Effects of Embodying Emotional Avatars on Thermophysiological Responses and Affective State in Virtual Reality

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Abstract

Designers of virtual characters use facial expressions to display avatar emotions. Previous work revealed connections between emotions and thermoregulatory, e.g., happiness increases and sadness decreases skin temperature. As virtual reality (VR) enables embodying avatars with any facial expression, it is unclear whether embodying avatars with different emotions also affect users' thermophysiological and emotional responses. We conducted a study with 24 participants who embodied customized avatars displaying happy, neutral, and sad facial expressions in VR. We found that participants' skin temperature was higher with sad avatars than with happy ones while resting. Despite non-significant pairwise comparisons, descriptive statistics suggest an opposite trend for skin temperature responses during grabbing interactions. We also show that participants felt happier while embodying happy avatars compared to sad avatars. Results indicate that avatars' emotions impact users' thermoregulation and affective states. We discuss underlying mechanisms and potential applications.

CCS Concepts

• **Human-centered computing** → **Virtual reality**; • **Applied computing** → *Computer games.*

Keywords

virtual reality, emotions, avatar, facial expressions, skin temperature

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1 Introduction

Designers and researchers of virtual characters aim to equip them with recognizable personalities and emotional expressions to foster user identification, empathy, and likability [13, 56]. Among the methods to convey the affective state of a character, e.g., body language [52], movement patterns [67], and vocal tone [36], facial expressions stand out as particularly salient and widely understood cues [15, 18, 19]. Facial representations of emotion are often processed rapidly and intuitively by observers and, while some nuances may be culturally specific [32], a core set of facial expressions has been shown to be universally recognized across societies [18].

While emotional expressions displayed using non-immersive technologies (e.g., 2D games, film, or desktop-based virtual agents) have long been studied for their influence on user attitudes and behaviors [49, 60], immersive technologies like VR offer a special affordance. In VR, users can embody a digital avatar—the virtual self-representation of the user. Hence, users do not merely observe a character but may experience a virtual avatar as their own body, a phenomenon known as the virtual embodiment illusion [37, 63, 69]. This illusion is typically induced through real-time motion tracking, where users' body movements are mirrored by the avatar, fostering a sense of ownership and agency over the virtual body. Because VR enables control over the avatar's appearance, users can embody forms that differ from their physical selves [38].

Users can embody avatars that display emotional expressions such as smiling, frowning, or appearing fearful [54]. These affective states may not only alter how others perceive the avatar but also influence the user's emotional states. For example, research on facial feedback suggests that adopting certain facial expressions can modulate one's own affective experience [26, 70]. Therefore, it is important to learn if and how embodying avatars with different emotional expressions in VR modulates users' emotions.

Interestingly, previous research recognized skin temperature as a marker of emotional responses [9, 64, 68]. Shelepenkov et al. [68], for example, showed that emotions can change thermoregulatory mechanisms. The authors induced different emotions (e.g., happiness and sadness) using images and measured participants' skin temperature. Findings indicate that different emotional states can change skin temperature due to varying levels of arousal [57], e.g., sadness decreases and happiness increases skin temperature. Another study showed that facial temperature changes when emotions are induced, e.g., the nose temperature decreased with negative valence stimuli but increased with positive emotions and arousal patterns [64]. Similar effects have been observed in monkeys, with skin temperature increasing in response to positive emotions and decreasing with negative emotions [9]. These findings raise the question whether embodying avatars that visually express different emotions also elicit corresponding thermal responses in users.

To increase our understanding of how embodying emotional avatars influences users' physiological and emotional response, we conducted a study with 24 participants. Using a repeated-measures design, participants embodied avatars with facial expressions that represent being happy, neutral, or sad. To learn about the robustness of the effects, participants performed two tasks: a static task where they rested for three minutes in front of a virtual mirror and an active task where they grabbed and moved virtual objects from one location to another. For the resting task, we found a higher skin temperature for sad avatars compared to happy avatars. For the grabbing task, however, we found the opposite effect, indicating a higher temperature for happy avatars compared to sad avatars. In line with theories on facial feedback [26, 70], we also found that participants were happier with the happy avatar compared to the sad avatar, indicating that an avatar's affective states are transferred onto the users. Overall, our findings show that avatar designers should consider that equipping avatars with emotional expressions can influence users' physiology and emotions.

2 Related Work

In the following, we first discuss theories of emotion as well as the autonomic and expressive components of emotional responses. We then summarize research examining how emotions are modulated, and measured in immersive environments. Finally, we cover research on avatars and how they influence users while embodying them in VR.

2.1 Emotions

James [33] proposed one of the earliest theories of emotion, positing that emotions arise from the perception of physiological changes. According to James [33] "bodily changes follow directly the perception of the exciting fact, and that our feeling of the same changes as they occur is the emotion". In other words, one feels fear because one trembles, rather than trembling because one is afraid.

Diverging from early perspectives, contemporary theories often adopt a componential view of emotion, recognizing multiple interacting systems, including appraisal, physiological response, expression, and subjective feeling [45]. For example, Scherer [65] proposed that emotions emerge from cycles of appraisals (novelty, valence, or goal relevance), which sequentially trigger physiological changes, motor expressions, and conscious feeling. In parallel, constructivist theories, such as those proposed by Barrett [3], argue that emotions are not discrete, evolutionarily encapsulated programs, but rather "constructed" mental events arising from core affect (valence and arousal) plus conceptual knowledge and context.

