The Effects of Self- and External Perception of Avatars on Cognitive Task Performance in Virtual Reality

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ABSTRACT

Virtual reality (VR) allows embodying any possible avatar. Known as the *Proteus effect*, avatars can change users' behavior and attitudes. Previous work found that embodying Albert Einstein can increase cognitive task performance. The behavioral confirmation paradigm, however, predicts that our behavior is also affected by others' perception of us. Therefore, we investigated the cognitive performance in collaborative VR when self-perception and external perception of the own avatar differ. 32 male participants performed a Tower of London task in pairs. One participant embodied Einstein or a young adult while the other perceived the participant as Einstein or a young adult. We show that the perception by others affects cognitive performance. The Einstein avatar also decreased the perceived workload. Results imply that avatars' appearance to both, the user and the others must be considered when designing for cognitively demanding tasks.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**.

KEYWORDS

virtual reality; Proteus effect; avatar embodiment; cognitive performance; body ownership

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1 INTRODUCTION

VR allows us to perceive the world through any possible embodiment – the *avatar*. The avatar is the virtual representation of the own self and its appearance determines how one perceives the own body in VR. Current VR systems can provide intuitive and natural interfaces and even track the users' limbs to transfer their motion onto the virtual skeleton of an avatar. Due to the plasticity of the human brain, VR is, therefore, able to create an illusory feeling of full body ownership over the avatar - the *body ownership illusion* (BOI) [27]. Thus, users experience the avatar's body as their own.

Previous work found that the illusory feeling of being in an avatar in VR goes beyond mere self-representation. Avatars can also influence users' behavior. An avatar's skin color [1, 48, 72, 74], the level of realism [62], shape [16, 51], and even athletic appearance [31, 33] can, for example, induce behavioral and attitudinal changes. These changes that are caused by embodying an avatar with specific characteristics are attributed to the *Proteus effect* [75]. The Proteus effect can occur when the characteristics and traits of an avatar are associated with stereotypes and individuals based on users' experience and knowledge. These identity cues let users behave in ways they believe others would expect the avatar to behave. Thus, users' behavior conforms with the expectations and stereotypes of the avatar's identity.

It has been shown that behavioral and attitudinal changes induced by embodying an avatar even retain after the gaming experience and exposition. Banakou et al. [6] showed that embodying a stereotype for superior intelligence can increase cognitive task performance. After embodying Albert Einstein, participants performed a cognitively demanding *Tower of London* (TOL) test that can be used to measure cognitive abilities. Notably, the TOL test has been conducted outside of VR after the participants have taken off the HMD. Participants that embodied the Einstein avatar performed significantly better in the TOL than participants that were embodied in a young adult avatar.

Due to the progress of VR technology virtual environments evolved into collaborative virtual environments (CVEs) where multiple users share the same virtual space regardless of their actual physical location. Nowadays, millions of users play and interact with each other in large-scale online games via avatars [12]. In these CVEs users' behavior is affected by the behavior of other users. This type of social interaction is described by the behavioral confirmation paradigm that predicts that a person's behavior depends on self-perception and the perception by others [69]. Snyder et al. [69] revealed the effect in what became a seminal study. Male participants (referred to as perceivers) who believed that the female counterpart (referred to as the target) was attractive caused her to behave more friendly and likable compared to targets whom perceivers believed to be unattractive. Results indicate that the perception of others defines and affects our behavior. Hence, behavioral changes due to one's avatar cannot be considered in isolation from others' perception. The reciprocal influence of perceivers' and targets' beliefs and expectations associated with the visual appearance of the avatars evoke behavioral changes. As prior research investigated behavioral changes caused by the avatar isolated from effects caused by the behavioral confirmation paradigm, it is unknown whether and how self- and external perception affect users' behavior.

In CVEs the visual appearance of an avatar can be rendered in any desired style for the user that embodies the avatar and also for the users that see or interact with the avatar. To understand how the visual appearance of avatars and the perception of users affect human behavior and cognition we conducted a study in a CVE. We investigate how the self- and external perception affect cognitive task performance and VR experience. Inspired by Banakou et al. [6], we conducted a study with 32 male participants performing a Tower of London (TOL) test in pairs inside a CVE. One participant, the target, embodied Einstein or a young adult while the other participants, the perceiver, embodied a young adult. While the target was unaware of what the perceiver was seeing, we changed the target's avatar for the perceiver only and investigated effects on the TOL. We found that the external perception affects cognitive task performance. This indicates that user performance in CVEs can be enhanced by manipulating the perception of others. Furthermore, the Einstein avatar significantly decreases the perceived workload. We argue that the avatars' visual appearance to both, the user and the others must be considered when designing virtual environments due to interpersonal perception of users in CVEs.

2 RELATED WORK

VR and CVEs enable to design experiences in which users embody different avatars. As VR in general and different avatars in particular can affect the feeling of presence we first discuss previous work on measuring presence in the following. Afterward, we discuss previous work on the BOI and inducing changes in behavior through avatars.

2.1 Presence and Social Presence in VR

VR systems are able to create a sense of presence – a psychological response resulting in a feeling and experience of being and acting in a computer-generated world – by immersing users in virtual environments. Previous work indicates that presence is a key characteristic of VR as it can affect the experienced quality and immersion of virtual environments [26, 56], task performance [29], and even treatment outcome of VR therapies [25, 41].

