Physiological Responses to Affective Virtual Coach Design in a VR Fear of Heights Consultation

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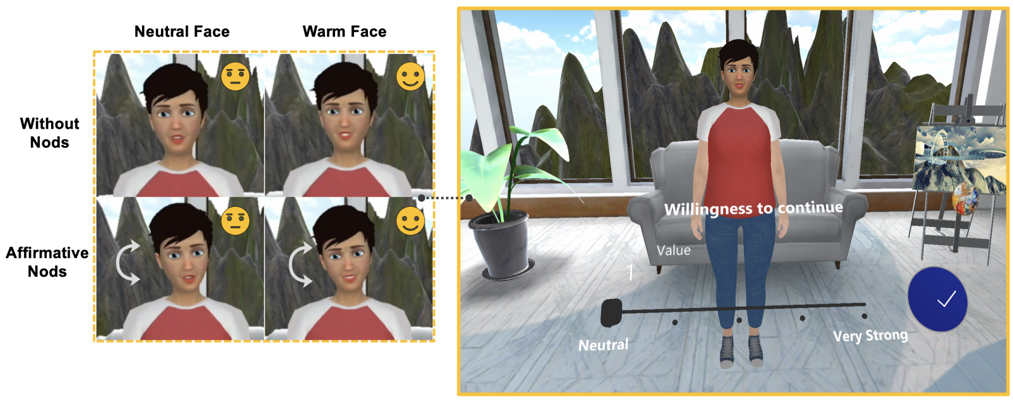

Fig. 1. VR consultation with virtual coach varied in facial expressions (neutral/warm) and affirmative nods (with/without).

Virtual coaches in virtual reality (VR) offer scalable mental health treatment without an on-site therapist, yet their impact on psychophysiological responses remains unclear. We examine how VR content and coach design influence physiological measures, such as heart rate (HR) and electrodermal activity (EDA), in a therapeutic setting. 120 participants with a fear of heights interacted with a virtual coach that varied in facial warmth (with/without) and affirmative nods (with/without) during a virtual consultation, followed by a virtual height exposure. Physiological responses were recorded. Virtual heights exposure elicited significantly higher HR ($p < 0.001, r = 0.347$) and EDA ($p = 0.003, r = 0.292$), but also increased heart rate variability (HRV, $p = 0.005, r = 0.272$) compared to the VR consultation. Warm facial expressions increased EDA peak amplitudes ($p = 0.043, \eta_p^2 = 0.574$) during the consultation

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Manuscript submitted to ACM

and raised HRV during height exposure ($p = 0.036, \eta_p^2 = 0.041$). This study highlights VR coach design's impact on physiological responses, emphasising the need for thoughtful emotional design to enhance therapeutic outcomes in automated VR therapies.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; **Virtual reality**.

Additional Key Words and Phrases: Virtual Reality (VR), Physiological Data, Agent, Virtual Coach, Mental Health, Psychotherapy

ACM Reference Format:

Shu Wei, Abdallah El Ali, Pablo César, Daniel Freeman, and Aitor Rovira. 2025. Physiological Responses to Affective Virtual Coach Design in a VR Fear of Heights Consultation. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '25), April 26-May 1, 2025, Yokohama, Japan.* ACM, New York, NY, USA, 11 pages. https://doi.org/10.1145/3706599.3719715

1 Introduction

Virtual reality (VR) has emerged as a powerful tool in mental health research, offering immersive environments where individuals can confront and practise managing psychological challenges in controlled settings. A key advancement in this field is the integration of physiological monitoring, which offers real-time, objective insights into users' emotional states [26]. Physiological measures, such as heart rate (HR) and skin conductance, have been widely used to assess people's general affective states (e.g. happiness, sadness, and fear) in VR scenarios [21, 41, 47]. By complementing subjective self-reports, physiological monitoring captures subtle emotional changes, revealing psychological states users may not consciously recognise [6, 24]. This continuous and objective data could enhance VR mental health applications by assessing the effectiveness of interventions and adapting scenarios to individual needs [4].