One of the most seminal theories on modeling human emotion is Ekman's work on universal basic emotions [18]. He identified six basic emotions—anger, disgust, fear, happiness, sadness, and surprise—and argues that they are biologically and evolutionarily grounded. Each basic emotion is characterized by distinct features, including unique facial expressions, physiological patterns, antecedent events, and probable behavioral responses. These features are not learned but are innate and shared across all cultures [10].

2.2 Facial Expressions and Emotions

Facial expressions are a primary channel for emotional communication [15]. Ekman and Friesen [19] described the established Facial Action Coding System (FACS) that decomposes facial movements into Action Units (AUs), which can be combined to represent discrete emotions. For example, AU6 corresponds to contraction of the the facial muscle called orbicularis oculi (pars orbitalis), producing crow's feet and slight lifting of the cheeks, often associated with genuine smiling. AU12 (Lip Corner Puller) corresponds to contraction of the facial muscle zygomaticus major, which raises the lip corners and creates a typical smiling expression. Hence, the FACS systematically matches facial muscles and their contraction with certain emotional responses and has become a widespread tool in research [15, 21].

Perceiving emotional states is a critical part of social interactions, shaping how people understand and respond to each other. In face-to-face communication, facial expressions are important non-verbal cues that allow people to derive the emotional state of the counterpart [16, 53]. Interestingly, previous work showed that emotions of others represented through facial expressions influence the own emotional state [58]. Ferrari and Coudé [23] describe that mirroring mechanisms in the brain are responsible for feeling empathy. Theories about mirror neurons postulate that the neurons fire in a similar but attenuated way when observing an emotional response compared to feeling the emotion [4, 58]. For example, merely seeing someone express disgust while eating can cause our own stomach to turn and discourage us from eating the same food [58]. In this vein, Gallese [26] coined the term "shared manifold" and explained that the same neural structures responsible for processing and controlling our own actions, sensations, and emotions are also activated when we observe these same experiences in others.

Research also suggests that our own non-verbal behavior and responses can also influence our perception and feelings [8]. The facial feedback hypothesis postulates that seeing (through a mirror [72]) or feeling our facial expressions by muscle contraction through the proprioceptive system influences the emotional sensations [47]. Strack et al. [70], for example, asked participants to hold a pen in their teeth, which creates a contraction of the zygomaticus major muscles that are the muscles involved when smiling. This procedure induced participants to smile or frown without mentioning any emotional expression. Findings suggest that participants found cartoons more humorous during the smiling condition implying that muscle contraction involved when smiling also increases positive affect and humor appreciation [47, 70, 72]. Similarly, there is evidence that when we look in the mirror, we view our own face from an external perspective, perceiving it as if it belonged to someone else. Consequently, person perception processes are activated as if we would see someone else, and, in turn, similar emotional responses are induced [72].

2.3 Emotions and Thermal Associations

Several studies demonstrate that specific emotions are systematically associated with thermal concepts such as happiness with warmth or sadness with cold [5, 20, 57, 68]. For example, Escobar et al. [20] found associations between temperature concepts and emotions, evidenced by correlations between temperature values and positions within the circumplex model of affect. In a second study, the authors employed an implicit association test and showed that the word "hot" is unconsciously linked to positive and high-arousal emotions, while "cold" is associated with negative and low-arousal emotions. These associations were robust across languages and cultures, supporting the idea that people mentally map emotional valence and arousal onto temperature concepts [20].

The thermal environment is also connected with emotions [78, 79]. While hot environments amplify emotional irritability, cold environments reduce emotional enjoyment [48]. Yang et al. [79], for example, found that emotions can influences thermal sensation and comfort. The authors systematically changed the environmental temperature while inducing negative emotions such as boredom, anxiety, and irritability using video clips. The authors found that emotions influence subjective thermal responses and even skin temperature. Anxiety decreased and boredom increased skin temperature [79]. The effects are explained by different sympathetic nerve activation. While anxiety causes skin blood vessel constriction, reduces blood flow, and, therefore, lowers skin temperature, boredom results in skin blood vessels relaxation leading to an increase in skin temperature. Peripheral skin temperature reflects cutaneous blood flow, which is modulated by the autonomic nervous system. Stress or arousal typically triggers vasoconstriction and a drop in peripheral temperature (e.g., in the fingertips, nose, or periorbital regions), whereas relaxation or positive affect can promote vasodilation and temperature increases [31].

2.4 Avatar Representation and Emotional Engagement

In VR, avatars represent the user in the virtual world. A growing body of work focuses on how avatar appearance and behavior influence users' perception and behaviors in VR [35, 41, 44]. Yee et al. [81] coined the term Proteus effect to describe a phenomenon whereby users' behaviors conform to the salient characteristics of their avatars. The authors demonstrated that users with taller avatars negotiated more aggressively in virtual bargaining tasks, whereas users with more attractive avatars behaved more confidently, revealing that avatar traits can shape self-perception and social behavior [81]. Kocur [38] extended the Proteus effect to physical performance, showing that embodying a muscular avatar in VR can enhance athletic performance (e.g., speed, endurance). Kocur et al. [42] also showed that personalized avatars can reduce perception of effort and heart rate responses during physical exercises. These studies show that avatar customization and embodiment modulate not only cognitive and social behaviors but also affective and motivational states [27, 29].