Described by Riva et al. [53] as the "product of an intuitive experience-based metacognitive judgment to the enaction of our intentions," we are present in a virtual environment when we are able to turn our intentions into actions. Additionally, Heeter [24] divides presence into three dimensions: personal, environmental and social presence. This is in line with Lombard et al. [39] who characterizes presence as a process of transportation and describe it using the following three phrases: "You are there", "It is here", and "We are together". The first depends on the authenticity and intensity of stimulation of human senses created by virtual environments. According to Zeltzer [77] the more natural and higher the fidelity of sensory stimuli created by virtual environments is, the higher is the "sense of being there" [37]. Biocca [9] supports this notion and adds sensory engagement, motor engagement and sensorimotor coordination as underlying factors for presence. Furthermore, the reaction of the virtual environment to one's existence is an additional component of presence. Sheridan [64] shows that the responsiveness of virtual worlds to user's actions is crucial for creating a feeling of presence.

Particularly in CVEs, the mere existence of others increases presence [24]. This concept, known as social presence, is defined as the "level of awareness of the co-presence of another human, being or intelligence" [10]. Hence, social presence in itself is multidimensional, consisting of the user's reaction to virtual agents, the perceived virtual agents' reaction, the impression of interaction possibilities and the co-presence of other people [52]. As social presence does not only depend on one user alone but also on the existence and behavior of others in VR, it is frequently regarded as an independent construct from presence [23]. Typically both, presence as well as social presence are being measured using standardized questionnaires [52, 65, 68]. Schwind et al. [60] recommend assessing presence within the virtual environment as the variance of presence scores increases when users leave VR, reorient in the real world, and only then fill in the questionnaire. Additionally, the authors suggest to use the IPQ by Schubert et al. [59] as it best covers the concept of presence.

2.2 Body Ownership Illusion

Prior research suggests that presence and social presence in VR increase when users embody an avatar [7, 71] and have the illusory feeling that the avatar's body is their own – the BOI [67]. This illusion is explained by the integration of visual and haptic cues into a unified percept [15]. Petkova et al. [50] underlines this notion and adds that a continuous match between visual and somatosensory information in combination with a first-person perspective are critical conditions for inducing perceptual illusions. Transferring this idea to VR, users can have the feeling of owning an avatar's body through a head-mounted display (HMD) perceiving the world from a first-person perspective in combination with tactile or motor stimulation [5, 6]. For example, synchronously stroking a real hand while seeing a virtual hand let a person perceive a surrogate limb as the own one [66]. Previous findings indicate that the technique of visuomotor synchrony – a synchrony between movements of the real body and the virtual body – induces a greater body ownership than synchronous visuotactile stimulation [6, 32].

In VR, visuomotor synchrony is typically created by motion capturing systems that track the users' limbs and transfer their motions onto the virtual skeleton of a avatar. When the user moves a limb, the corresponding virtual limb of the avatar is moving accordingly. In contrast to asynchronous sensory stimulation that can decrease the experience of being located within and of owning a body [32, 50], strong body ownership induced by multisensory correlations lets users even accept bodies that are different from their own [5, 27]. For example, a body swap that includes a mismatch in gender [67], body shape [45], ethnicity [22, 48], and age [5, 46] still establishes a feeling of body ownership. These results suggest that this illusion is rather a bottom-up mechanism that dominates top-down processing [67]. Botvinick and Cohen [11] discuss the "rubber hand illusion", finding that visuotactile information is sufficient to trigger a proprioceptive drift as an indicator for limb ownership. Conversely, Tsakris and Haggard [70] report that a wooden stick is not accepted by persons as a their own limb. That is why the authors conclude that both, bottom-up as well as top-down processes are important factors how multisensory cues are integrated into the own body scheme. Nevertheless, it remains unclear whether and which process overweighs the other.

Prior work investigated various methods to measure BOIs in VR experiences. Llobera et al. [38], for example, assessed the users' sensitivity towards temperature changes to determine the extent of the induced BOI. The authors showed a negative correlation between the BOI and the temperature sensitivity threshold. Sanchez-Vives et al. [57] used the "proprioceptive drift" as a behavioral measure that describes an illusory displacement of the real limb position towards the fake limb [70]. Matsumiya [42], however, revealed that the proprioceptive drift via haptics and the subjective sensation of body ownership are two distinct processes. This is in line with Schwind et al. [62] who could not find a systematic relationship between the degree of perceived body ownership and tactile sensitivity. These ambiguous findings demonstrate the difficulty to interpret behavioral measures as an instrument for quantifying the BOI. Therefore, motor responses [18, 28, 57], cortical activity [43], breaks in illusions [32], and physiological measures [32, 78] were also applied in prior investigations to assess the BOI. To support these objective measures, researchers frequently use questionnaires [5, 17, 55] that cover the users' subjective experience of embodiment.

2.3 Behavioral Changes through Avatars

Users can have the feeling of embodying an avatar through the BOI. As a consequence, this experience of being in the virtual avatar triggers a multitude of psychophysical effects on one's self and other users in CVE. Previous work found that a user embodying an avatar can be affected by its visual appearance. This phenomenon is attributed to the Proteus effect [75]. Yee et al. [75], for example, showed that being in a more attractive avatar increases self-confidence in terms of interpersonal distance and self-disclosure in a dialogue [75]. As the virtual appearance indicates attractiveness, which is associated with higher confidence, extraversion, and friendliness [35], users' behavior conforms with the common expectations. The authors showed similar results in a second experiment where they manipulated the height of avatars as height is associated with self-esteem and competence. In a VR bargaining task, taller participants behaved more confidently and performed better in negotiation. There is further evidence for the Proteus effect in an experiment where the embodiment of a child causes overestimation of object sizes [5]. The connection of users' stereotypical assessments of their avatars and the impact on their attitude was illustrated by Yang et al. [74] who revealed that players with dark-skinned avatars played more aggressively in a non-immersive violent game than with light-skinned avatars.

