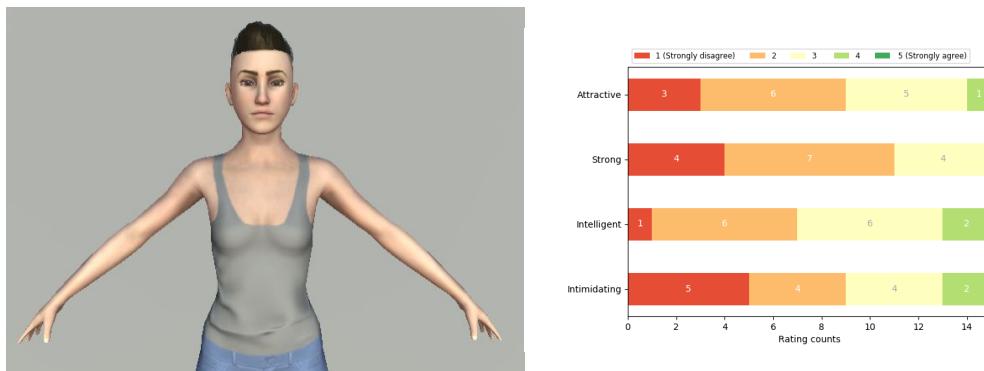


Figure 64: Female 18 thumbnail and ratings.

12.9.2 Males

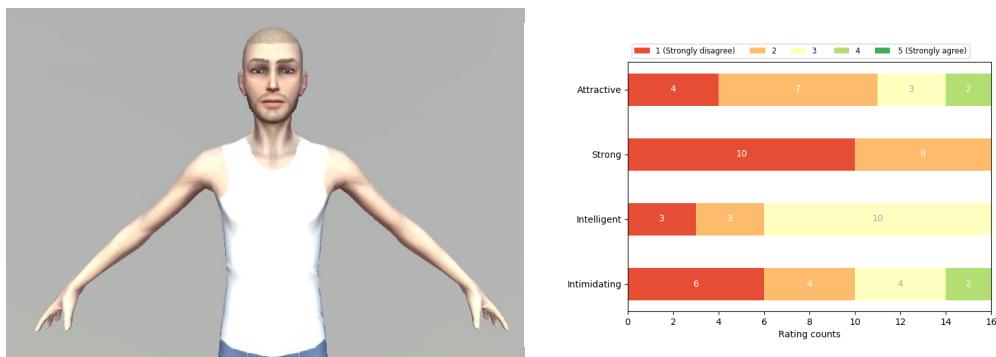


Figure 65: Male 1 thumbnail and ratings.



Figure 66: Male 2 thumbnail and ratings.



Figure 67: Male 3 thumbnail and ratings.



Figure 68: Male 4 thumbnail and ratings.

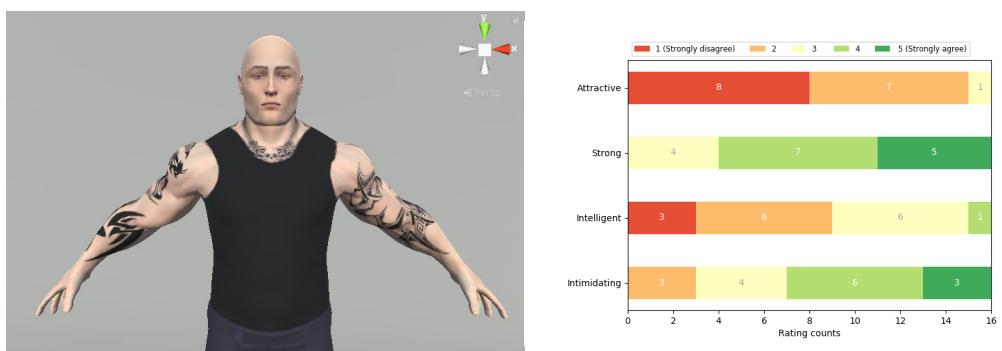


Figure 69: Male 5 thumbnail and ratings.



Figure 70: Male 6 thumbnail and ratings.



Figure 71: Male 7 thumbnail and ratings.

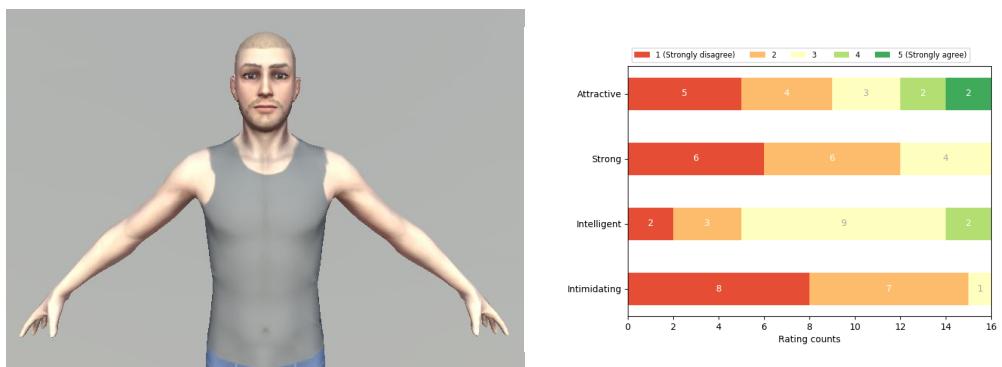


Figure 72: Male 8 thumbnail and ratings.