Beyond the Proteus Effect, researchers explored emotional avatars that visibly express users' affective states. Oh et al. [59] manipulated avatar smiling behavior (e.g., enhancing smiles) during collaborative VR tasks and found that observers rated counterpart avatars as more trustworthy and likable when they displayed stronger smiles. This indicates that avatar expressions can foster positive social impressions [59]. Mottelson and Hornbæk [54] explored the interplay between affect and ownership of a virtual body. Findings indicate that congruence between the avatar's displayed emotion and the user's actual affective state enhanced the sense of embodiment, whereas incongruence diminished it [54].

Broekens et al. [7] studied user perception of facial expressions in virtual characters, identifying factors such as facial geometry fidelity, animation smoothness, and contextual cues (e.g., background scene, lighting) that influence recognition accuracy and emotional engagement [7]. Dirin and Laine [14] investigated how virtual character design, photorealistic versus stylized, influences feelings of presence and emotional engagement. Results show that higher realism increased immersion but occasionally elicited uncanny-valley effects that reduced emotional involvement [14].

2.5 Summary

Emotions are a natural human response. Designers and researchers harness facial expressions of avatars to display emotions and show what the avatars feel to create realistic and human-like characters. Research found that different emotions influence physiological responses such as heart rate or skin conductance [46, 77]. Prior research also revealed that humans associate emotions with temperature [20] and that emotions even influence skin temperature [48, 79]. While such responses are known from the real world, it is unknown if avatars displaying emotions through facial expressions also cause similar reactions and transfer onto users embodying them.

3 Method

As the effects of emotional avatars on users' thermophysiological and emotional responses are unclear, we investigate whether embodying avatars displaying different emotions through facial expressions influences users. Hence, we aimed to answer the following research question: How does embodying avatars representing facial expressions that are associated with certain emotions influence users' physiological responses and affective state? We hypothesize that an avatar's emotional state changes users' thermal responses as well as their affective state while embodying them.

3.1 Study Design

We conducted a controlled experiment using a within-participants design with the independent variable, Avatar Emotion. Avatar Emotion had the three levels: *happy*, *neutral*, and *sad*. Hence, participants embodied avatars in VR that displayed static facial expressions conveying happiness, sadness, or neutrality (see Figure 1). To eliminate potential sequence or carryover effects, the order of these emotional conditions was counterbalanced across participants via a balanced Latin-square design.

Figure 1: An avatar with happy, neutral, and sad emotional facial expressions (from left to right) while looking in the virtual mirror.

3.2 Apparatus and Stimuli

All virtual content was created in Unreal Engine 5.3 and delivered through a Meta Quest Pro headset. The Quest Pro is powered by a Qualcomm Snapdragon XR2+ processor with 12 GB RAM. Prior to the lab session, participants were asked to create an avatar that best represents themselves using the MetaHuman Creator. They followed our step-by-step guide to select a base model, then used "Mix," "Sculpt," and "Move" tools to personalize facial proportions. Due to measuring the skin temperature, the avatars' clothes were predefined by the experimenter so that all participants embodied avatars wearing the same clothes, i.e., a sweater, pants, and sneakers. The participants did not configure the emotional expressions but only focused on the visual appearance of the avatar. We then configured each avatar to display one of three discrete emotional facial expressions (happy, neutral, and sad) in accordance with the FACS (see Figure 1).

Neutral expressions retained relaxed musculature without the prototypical AUs associated with specific emotions, ensuring a baseline state of minimal facial activation. Happy expressions were generated by combining AU 6 (Cheek Raiser) with AU 12 (Lip Corner Puller), producing a genuine smile configuration, while sad expressions incorporated AU 1 (Inner Brow Raiser), AU 4 (Brow Lowerer), and AU 15 (Lip Corner Depressor) to create the characteristic downturned mouth and raised inner eyebrows. These AU combinations were chosen based on the guidelines outlined in the FACS [21], and were implemented via Unreal Engine blend shapes that mapped directly to each AU parameter. During the experiments, the avatars' facial expressions were static, i.e., they continuously held the facial expression throughout the entire avatar condition.

Physiological recordings were obtained using a TC-08 8-Channel USB Thermocouple Data Acquisition Module (Omega Engineering, USA), which samples at 4 Hz with 20-bit resolution. We employed five Type T thermocouples (5SRTC-TT-TI-20-2M, Omega, USA) to measure skin temperature: two thermocouples were affixed to the participant's left hand and two to the right hand (using adhesive tape to improve contact), while a fifth thermocouple was placed at the center of the table to record ambient room temperature. All temperature channels were logged in real time via PicoLog software.

We used a WAHOO TRACKR heart rate monitor paired with the Wahoo mobile fitness app on a smartphone to continuously track participants' heart rates throughout each condition. The chest-worn sensor remained in place for the entire session.

Grip strength was assessed with an Interlink Force-Sensing Linear Potentiometer (FSLP, 4 inch × 0.4 inch strip) mounted on a graspable wooden cylinder and interfaced to an Arduino Uno. The FSLP's resistance changes were read in a voltage-divider configuration (external resistor R0 = 4.7 kΩ) and sampled at 100 Hz to compute both applied pressure and finger position along the strip. All analog signals from the Arduino (FSLP) and TC-08 (thermocouples) were timestamp-synchronized to the VR event log.

FAUs and gaze metrics were captured by the Quest Pro's onboard face- and eye-tracking cameras. Unreal Engine scripts polled the OVR Face and OVR Eye APIs at 60 Hz to extract raw blink, smile, eyebrow, and fixation-duration data. All physiological and behavioral streams were stored to local SSD and backed up to our lab server at the end of each session. Participants' arm and upper-body movements were tracked using the off-the-shelf Meta Quest Pro tracking system and mapped onto a virtual avatar to enhance the sense of body ownership.