Prior research reported a decrease of implicit racial bias after embodying light-skinned participants in dark-skinned avatars after the exposition in VR [40, 48]. Similar could be evidenced by Yoon and Vargas [76] and Rosenberg et al. [54] where players embodied in an heroic avatar exhibited more prosocial behavior. These results are in line with the studies by Peña et al. [49] who demonstrated that users employing avatars in Ku Klux Klan ropes exhibited more negative thoughts after the playful exposition. These after-effects were also shown by Banakou et al. [6] as being Albert Einstein – a stereotype for superior intelligence – resulted in a higher cognitive task performance than being in a young adult avatar. These results were measured through the TOL test, derived from the *Tower of Hanoi* test, a neuropsychological test for assessing executive functioning, problem solving skills and planning abilities [63]. Participants performed the TOL in reality after they embodied Einstein or a young adult.

Prior work revealed the concept of user identification with media characters as an explanation for behavioral changes caused by avatars [13]. As the BOI describes the feeling of being physically in a virtual body, user identification is a cognitive and emotional state where users are not aware of themselves as users but have the experience of being the avatar. The users turn into the avatar and experience and perceive virtual events from inside as if they were actually happening to them [13, 30]. Due to this strong bond between avatar and user psychophysical effects like the Proteus effect can occur. However, previous investigations found that the visual appearance of an avatar does not only affect the user that is embodying the avatar but also the other users in CVEs [47]. Bailenson [3], for example, investigated social interaction in virtual environments and found that participants embodied in an avatar walked significantly closer to the other participants' avatar when approaching their backs than their fronts [2]. These results suggest that the same psychological social interaction effects that occur in reality can also occur in CVEs.

One fundamental of human interaction is the fact that the behavior of a person is affected by the behavior of others [8]. Green [19] defined social interaction as "the mutual influences that individuals and groups have on one another in their attempts to solve problems and in their striving towards goals". This is in line with behavioral confirmation paradigm described by Snyder et al. [69] that indicates that the mutual influence of perceivers' and targets' beliefs and expectations associated with the visual appearance of the avatars evoke behavioral changes.

2.4 Summary

Previous investigations showed effects on users' behavior and even cognition due to the visual appearance of avatars. These effects were shown outside or within the virtual environment. Theories from social interaction, however, state that the behavior of a person is affected by the behavior of others. Hence, in CVEs where multiple users share the same virtual space and interact with each other behavioral changes of a user are not only induced by the own