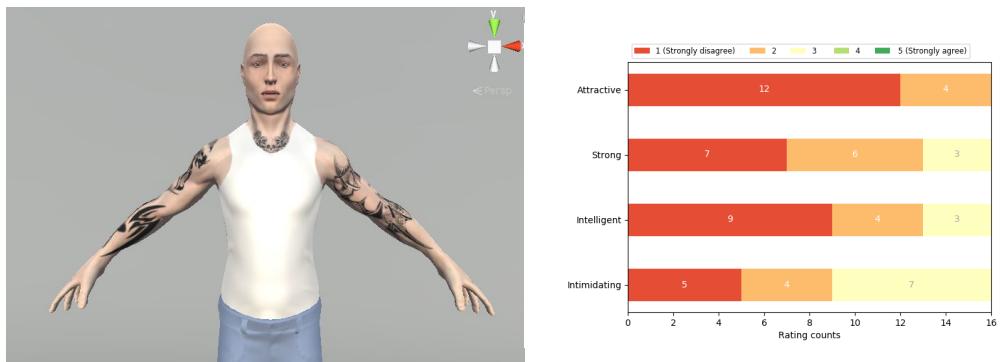


Figure 73: Male 9 thumbnail and ratings.



Figure 74: Male 10 thumbnail and ratings.



Figure 75: Male 10 thumbnail and ratings.

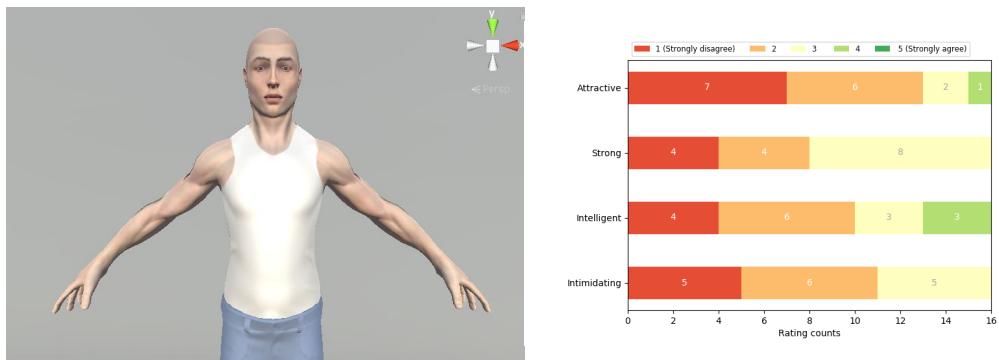


Figure 76: Male 11 thumbnail and ratings.

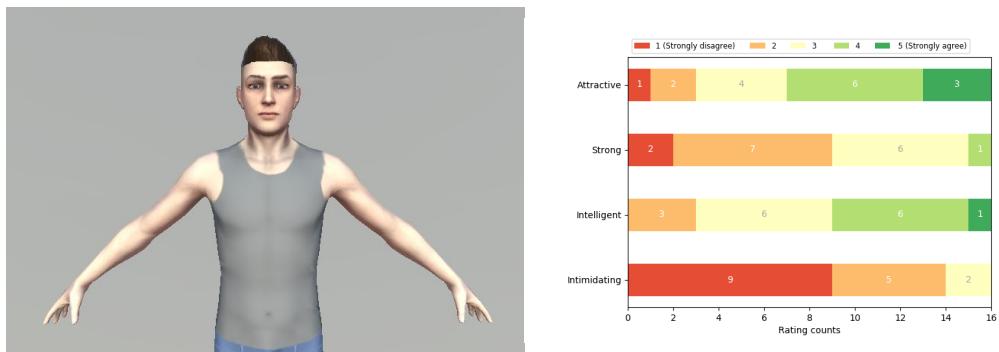


Figure 77: Male 12 thumbnail and ratings.