3.3 Tasks

Participants had to perform two simple tasks during avatar embodiment. The first task was passive and consists of simply resting for three minutes with the arms stretched and comfortably placed on the table while embodying the respective avatar and looking in the virtual mirror (see Fig. 2). This resting task ensured to isolate physiological responses from effects caused by physical activity. The second task was active and consists of repeatedly grabbing and releasing a wooden cylindrical object and place it from one location on the table to another back-and-forth (see Fig. 2). We attached a force-sensing linear potentiometer to the grabbing object to measure grip strength recorded at 100 Hz. This allowed to control for behavioral changes that may influence physiological responses such as skin temperature or heart rate. In addition, we attached velcro stripes on one side of the table and on the bottom of the grabbing object to create different resistances (with and without velcro) while grabbing and placing the objects (see Figure 2).

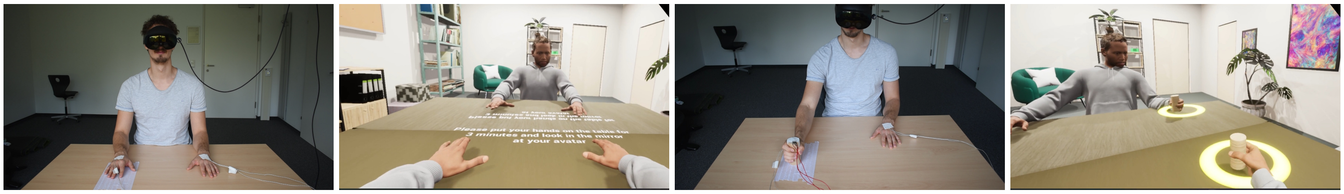

Figure 2: User during the resting task (left) while looking in the virtual mirror during embodiment (left center) and the grabbing task (right center) while embodying the avatar (right).

3.4 Measures

We took objective and subjective measures to learn about the effects of the avatar's emotional facial expressions during virtual embodiment.

3.4.1 Skin Temperature. We continuously recorded skin temperature (°C) every second on the back of the left and right hand using type-t thermocouple sensors. We averaged the four temperature values (two per hand) at each time point to yield a single temperature trace per participant. To control for individual baselines, each participant's first temperature reading, at the start of each emotion condition, was subtracted from all subsequent values.

3.4.2 Self-Reported Affective State. After each task, participants completed three different scales in VR. First, the Positive and Negative Affect Schedule (PANAS) [71] was used to measure positive and negative affect. The Virtual Embodiment Questionnaire (VEQ) [63] assessed participants' sense of embodiment with the avatars using a 7-point Likert scale. In line with mood scales [51, 73], we additionally surveyed participants using a 7-point Likert item "How do you feel right now?" ranging from "very sad" to "very happy" ("very sad", "sad", "somewhat sad", "neutral", "somewhat happy", "happy", "very happy").

3.4.3 Grip Strength. Since grip strength was used as a measure for behavioral and performance-related changes caused by an avatar's visual appearance in previous work [43], we aimed to control for behavioral changes caused by the avatar's emotional response [54]. During the grabbing task participants completed twenty trials per emotion condition while force was recorded via the force-sensing linear potentiometer at 100 Hz through the Arduino. For each emotion condition, we averaged all force samples across those twenty trials to yield a single mean force score.

3.4.4 Heart Rate. Heart rate (bpm) was logged every second via the chest-strap WAHOO TICKR monitor throughout the experiment. Recorded heart rate values were then normalized relative to each participant's starting heart rate in the beginning of each task, enabling assessment of autonomic responses to the different avatar expressions.

3.5 Participants

We recruited 30 participants from the University and the local community who participated voluntarily or for course credits to achieve an effective sample size of at least 24 participants. Data of six participants were excluded from the analysis due to technical issues, i.e., electrode detachment and signal loss. The final sample consisted of 24 participants (17 male, 6 female, 1 non-binary) aged between 20 and 30 years ($M = 23.71$, $SD = 2.27$). The conditions were assigned according to a fully balanced 3×3 Latin square design. In a pre-experiment questionnaire, participants reported their prior VR experience: 9 had never used VR, 11 had used it a few times per year, and 4 reported using it a few times per month. Regarding vision status, 14 reported a vision impairment, and 10 indicated no impairment. Positive ($M = 2.55, SD = 0.38$) and negative ($M = 1.47, SD = 0.40$) affect using the PANAS was assessed to obtain insights into participants' affective state serving as a baseline. Participants' affective state was generally more positive than negative before the VR experiment. All participants provided written informed consent and were informed they could withdraw at any time without penalty.

3.6 Procedure

Prior to the experiment in the VR laboratory, participants were asked to create an avatar that best represents themselves using the MetaHuman Creator. We then accessed the avatars in MetaHuman Creator and integrated them into our VR application to prepare the avatars and their facial expressions for the experiment in our VR laboratory. Due to measuring the skin temperature, the avatars' clothes were predefined by the experimenter so that all participants embodied avatars wearing the same clothes.

Upon arrival at the lab, they confirmed their informed consent and provided demographic information. The experimenter then launched the VR environment and guided participants through an introductory questionnaire that familiarized them with the in-VR survey interface and response procedures. This served as both an orientation and a brief training phase.