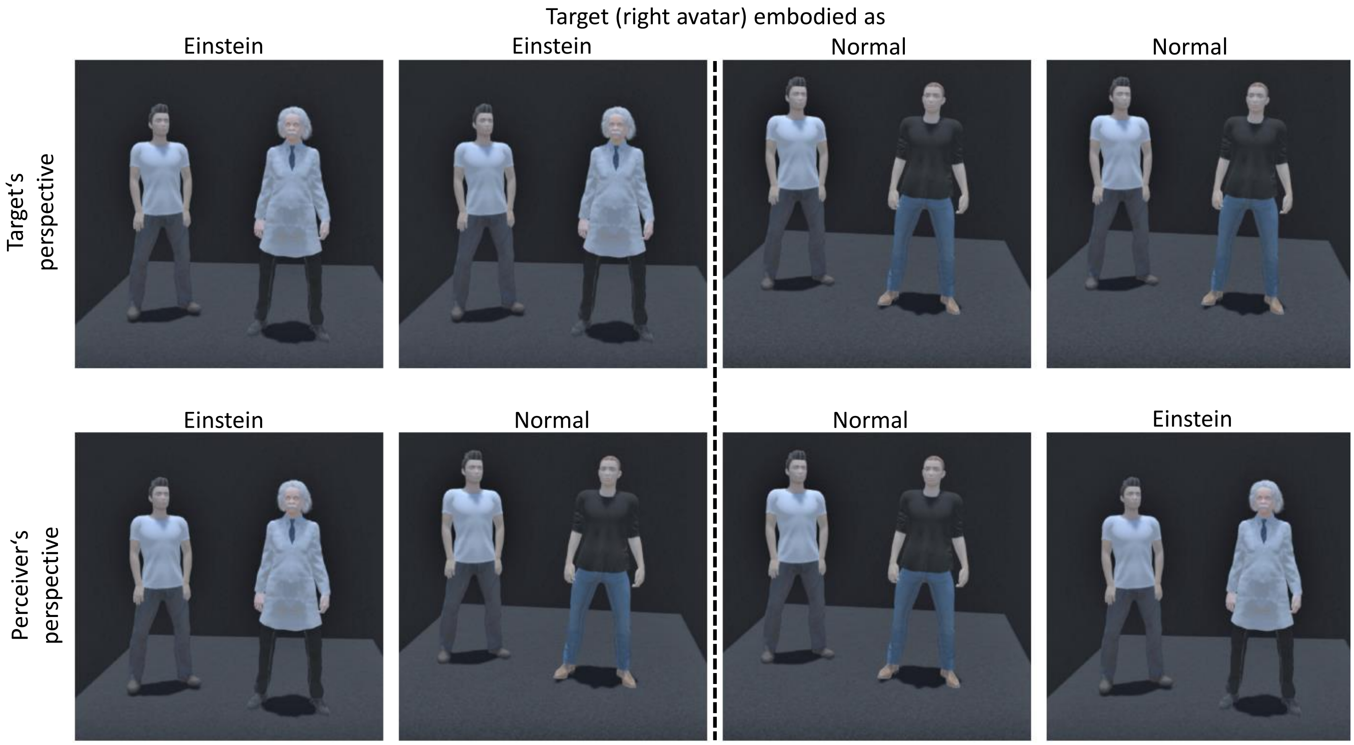

Figure 1: The perception of the scene from the target's perspective (top) and the perceiver's perspective (bottom) in each condition. In one group (left of the dotted line), the target was embodied as Einstein and perceived as Einstein, and the target was embodied as Einstein and perceived as normal. In the other group (right of the dotted line), the target was embodied as normal and perceived as normal, and the target was embodied as normal and perceived as Einstein (from left to right).

avatar but also by the avatars of other users. Prior work suggests that these effects can occur in CVEs, nevertheless little is known about the mutual influence of virtual avatars on multiple users interacting with each other. Due to the importance of avatars on users' experience and performance in CVEs it is crucial to understand and consider these effects caused by social interaction.

3 METHOD

Related work found that embodying an avatar that is associated with superior intelligence – such as Albert Einstein – affects cognitive task performance after the exposition in VR. However, it is unknown to what degree the Einstein avatar influences the behavior and cognition of other users in CVEs. It is important for the design of CVEs in general and virtual characters in particular to understand how the visual appearance of an avatar affects the behavior and VR experience of one's self and the other users. Thus, we investigate whether and how the embodiment of Einstein influences the performance in a cognitively demanding TOL task [63] performed within a CVE when a user's self-perception and external perception differ. The effects on the perceived task load, the sense of presence, social presence as well as body ownership were assessed.

3.1 Study Design

We selected the stimuli based on previous work by Banakou et al. [6] to investigate the effects of users' self- and external perception on their cognitive task performance. We conducted a mixed-design study with two independent variables. Two participants were simultaneously in the same virtual environment. In line with behavioral confirmation theory [69], we considered their roles as *target* or *perceiver*. One participant was the *target* whereas the other was the *perceiver*. The only between-subject variable was the target's Self Perception with the two levels being *Einstein* or being a *Normal* avatar. Thus, the targets embodied either Einstein or a normal avatar.

To assess how the perception of the other participant affects cognitive performance, we used the External perception as within-subject variable with the two levels as *Seeing Einstein* or *Seeing a Normal* avatar. The perceivers embodied a normal avatar and saw the target either as Einstein or a normal avatar. The targets were unaware of what the perceivers saw. Since we assumed that a cognitively demanding task can benefit from collaboration, we measured cognitive task performance in a classical TOL solo task as well as in a cooperative task. In the solo task, both participants simultaneously performed a TOL task next to each other. They were not aware of the other's score and game state. In the cooperative task, the two participants played the TOL together on the same board.

Figure 2: Participants in the real world (top) wearing motion capturing suits and their avatars in VR (bottom) performing the solo TOL task (left) and the cooperative TOL task (right).

To reduce the frequency of swapping the avatars, participants performed both TOL tasks (solo and cooperative) consecutively. After completing both tasks, we changed the External perception of the perceiver. We counterbalanced the conditions to reduce order effects.

3.2 Participants

In line with Banakou et al. [6] we recruited 32 male participants to avoid gender mismatches between participant and avatar [61]. The recruitment was done through our institution's mailing lists. On average, participants were 25.65 years old (SD = 4.53) ranging from 20 to 41 years. All of them had a technical background in computer science or engineering. Participants were compensated with credit points for their study course. We had 29 right-handed and 3 left-handed participants in our study. All of them had light skin tones matching the visual appearance of the avatars. None of the participants have taken part in a TOL experiment before. All of them had either normal or corrected-to-normal vision. We had no drop-outs in the study. This study received ethics clearance according to the ethics and privacy regulations of our institution.

3.3 Apparatus

To immerse participants in a high-fidelity environment, we developed an apparatus that tracks their motions using a full-body motion capture system and renders the scene using a state-of-the-art 3D engine. We implemented the VR application using the *Unity3D* game engine (v. 2018.3.2f1). As the study requires a multi-user setup, the application runs on two identical PCs with *Windows 10*, *Intel* i7-8750H, 16GB RAM, and an *NVIDIA GeForce GTX 1060* graphics card. We set the target frame rate to 90 frames per second (fps) on both PCs to ensure a constant frame rate for both participants. We used two *HTC Vive* HMDs with wireless adapters.

We designed a simple virtual scene consisting of a room with dark walls, a virtual mirror, questionnaires, and a TOL board. We integrated a virtual mirror into the scene to ensure that the participants could see themselves in the avatars' bodies (see Figure 2). Hence, we limited technical factors causing VR sickness through constant visuomotor synchrony. We created three avatars using the 3D-suite *Daz3D*. We used the character *Genesis 8* for the normal avatars and *Floyd 8* for the Einstein avatar and adapted their appearance (body shape, facial expressions, skin) by morph targets and textures. To track participants' full-body motion with high accuracy and low latency, we used an *OptiTrack* motion tracking system with twelve cameras (eight *PRIME 13* and four *PRIME 13W*) and the software *Motive* (v. 2.1).