A notable application in mental health VR is automated VR therapy, where a VR coach guides users through virtual scenarios. As demonstrated in the automated VR fear of heights programme developed for individuals with acrophobia [11], a VR coach provides structured guidance to help users confront and reassess their fears in height-related scenarios. Users engage in progressively challenging exposure tasks, such as standing on virtual platforms at increasing heights, while receiving encouragement and coping techniques from the VR coach. The emergence of virtual coaches could offer reassurance, prompt self-reflection, and reinforces coping strategies without an on-site clinician. By addressing the shortage of clinical psychologists and overcoming logistical barriers, such as time and location constraints, virtual coaches offer a scalable solution to expand access to evidence-based treatments [11, 12, 36].

Developing effective VR coaches requires a multidisciplinary approach, involving expertise from psychology, computer science, and 3D design [31, 36]. While research has shown that non-verbal behaviours, such as facial expressions and head movements, from VR characters influence users' psychophysiological and behavioural responses [16, 41, 43], little is known about their effects on physiological responses during VR therapy. Understanding these effects is crucial for optimising virtual coaches to enhance therapy engagement and support individuals in confronting their phobias.

To address this gap, our study examines how a VR coach's emotional attributes—specifically warm facial expressions and affirmative nods—affect users' physiological responses. Acrophobia was chosen as the focused condition due to its prevalence in non-clinical populations, facilitating participant recruitment. As a "sequel" to our previous study [44], we utilised our two-part VR scenario featuring a consultation with a virtual coach followed by a virtual heights exposure, to explore the following research questions: **RQ1:** Does the VR heights scenario elicit changes in physiological responses in individuals with fears of heights? **RQ2:** Do the emotional attributes of a virtual coach affect participants' physiological responses during a VR consultation and subsequent virtual heights exposure?

We provide novel insights into how the content design of VR and virtual human (VH) influences physiological responses. By revealing the physiological impact of VH emotional attributes, our findings can help inform the development of more effective and empathetic virtual agents, potentially enhancing therapy engagement and outcomes.

2 Related Work

2.1 Physiological Responses in Stressful VR Scene

VR mental health studies have incorporated physiological measures, commonly cardiac and electrodermal activity (EDA), to assess affective states in phobia-related scenarios [14, 25, 29]. Mühlberger and colleagues [29] examined the effects of repeated VR flight exposure on individuals with a fear of flying, showing that such exposures elicited subjective and physiological fear responses characterized by elevated HR and skin conductance levels (SCL). Repeated sessions led to gradual reductions in these responses. Martens et al. [25] assessed stress responses during an open-platform lift ride outside a tall building compared to a controlled indoor lift condition. Participants stepping off the virtual platform showed significantly increased SCL and pulse, indicating strong physiological arousal. Similarly, a fear of spiders study [27] found that greater skin conductance responses (SCR) were associated with higher subjective fear ratings, demonstrating VR's ability to evoke phobia-specific fear responses. Beyond phobias, VR has been used to simulate other stressful environments, such as war zones to study trauma responses [23] and public speaking scenarios to assess anxiety-induced physiological changes [19, 20]. These studies provide evidence that VR can elicit physiological responses comparable to real-life stressors, supporting its potential for assessment and treatment through virtual exposure therapy.

2.2 Physiological Responses to Virtual Humans

VR mental health studies have focused on the physiological responses to VHs in social interactions, offering a relevant basis for investigating the emotional cues of a virtual coach. These studies primarily use VHs as stressors to study the changes in people's physiological reactions. Brinkman et al. [3] exposed participants from the general population to varying crowd densities and different ethnic appearances of VHs. They found that exposure to dense crowds or characters of different ethnicities led to stronger fluctuations in HR and SCR. Also, Reichenberger et al. [35] compared responses to VR human exposure between patients with social anxiety disorder (SAD) and healthy controls. While SAD group showed higher subjective fear, there were no significant group differences in SCL and HR.

Furthermore, researchers have begun investigating the potential benefits of supportive VHs in stressful scenarios, with mixed results. Kothgassner et al. [18] found that receiving social support from a VH in VR prior to a stressor could reduce stress indicators, such as lower HR. However, Stallmann et al. [39] reported that while support from a virtual agent improved self-reported emotional states, it did not alter stress responses, as indicated by unchanged heart rate variability (HRV) and SCL. Although research has examined VHs as stressors, the effect of detailed characteristics in supportive VHs, such as a virtual coach, on physiological responses remains unexplored.