Next, participants entered the embodiment phase. For each of the three avatar emotions—*happy*, *neutral*, and *sad*—they experienced a 15-second embodiment phase. During this time, they viewed their customized avatar in a virtual mirror, allowing them to establish a sense of body ownership and agency before any physiological or behavioral measurements were taken. Following the embodiment phase, participants entered the first task consisting of looking the virtual mirror for 3-minute with the arms stretched and place on the table while embodying the respective avatar condition. While remaining seated, their skin temperature and heart rate were continuously recorded. During this phase, they were instructed to look at their avatar in the mirror to maintain consistency in visual focus.

Afterward, participants proceeded to second task, during which they performed twenty grasping trials using a force-sensing linear potentiometer attached to a cylindrical object. Force data were

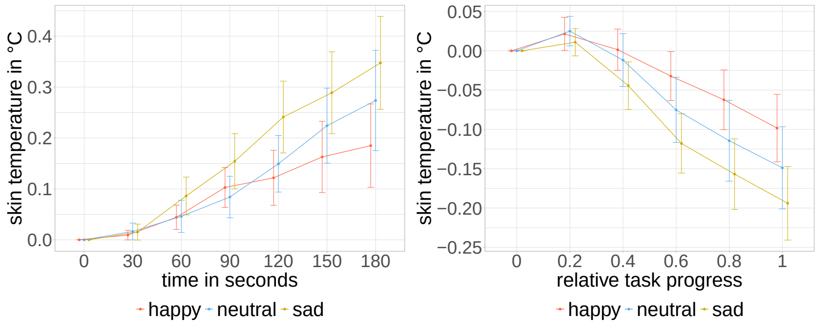

Figure 3: Normalized hand skin temperature for both hands per minute during the resting task (left) while embodying the *happy*, *neutral*, and *sad* avatars. For the grabbing task (right), we used relative task progress (i.e., the proportion of time to finish all trials), as participants were not restricted by time. The error bars show the standard error.

recorded at 100 Hz, enabling measurement of grip strength. Subsequently, participants completed a questionnaire presented in VR. The survey remained available for a minimum of two minutes. If a participant finished earlier, they stayed idle in the virtual environment until the two minutes had passed. This ensured a controlled cool-down phase for each participant to prevent rapid transitions between emotional states and task phases, and confound physiological measures. The same procedure was repeated for all avatar conditions.

Afterwards, participants exited the VR environment and responded to a final set of questions outside of VR. This debriefing addressed their overall experience, perceived task difficulty, and any general feedback. The experiment took about 45 minutes in total.

4 Results

Data was analyzed in R (version 4.2.2, [62]). Our measures consist of parametric and non-parametric data. Shapiro-Wilk tests for normality were used to determine the assumption of normal distribution of all measures. Results show violations of normality for all measures ($p < .05$) except for the dimension *ownership* and *agency* of the VEQ as well as the positive affect score of the PANAS. Hence, we used the ARTool package for R by Wobbrock et al. [75] to apply an aligned rank transform (ART) analysis of variance (ANOVA) for hypothesis testing of non-parametric data. A repeated-measures ANOVA was applied to analyze parametric data. Participation was entered as a random factor in all analyses. All pairwise cross-factor comparisons are Bonferroni corrected.

4.1 Skin Temperature

To control for individual baselines, each participant's first temperature reading, at the start of each emotion condition, was subtracted from all subsequent values. We included the factor Time with six levels (after *30*, *60*, *90*, *120*, *150*, and *180* seconds) for the resting task to learn about the effects over time. For the grabbing task, we used relative task progress (i.e., the proportion of time to finish all trials) by including the factor Time with 5 levels (after *20*, *40*, *60*, *80*, and *100* percent of the task), as participants were not restricted by time during the grabbing task.

4.1.1 Resting Task. A 3(Avatar Emotion: *happy* vs. *neutral* vs. *sad*) × 6(Time: after *30*, *60*, *90*, *120*, *150*, and *180* seconds) ART ANOVA revealed a significant effect of Avatar Emotion, $F(2, 391) = 7.015$, $p = .001$, $\eta_p^2 = .035$, on skin temperature. There was also a significant effect of Time, $F(5, 391) = 11.642$, $p < .001$, $\eta_p^2 = .129$. The interaction effect of Avatar Emotion × Emotion was not significant, $F(10, 391) = 1.116$, $p = .348$, $\eta_p^2 = .028$. A posthoc pairwise comparison using the Wilcoxon signed-rank test found a significant difference between the *happy* and *sad* avatar, $p = .013$. All other pairwise comparisons were not significant (all $p > .05$). Results indicate that avatars' emotional responses systematically influence skin temperature: *sad* avatars resulted in higher skin temperature compared to *happy* avatars. Over time, participants skin temperature increased irrespective of the avatar condition (see Figure 3).

4.1.2 Grabbing Task. A 3 (Avatar Emotion: *happy* vs. *neutral* vs. *sad*) × 5 (Time: after *20*, *40*, *60*, *80*, and *100* percent of the task) ART ANOVA revealed a significant effect of Avatar Emotion, $F(2, 322) = 3.899$, $p = .021$, $\eta_p^2 = .035$, on skin temperature. There was also a significant effect of Time, $F(4, 322) = 18.689$, $p < .001$, $\eta_p^2 = .188$. The interaction effect of Avatar Emotion × Emotion was not significant, $F(8, 322) = 0.425$, $p = .905$, $\eta_p^2 = .010$. A posthoc pairwise comparison using the Wilcoxon signed-rank test did not find a significant difference between the avatars (all $p > .05$). Figure 3 shows the mean skin temperature over time during the grabbing task.