The motion tracking software runs on a dedicated PC with *Windows 10, Intel* i7-8700, 26GB RAM, and an *NVIDIA GeForce GTX 1080* graphics card. We calibrated the *OptiTrack* system according to the manufacturer's specification and achieved an exceptionally precise calibration result (overall reprojection mean 3D error: 0.852mm, triangulation residual mean error: 0.8mm, overall wand mean error: 0.187mm, worst camera mean 3D error: 0.949mm). The system tracks the participants while wearing motion capturing suits. We provided suits in different sizes (2 ×S, 2 ×M, and 2 ×L) with 49 optical markers attached in a given pattern. The *OptiTrack* system tracks participants' skeleton with 240 fps. The skeletons are transmitted through a local 1000 Mbit network connection to the two PCs rendering the 3D scene using UDP multicast.

3.4 Measures

We took one objective and a number of subjective measures to determine the effects of the independent variables. We used the score computed when performing the TOL task to measure objective cognitive performance. Participants were asked to fill a raw NASA-Task Load Index (raw TLX) [20, 21] for the solo task and an extended version of the NASA-Task Load Index (TLX Team) to measure perceived task load of a team for the cooperative task [58]. We determined participants' sense of presence using the IPQ questionnaire [59], their sense of social presence using the social presence questionnaire [52] and quantified the experience of body ownership using the five-post statement-questionnaire [6]. In line with [60], all questionnaires were filled in the VR environment. Participants filled in the IPQ, the five-statement post-questionnaire, and the social presence questionnare after completing both TOL tasks.

3.4.1 Tower of London Score. The TOL score was used to assess cognitive task performance. Originally defined to detect cognitive impairments, the TOL is a neuropsychological test to assess executive functioning, planning, and problem-solving skills [63]. The TOL task was implemented as suggested by Krikorian et al. [34].

In the solo task, each participant simultaneously played the TOL alone on a virtual board. In the cooperative task, participants share one virtual TOL board and performed the task together (see Figure 2). The TOL board consisted of three rods in descending heights from left to right and three different bricks colored in blue, red and green. The heights of the rod indicate the maximum number of bricks allowed to be placed on a rod (left rod: 3, middle rod: 2, right rod: 1). From a predefined starting position participants were asked to strategically move the bricks from one rod to another to match a given pattern. The pattern was shown in the upper part of the TOL board. To complete the TOL task participants had to solve 12 problems with different difficulties depending on the number of allowed moves per problem. The first two problems allow two moves, problem 3 and 4 allow three moves, problem 5 to 8 allow four moves and problem 9 to 12 allow five moves for solving. A problem is solved when the bricks are arranged in the given order within the prescribed number of moves. Participants had a maximum of three attempts to solve a problem.

The TOL score was calculated according to the algorithm provided by Krikorian et al. [34]. The participants received three points for solving a problem in the first attempt, two points in the second attempt, one point in the third attempt and zero points if they failed to solve the problem three times. Hence, the maximum score that can be achieved is 36 (solving all of the 12 problems in the first attempt).

3.5 Procedure

As participants experienced the VR environment in pairs, we invited them to different rooms in our lab to ensure that they do not meet each other before entering the VR scene. To avoid that the perceiver informed the target about his visual appearance and to prevent mismatches between the appearance of the Einstein avatar and the target's voice, we asked the participants not to speak during the experiment. Hence, there was no conversation between the target and the perceiver before and during the experiment. After welcoming the participants individually, we explained the course of the study. We provided a brief introduction into VR, asked them to sign an informed consent form, and to fill a demographic questionnaire. To familiarize participants with the TOL task, we included a short training phase where they performed the task on a standard desktop computer using a mouse before entering the VR scene. In line with Lazar et al. [36], we also tried to reduce the impact of learning effects with this training phase, since users learn the most in initial stages with a lesser improvement in subsequent trials.

After participants felt confident to perform the TOL task, we helped them to put on the motion capture suit and attached 49 markers to track their skeleton. We further explained that while in VR, they can interact with the TOL task and the questionnaires using their hands instead of a mouse. Before leading them into the VR lab, we adjusted the HMDs to the participants' head and calibrated it to their inter-pupil distance for best visual results. After putting on the HMD, we guided both participants into the VR lab where they entered the designed scene. We highlighted that participants could withdraw or discontinue participation at any time without penalty or losing their compensation.

Before participants entered the VR scene, we adjusted the external and internal perception of both participants according to the respective condition. After entering the scene, participants (virtually) met for the first time. To accustom themselves to the VR environment, to perceive their avatar, and to perceive the other participant's avatar, they waited in the VR scene for 30 seconds. Afterward, participants were asked to perform the TOL task as fast and precisely as possible. After completing the TOL task, we asked them to fill in the NASA TLX questionnaire. They continued with the cooperative TOL task which was again followed by the NASA TLX and TLX Team, IPQ, social presence, and five post-statement questionnaires.