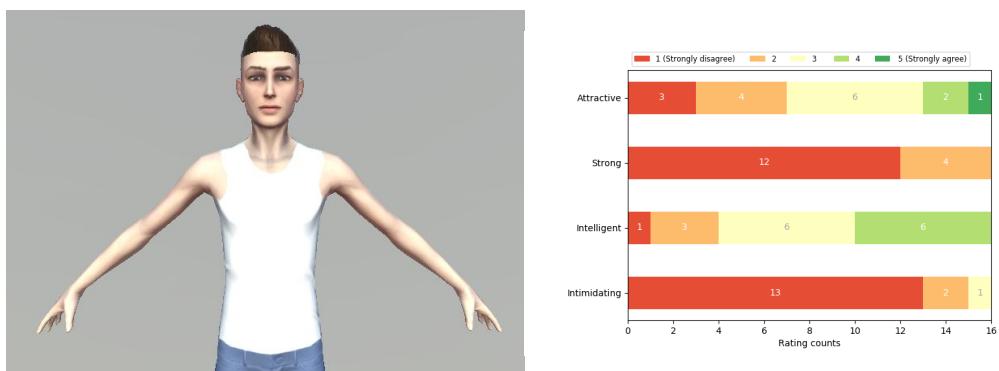


Figure 78: Male 13 thumbnail and ratings.



Figure 79: Male 14 thumbnail and ratings.



Figure 80: Male 15 thumbnail and ratings.



Figure 81: Male 16 thumbnail and ratings.

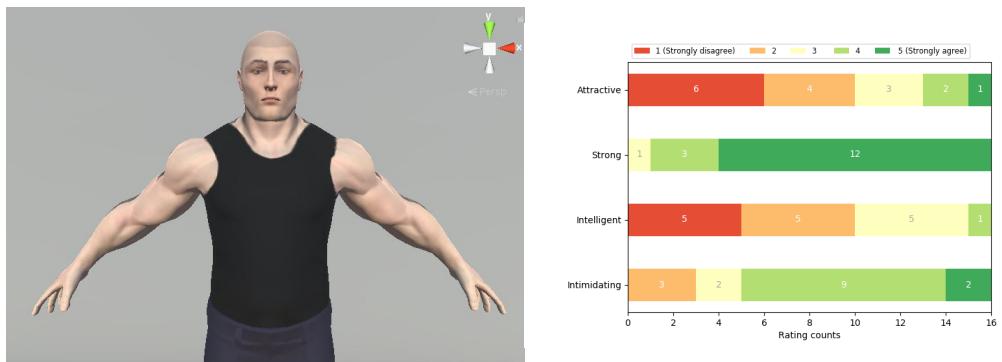


Figure 82: Male 17 thumbnail and ratings.

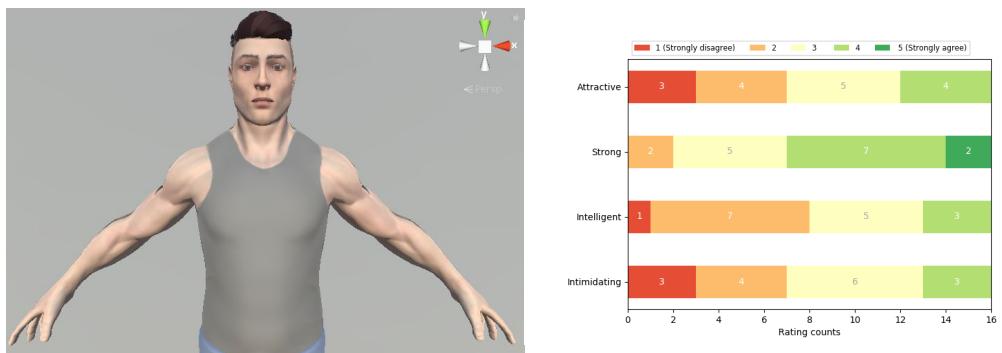
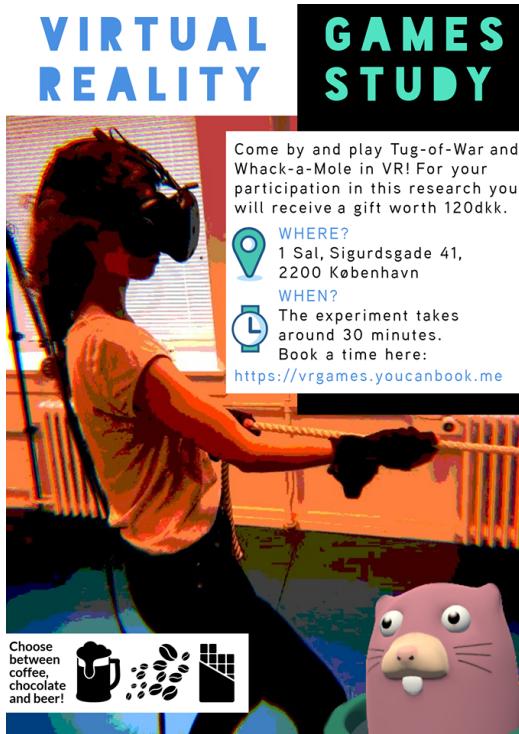


Figure 83: Male 18 thumbnail and ratings.

12.10 Recruiting Poster



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