4.2 Affective State

We aggregated the values per task for each condition and calculate an overall score indicating the self-reported affective state. A 3(Avatar Emotion: *happy* vs. *neutral* vs. *sad*) ART ANOVA revealed a significant effect of Avatar Emotion, $F(2, 46) = 4.180$, $p = .021$, $\eta_p^2 = .154$, on the self-reported affective state. A posthoc pairwise comparison using the Wilcoxon signed-rank test found a significant difference between the *happy* and *sad* avatar, $p = .03$. All other pairwise comparisons were not significant (all $p > .05$). Results indicate that avatars' changed users' affective state, i.e., the happy avatars made participants feel more happy while embodying them than the sad avatars (see Figure 4).

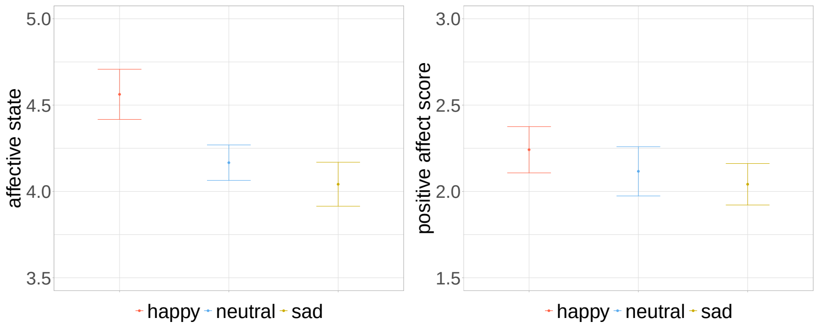

Figure 4: Perceived affective state (left) ranging from 1 to 7 (very sad to very happy) and positive affect score of the PANAS (right) while embodying the *happy*, *neutral*, and *sad* avatars. The error bars show the standard error.

In addition, we performed a 3(Avatar Emotion: *happy* vs. *neutral* vs. *sad*) ANOVA on the positive and an ART ANOVA on the negative affect score of the PANAS. We could not find any significant effects on the positive affect score, $F(2, 46) = 2.527$, $p = .091$, $\eta_p^2 = .099$. We could also not find any significant effect on the negative affect score, $F(2, 46) = 1.302$, $p = .282$, $\eta_p^2 = .053$. While the trend for the positive affect score is in line with the current affective state (see Figure 4), our analysis could not reveal any effects on the dimensions of the PANAS.

4.3 Virtual Embodiment

A 3(Avatar Emotion: *happy* vs. *neutral* vs. *sad*) ANOVA did not show any significant effects on the dimensions ownership and agency VEQ (all $p > .05$). Accordingly, a 3(Avatar Emotion: *happy* vs. *neutral* vs. *sad*) ART ANOVA did not show any significant effects on the dimension change of the VEQ (all $p > .05$). Figure 5 shows each dimension of the VEQ for all three conditions. Results indicate that the experienced embodiment of the avatars was not influenced by the avatars' emotions implying that virtual embodiment is not responsible for the physiological and subjective effects that were found in the data.

4.4 Heart Rate

For analyzing the effects on the HR, we normalized the data by centering it at zero with the start of each condition and for each participant. We included the factor Time with six levels (after *30*, *60*, *90*, *120*, *150*, and *180* seconds) for the resting task to learn about the effects over time. For the grabbing task, we used relative task progress (i.e., the proportion of time to finish all trials) by including the factor Time with 5 levels (after *20*, *40*, *60*, *80*, and *100* percent of the task), as participants were not restricted by time.

4.4.1 Resting Task. A 3(Avatar Emotion: *happy* vs. *neutral* vs. *sad*) × 6(Time: after *30*, *60*, *90*, *120*, *150*, and *180* seconds) ART ANOVA revealed a significant effect of Avatar Emotion, $F(2, 391) = 5.862$, $p = .003$, $\eta_p^2 = .029$, on the normalized HR during the resting task. However, there was no significant effect of Time, $F(5, 391) = 1.777$, $p = .116$, $\eta_p^2 = .022$. The interaction effect of Avatar Emotion × Emotion was not significant, $F(10, 391) = 0.242$, $p = .991$, $\eta_p^2 = .006$. A posthoc pairwise comparison using the Wilcoxon signed-rank test found a significant difference between the *happy* and *sad* avatar, $p = .01$. All other pairwise comparisons were not significant (all $p > .05$).

Results indicate that avatars' emotions influence HR while resting: *sad* avatars resulted in higher HR compared to *happy* avatars (see Figure 6).

4.4.2 Grabbing Task. A 3(Avatar Emotion: *happy* vs. *neutral* vs. *sad*) × 5(Time: after *20*, *40*, *60*, *80*, and *100* percent of the task) ART ANOVA did not find a significant effect of Avatar Emotion, $F(2, 322) = 2.647$, $p = .072$, $\eta_p^2 = .016$, on normalized HR during the grabbing task. There was a significant effect of Time, $F(4, 322) = 5.601$, $p < .001$, $\eta_p^2 = .065$. The interaction effect of Avatar Emotion × Emotion was not significant, $F(8, 322) = 0.331$, $p = .953$, $\eta_p^2 = .008$. Hence, our findings indicate that the avatars' emotions could not influence HR during the grabbing task.