After completing both tasks and filling all questionnaires, the whole scene faded to black for one second and we adjusted participants' external- and self-perception to the next condition. We counterbalanced the order of the conditions in a 4×4 latin square design. To reduce the frequency of swapping the avatars, participants performed both TOL tasks (solo and cooperative) consecutively. After completing both tasks, we changed the External

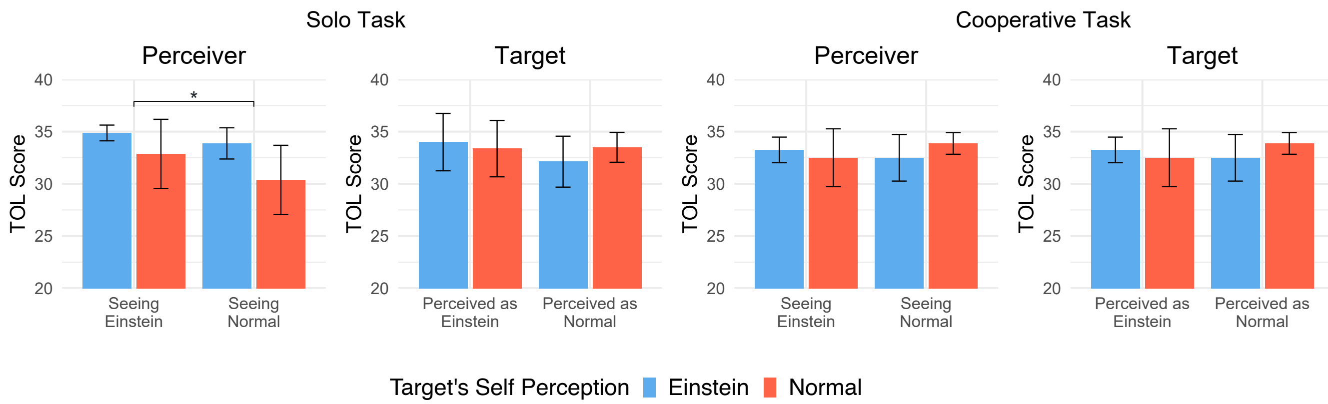

Figure 3: Average TOL scores of the target and the perceiver during their solo and cooperative tasks. The score of the perceiver in the solo task (left) was significantly better when the target was seen as Einstein instead of Normal.

PERCEPTION of the perceiver (see Figure 1). At the end of the study, participants were asked to give feedback about the overall experience, the avatars in VR, and their physical and mental well-being in a brief questionnaire. On average, the study took 75 minutes per participant in total.

4 RESULTS

Our measures include both parametric as well as nonparametric data. Shapiro-Wilk tests for normality indicates that the assumption of normal distribution has been violated for scores of the TOL task and of social presence. Items of the 5-statements post questionnaire concern ordinal data. For multiple factor analyses of nonparametric data we used the ARTool package for R by Wobbrock et al. [73] for hypothesis testing. We performed a multifactorial mixed-design ANOVA on parametric data. Participation was entered as a random factor in all analyses. To ensure that the task completion time (TCT) is not a confounder, we tested the effects of both EXTERNAL PERCEPTION as well as SELF PERCEPTION on the duration of the TOL tasks and found no statistically significant effects (all $p > .274$). The following results are structured according to whether the measurements were taken from the perceiver or from the target.

4.1 Perceiver

4.1.1 Solo TOL Scores. We found a significant main effect of EXTERNAL PERCEPTION, $F(1, 14) = 6.429$, $p = .024$, $\eta_p^2 = .314$, however, not of SELF PERCEPTION, $F(1, 14) = 2.837$, $p = .115$, $\eta_p^2 = .168$, and no interaction effect of EXTERNAL PERCEPTION × SELF PERCEPTION $F(1, 14) = 2.168$, $p = .163$, $\eta_p^2 = .134$, on the TOL score. Thus, the perceivers' performance during the solo task depended on the targets' avatar. When the perceivers saw the target as Einstein, their TOL scores significantly increased (see Figure 3).

4.1.2 Cooperative TOL Scores. We found no significant main effects of EXTERNAL PERCEPTION, $F(1, 14) = .022$, $p = .885$, $\eta_p^2 = .001$, and SELF PERCEPTION, $F(1, 14) = .191$, $p = .669$, $\eta_p^2 = .013$, and no interaction effect of EXTERNAL PERCEPTION × SELF PERCEPTION, $F(1, 14) = .047$, $p = .832$, $\eta_p^2 = .003$, on the TOL score. Thus, the perceivers' TOL scores during the cooperative tasks were neither affected by the target's avatar nor by how the targets saw themselves.

4.1.3 Solo TLX Scores. We found no significant main effect of EXTERNAL PERCEPTION, $F(1, 14) = .101$, $p = .755$, $\eta_p^2 = .007$, however, we found a significant effect of SELF PERCEPTION, $F(1, 14) = 6.586$, $p = .022$, $\eta_p^2 = .319$. There was no interaction effect of EXTERNAL PERCEPTION × SELF PERCEPTION, $F(1, 14) = 2.419$, $p = .142$, $\eta_p^2 = .147$, on the TLX score. Thus, for the solo task we found that the perceivers' task load depended on how the targets perceived their avatar. When the targets perceived themselves as Einstein, the perceivers had a significantly lower task load (see Figure 4).

4.1.4 Cooperative TLX Scores. We found no significant main effects of EXTERNAL PERCEPTION, $F(1, 14) = 1.556$, $p = .233$, $\eta_p^2 = .052$, SELF PERCEPTION, $F(1, 14) = 4.518$, $p = .051$, $\eta_p^2 = .224$, and no interaction effect of EXTERNAL PERCEPTION × SELF PERCEPTION, $F(1, 14) = 2.694$, $p = .123$, $\eta_p^2 = .213$, on the TLX score. Thus, the perceivers' scores during the cooperative task were not affected by the targets' avatar.