4.5 Grip Strength

To control for behavioral changes, we analyzed whether avatar emotional expression influenced users' grip strength during the grabbing task. A 3(Avatar Emotion: *happy* vs. *neutral* vs. *sad*) ART ANOVA did not find a significant effect of Avatar Emotion, $F(2, 46) = 0.256$, $p = .775$, $\eta_p^2 = .011$, on grip strength during the grabbing task. Hence, the emotional avatars did not influence users' grabbing behavior in terms of grip strength.

5 Discussion

Our results show that embodying avatars expressing different emotions does not only influences users' affective state but also their thermophysiological responses. Although the extent of experienced embodiment while embodying an avatar is known to modulate physiological responses [6, 40, 69], we found no effect of the emotions displayed by the avatar on the perceived embodiment. Hence, we can rule out the possibility that the experienced embodiment is responsible for the physiological and perceptual effects. Instead, our findings indicate that the emotional cues represented by an avatar's facial expressions translate onto users' emotional responses and even influence thermal regulation.

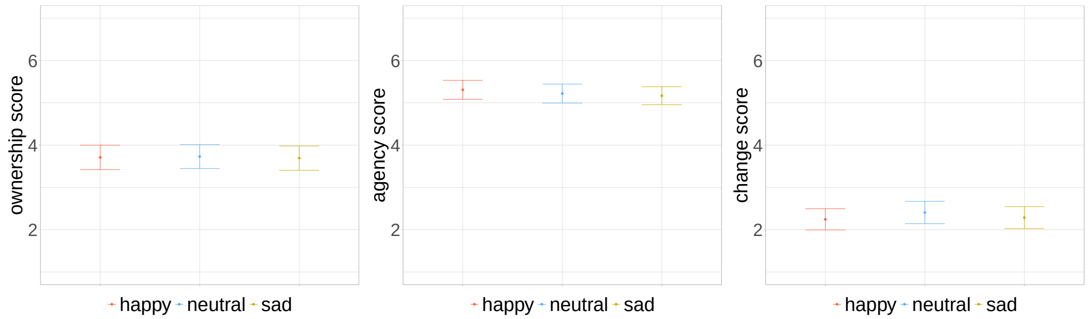

Figure 5: Scores the dimensions ownership, agency, and change (from left to right), ranging from 1 to 7 while embodying the *happy*, *neutral*, and *sad* avatars. The error bars show the standard error.

5.1 Skin Temperature

In line with the Proteus effect [38, 80], the visual appearance of the avatar could influence users' behavior and perception. Nummenmaa et al. [57] revealed that sadness and depression is associated with low bodily activity and energy while happiness is associated with high activity throughout the entire body. The avatar with sad facial expressions could prime concepts such as sadness, which is perceived as a negative emotion. Gross et al. [28] investigated crying and showed that crying produces an aversive high-arousal state that motivates behavior aimed at ending tears. Although we did not show a crying avatar, the findings could still suggest that the user's level of arousal increased to compensate for the negative sensation and overcome it. This could, in turn, influence users' activity and readiness level due to an increased level of arousal.

This explanation is supported by baseline affective states measured by the PANAS before the experiment as part of the demographic questionnaires (see section 3.5), which indicate that participants generally experienced higher levels of positive affect than negative affect. Consequently, during the resting task, participants could have a higher arousal level while embodying the sad avatar, causing the skin temperature to rise more than while embodying the happy avatar, e.g., due to increased blood flow to the limb. Significant effects on heart rate responses could support this assumption, showing a higher HR for the sad avatar compared to the happy avatars. The effects on skin temperature are also in line with Shelepenkov et al. [68], who showed similar results when comparing happiness and sadness by measuring skin temperature in the shoulder region while watching emotionally inducing images. The authors showed a higher skin temperature during the sad emotional stimuli compared to happy ones. However, skin temperature changes depend on the body part showing different effects on other body locations, e.g., the skin temperature on the chest was higher for happy stimuli compared to sad ones [68]. Hence, more research is required to learn more about location-specific changes of thermoregulation caused by emotional responses.

During the active grabbing task, however, descriptive statistics show an opposite trend for skin temperature responses. The skin temperature generally decreased for all conditions (see Figure 3) typically due to physical activity and the resulting airflow over the skin, which enhances convective and evaporative cooling [30, 55]. Moreover, by considering compensatory mechanisms counteracting sadness, the stronger decrease in skin temperature when embodying the sad avatar compared to the happy avatar, could indicate a higher level of arousal. However, we did not show any effects of the avatars on grip strength and on the task completion time which indicates no behavioral changes induced by the avatar. Instead, the body appears to activate thermoregulatory mechanisms irrespective of the performance and behavior that cause a higher drop in skin temp while embodying the sad compared to the happy avatar. In addition, the pairwise comparisons did not reveal significant differences. Consequently, we cannot conclusively determine why emotional responses displayed by avatars differently influenced users' skin temperature during the resting and grabbing task. We intentionally did not randomize the order of tasks to reduce variance in data as we did not aim to explore interaction effects with the tasks. Thus, future work should systematically explore how physical activity modulates thermoregulatory effects caused by the avatars' emotional expressions.

Across both tasks, it is notable that the happy avatar is closer to the baseline skin temperature (see Figure 3) than the sad avatar. This may suggest that positive emotions, such as happiness, do not require physiological adaptation – probably because they align more closely with participants' baseline affective state during the study – whereas negative emotions are more likely to trigger physiological changes.