4.1.5 Presence. We did not find a significant main effect of EXTERNAL PERCEPTION, $F(1, 14) = .669$, $p = .427$, $\eta_p^2 = .045$, and of SELF PERCEPTION, $F(1, 14) = 1.415$, $p = .254$, $\eta_p^2 = .091$, and no interaction effect of EXTERNAL PERCEPTION × SELF PERCEPTION, $F(1, 14) = .283$, $p = .603$, $\eta_p^2 = .019$ on the IPQ score indicating that presence did not significantly differ between the conditions.

4.1.6 Social Presence. We found a significant main effect of EXTERNAL PERCEPTION, $F(1, 14) = 4.759$, $p = .047$, $\eta_p^2 = .253$, however, not of SELF PERCEPTION, $F(1, 14) = .917$, $p = .354$, $\eta_p^2 = .061$, and no interaction effect of EXTERNAL PERCEPTION × SELF PERCEPTION, $F(1, 14) = .578$, $p = .460$, $\eta_p^2 = .039$, on the social presence scores. We assume that the external appearance of the target's avatar changed the level of social presence of the perceiver.

4.1.7 5-Statement Post-experience Questionnaire. Individual multifactorial ART ANOVAs on the items of the post-experience questionnaire as used by Banakou and Slater [6] show significant main

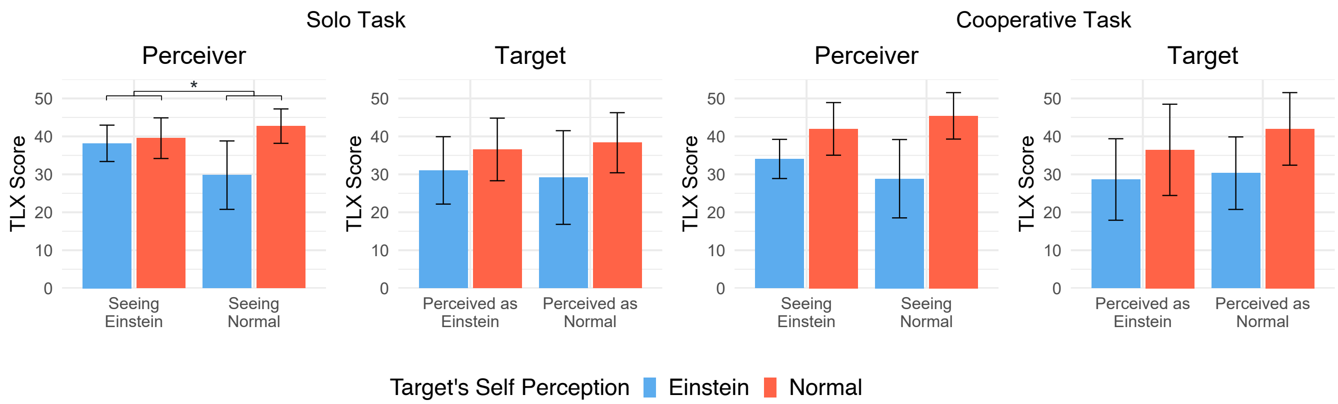

Figure 4: Average TLX scores of the target and the perceiver during their solo and cooperative task. The perceivers' task load in the solo task depends on how the target perceived the own avatar (left). When the targets perceived themselves as Einstein, the perceivers had a significantly lower task load. In all conditions, the TLX scores from target or perceiver were lower, when the target's self perception was Einstein. This indicates that there is a systematic relation between how the participants perceive themselves and a behavioral change causing a lower workload for their companions when they saw themselves as Einstein.

effects of External Perception, $F(1,14) = 4.722$, $p = .047$, $\eta_p^2 = .252$, and of Self Perception, $F(1,14) = 5.935$, $p = .028$, $\eta_p^2 = .297$, but no interaction effect of Self Perception × External Perception, $F(1,30) = 2.250$, $p = .155$, $\eta_p^2 = .138$, on the measure *features*. The measures of *vrbody* (all with $p > .333$), *mirror* (all with $p > .270$), *twobodies* (all with $p > .321$), and *agency* (all with $p > .227$) shows no significant main or interaction effects. Thus, perceived features of Einstein that do not resemble one's own body were affected through the external appereance of the targets' avatar and how the targets saw themselves.

4.2 Target

There we no significant main effects of External Perception, Self Perception, and no interaction effects of External Perception × Self Perception on the target's solo and cooperative TOL scores, solo and cooperative TLX scores, presence, social presence and the 5-statement post-experience questionnaire (all with $p > .05$).

5 DISCUSSION

In this paper, we investigate the effects of self- and external perception on cognitive task performance in VR. A total of 32 male participants performed a TOL task. We investigated the effects on cognitive performance when one participant (target) was perceived as Einstein even when another participant (perceiver) perceived the target as a normal young adult avatar. We found that the external perception of the target significantly affected the cognitive performance of the perceiver. Thus, cognitive performance increased while seeing another person as Einstein. Furthermore, we found that perceivers who saw targets perceiving themselves as Einstein had a significantly lower task load. While inferential statistics revealed no significant effects on the cooperative task, descriptive results are in line with the solo task.

We assume that the cooperative TOL task, used to determine performance in collaborative problem solving, did not show significant effects as the task was originally designed for individual problem solving and, thus, not sensitive enough for determining effects during collaboration. In addition, the perceivers' social presence and the degree to which the perceived features resemble the own body significantly decreased when the perceiver saw another person as Einstein instead of a normal young adult. We assume that being together in a virtual room with the universally known Einstein who died a long time ago is an unrealistic scenario leading to a significant drop in social presence. Similar was shown in prior investigations which revealed a relationship of the avatars' realistic appearance and the degree of social presence in CVEs [4, 79, 80].

Previous work on the Proteus effect suggests that embodying Einstein should cause a higher cognitive performance. This is supported by Banakou et al. who found that after embodying Einstein, participants had a significantly higher cognitive performance [6]. Thus, our results do not support the findings by Banakou et al. [6], which can be attributed to a number of differences between the study by Banakou et al. and our study. We measured cognitive performance in VR *while* embodying Einstein in a CVE whereas Banakou et al. measured cognitive performance *after leaving the VR* [6]. We, however, would expect that cognitive performance should be highest while embodying Einstein. Additionally, exposure time also differed. Banakou et al. embodied participants for 12 minutes in Einstein, our participants embodied Einstein for around 30 minutes per condition resulting in being Einstein for 60 minutes [6]. The Proteus effect suggests that cognitive performance should increase the longer Einstein is embodied. Consequently, we should have observed a stronger effect on cognitive performance, which was not the case. That is why we assume that being and interacting with another person might have interpersonal and disruptive effects confounding an increasing cognitive performance while being Einstein.

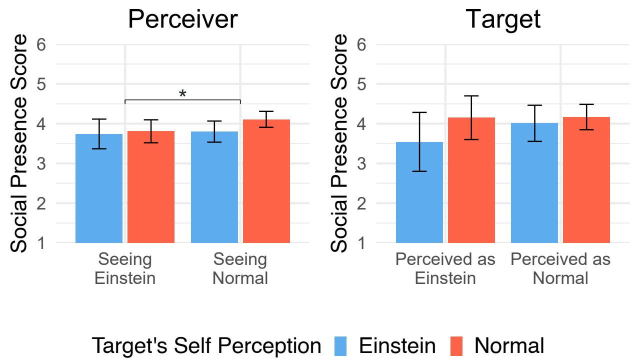

Figure 5: Social presence scores of the target and perceiver. The external appearance of a target's avatar changed the level of social presence for the perceiver.

The behavioral confirmation paradigm would suggest that being perceived as Einstein should result in a behavior that resembles Einstein. Thus, participants embodied as Einstein should change their behavior according to how they expect that Einstein would behave. As Einstein is a stereotype for superior intelligence, one should behave according to the expectation of having high intelligence when embodying Einstein. We, however, found neither effects on cognitive performance nor perceived task load of the person embodied as Einstein. As we limited the interaction between participants to observing each others movement, we assume that the level of social interaction was not sufficient to trigger direct behavioral confirmation effects. Nevertheless, perceived task load depends on how the other person perceives their own body. There are a number of potential explanations: One might assume that if the target performs the task faster, this could encourage the perceiver. We, however, found no effects on task completion time indicating that the targets' speed did not change. We assume that there must be more underlying factors of social interaction and the targets' behavior that systematically or subconsciously communicates that someone embodied as Einstein is confident or assertive in doing the task.

We found significant effects of the targets' own perception on task load of the perceiver. In all conditions, the TLX scores were lower, when the target's self perception was Einstein. This indicates that there is a systematic relation between how the participants perceive themselves and a behavioral change causing a lower workload for their companions. However, neither the Proteus effect nor the theory of behavioral confirmation can explain that increased cognitive performance. The increased TOL score might be explained by an increase in perceived competition and engagement due to competitive behavior. Research in psychology suggests that competition can increase performance but that the effect is mediated by effects on the individual goals [14, 44]. Performance-approach goals, trying to do well relative to others, increase performance and performance-avoidance goals, trying to avoid doing poorly compared to others, decrease performance. We assume that seeing Einstein might have motivated participants to try doing well relative to the other participant. Similarly, targets seeing themselves as Einstein might have displayed behavior that motivated perceivers, who had a lower task load. While effects mediated by competition are plausible, we cannot rule out other explanations.

The impact of learning caused by order effects have to be considered in repetitive tasks as well. Learning effects could increase the amount of unsystematic variance making it more difficult to find a significant difference between conditions. Although participants performed better in the TOL game in later stages of the experiment, we could find a significant effect of external perception on the TOL score. Since we counterbalanced the conditions, we can rule out that it is the process of learning that enhances participants' cognitive performance when the target is perceived as Einstein compared to a young adult.

6 CONCLUSION

In this paper, we have conducted a study to investigate the effects of self- and external perception. We found that seeing another person as Einstein as well as seeing persons who perceive themselves as Einstein can significantly affect the user. While previous work showed that embodying avatars can have effects, we show that being with someone embodying different avatars can affect the user as well. While this effect cannot be explained by the Proteus effect or behavioral confirmation, we assume that other psychological mechanisms, such as effects of competition might explain the impact of avatars on users. From a HCI perspective, however, the conclusion is rather simple. When designing avatars for CVEs it is important to not only consider effects on the user embodying the avatar but also effects on other users.

Future work should further explore the effects of self- and external perception. We found effects on cognitive performance and perceived task load. We, however, assume that other effects could be even stronger. If embodying avatars can reduce racial biases [40, 48], it is likely that seeing certain avatars can further reinforce the effect. To avoid gender mismatches between participant and avatar [61], we only investigated avatars' effects on male users. Therefore, the embodiment of "Marie Curie" and the impact on female users could provide further insights into the underlying mechanisms. Future work should also find ways to quantify the Proteus effect. The current body of work only determined effects caused by the Proteus effect without a direct way to measure it. If effects are indeed mediated by the Proteus effect, we need ways to quantify it to predict the effect of different avatars on users.

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