5.2 Affective State

Our findings indicate the participants felt happier while embodying the happy avatar compared to the sad avatar (see Figure 4). In line with Mottelson and Hornbæk [54], results imply that embodying avatar representing certain emotions can influence users' affective state, e.g., an happy avatar can activate positive affect during embodiment. These findings are in accordance with the Proteus effect [38] so that the avatars' visual appearance—in this case the emotional expression—influences users' affect and perception. Hence, our study extends the Proteus effect that not only the stereotypical appearance, e.g., muscles [40], age [1], ethnicity [2], or gender [66], but also emotions change how users feel during virtual embodiment.

Designers of VR applications could utilize avatar embodiment to induce emotional sensations [24, 54], e.g., sadness during embodiment to increase empathy for others [34] or happiness to enhance

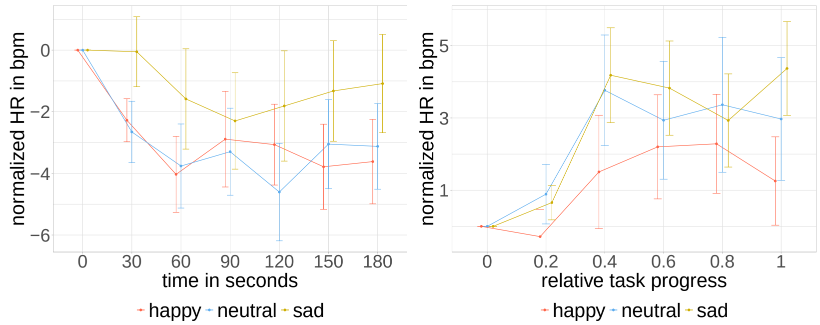

Figure 6: Normalized HR during the resting task (left) and grabbing task (right) while embodying the *happy*, *neutral*, and *sad* avatars. The error bars show the standard error.

positive feelings [76], particularly as facial expressions are easily identified and interpreted [12]. In general, equipping avatars with salient emotional states during embodiment can enhance users' cognitive and emotional engagement [11], and contribute to more immersive and lifelike virtual experiences due to the ubiquity of human emotions in the real world.

Our results also suggest that researchers need to consider the impact of avatar emotions on perceptual responses. Many physiological responses are driven by affect as a consequence to the experience of a certain situation such as skin conductance [25] or cardiovascular responses [22]. Hence, researchers need to be aware that embodying avatars that are perceived as feeling any kind of emotion could change basal physiological responses that are unintended in empirical experiments. Kocur et al. [39], for example, shows that sweating avatars can positively influence users while cycling in VR. However, the avatars in the study displayed neutral facial expressions during physical exertion, which may have influenced participants' perceptions of exertion. For instance, sweating accompanied by a neutral expression might be interpreted more positively, whereas sweating combined with an exhausted expression could be perceived more negatively. Consequently, future research on the Proteus effect should also consider the face as a design space for reinforcing certain characteristics to enhance or not to confound avatar effects on users [38, 61].

5.3 Limitations and Future Work

Even if MetaHuman Creator provides various options for avatar personalization, future work could utilize 3D-scanned avatars to offer a higher level of individualization [74]. While our results suggest that the available options were sufficient to elicit a high degree of body ownership, they still did not allow for a photorealistic self-depiction. Allowing users to customize their avatars increases embodiment [42]. However, it also increases the variance in data due to individualized characteristics that may influence the salience of the facial expressions, e.g., having a beard or eye-catching hair. Nonetheless, since we were able to find effects on skin temperature, our findings imply that the effects are robust enough to be detected despite a higher variance than when using generic avatars [40, 54].

Additionally, the study was limited to examining short-term physiological responses during avatar embodiment in VR. Long-term effects still remain unexplored. Future research should investigate these longer-term impacts to better understand how emotional avatars influence users particularly when considering habituation effects [38]. Moreover, our sample generally felt more positive than negative before the VR experiment. Systematically comparing avatar and user emotions could yield insights into how both avatar and user's affect interact. In addition, the happy avatars were perceived as happier as the sad avatars, which indicates a successful manipulation. However, the sad avatars were still perceived as less sad than the happy avatars as happy. Hence, future work should explore more extreme facial expressions to create equidistant emotion levels.

Another potential limitation lies in the variability of observed effects for both tasks. While sad avatars led to increased skin temperature during the resting task, this effect was inverted during the grabbing task. This inconsistency suggests that avatar emotions may not generalize uniformly and could be task-dependent. Further research is needed to determine the extent to which these effects can be generalized across a broader range of tasks. In addition, skin temperature was measured only on the hands. While hand temperature provides useful peripheral indicators of physiological changes, it does not necessarily reflect core body temperature [17, 50]. Future research should extend measurements to additional body sites, e.g., the chest or abdomen, that are physiologically closer to core temperature. This would allow for a more accurate assessment of thermoregulatory responses during avatar embodiment and help clarify the relationship between emotional states and autonomic regulation.

6 Conclusion

In this paper, we investigated the thermophysiological and emotional impact of avatars representing three different facial expressions while embodying them in VR. We followed the FACS to create each emotional expression. We conducted a controlled VR experiment in a repeated-measures design with 24 participants, who embodied a customized avatar with either a happy, neutral, or sad face. Our results show that participants had a higher skin temperature when embodying the sad avatar compared to the happy avatar while resting. Despite non-significant pairwise comparisons, descriptive statistics suggest an opposite trend during a grabbing task while embodying the happy compared to the sad avatar. Furthermore, embodying the happy avatar resulted in a more positive affective state than embodying the sad avatar. These findings indicate that avatar emotions can impact users' thermoregulation and affective states. Overall, our work highlights that avatars' emotions need to be considered during virtual embodiment when designing immersive VR experiences.

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