3 Method

3.1 Study Design

We used a 2×2 between-subjects design with two factors: warm facial expressions (with/without) and affirmative head nods (with/without). Participants were randomly assigned to one of four virtual coach versions: (1) neutral face, (2) neutral face with nods, (3) warm expressions, or (4) warm expressions with nods (shown in Fig 1). All coaches

Table 1. Participant characteristics by randomisation group.

	Neutral Face (n=30)	Neutral Face with Nod (n=30)	Warm Face (n=30)	Warm Face with Nod (n=30)
Age in years, Mean (SD), range	40.7 (16.6), 18–70	48.2 (16.4), 18–72	41.1 (17), 19–77	47.8 (14.9), 24–74
Gender *female (F), male (M), non-binary (NB)*	15 F/13 M/2 NB	15 F/15 M	18 F/12 M	18 F/10 M/2 NB
Fear of Heights Scores (HIQ scores)	43.8 (10.5)	43.7 (10.8)	43.9 (11.2)	43.8 (11.0)
VR Experience	1.97 (0.85)	1.63 (0.72)	1.80 (0.96)	1.80 (0.85)

exhibited baseline behaviours (e.g. blinking, lip-syncing). The study was single-blind, with participants unaware of coach variations. Ethical approval was obtained from the university ethics committee, and all participants provided written informed consent following relevant guidelines.

3.2 VR Scenario

VR coach animations were created using motion capture (from a female psychologist) and blend-shape in iClone7[1] to achieve realistic facial expressions and nods. The head movements were further adjusted according to real-life psychotherapy patterns [15]. The VR experience, developed in Unity 2020.3.22, was run on a Meta Quest 2 headset via Air Link. Physiological data were collected using an Empatica E4 wristband. The experience consisted of two stages: an indoor consultation and an outdoor heights exposure.

Indoor VR: Participants engaged in an introductory session with a virtual coach, following a script adapted from a VR fear of heights clinical trial [11]. The coach explained the cognitive approach to understanding the fear (e.g. "The reason we're afraid of heights is because we think something bad is going to happen...then we end up avoiding heights because they feel so scary"). Participants were asked about their fears and provided responses. This interactive session lasted approximately four minutes at the participant's own pace.

Outdoor VR: Participants walked along an elevated virtual walkway. Starting at the centre of a terrace, they received instructions from the coach, then proceeded to walk to a circular platform at the far end and return to the starting point by themselves. The scene concluded either upon completion of the task or if participants chose to end it early.

3.3 Participants

120 participants (female = 66, male = 50, non-binary = 4; mean age = 44.4, SD = 16.4) were recruited out of 705 screened via social media. Eligibility required a fear of height score > 29, in the Heights Interpretation Questionnaire [40]. Exclusion criteria included age < 18, photosensitive epilepsy, significant sensory/mobility impairments, or medication that causes motion sickness. Participant characteristics are summarized in Table 1.

3.4 Measures

3.4.1 Physiological Data. We recorded participants' cardiac activity and EDA using the Empatica E4 wristband during the baseline, indoor VR, and outdoor VR sessions. Data were collected via the E4 streaming server mode, with a Unity-integrated script, ensuring all signals were synchronised with the VR experience.

3.4.2 Subjective Measures. We collected participants' subjective ratings of therapeutic alliance by the Virtual Therapist Alliance Scale [28] and treatment credibility/expectancy [7] after the VR indoor consultation. The sense of presence

[1]https://www.reallusion.com/iclone/

was measured separately after both the VR indoor and VR outdoor sessions. Detailed results on subjective measures can be found in [44].

3.5 Experimental Procedure

Participants attended a single session at our VR lab to try the introductory part of a VR therapy for fear of heights. Heart rate and skin conductance data were recorded using the Empatica E4 wristband, with a five-minute baseline recorded first. Participants were then fitted with the VR headset and experienced the indoor scene, tailored to their allocated experimental group. After the indoor scene, participants removed the headset and completed measures on therapeutic alliance, treatment credibility/expectancy, and presence. They then re-entered VR for the outdoor scene, with the option to stop at any time. Following the outdoor scene, participants completed presence questionnaires before being debriefed. The entire session lasted approximately 45 minutes, and participants were reimbursed for their time. Figure 2 provides an overview of the procedure.

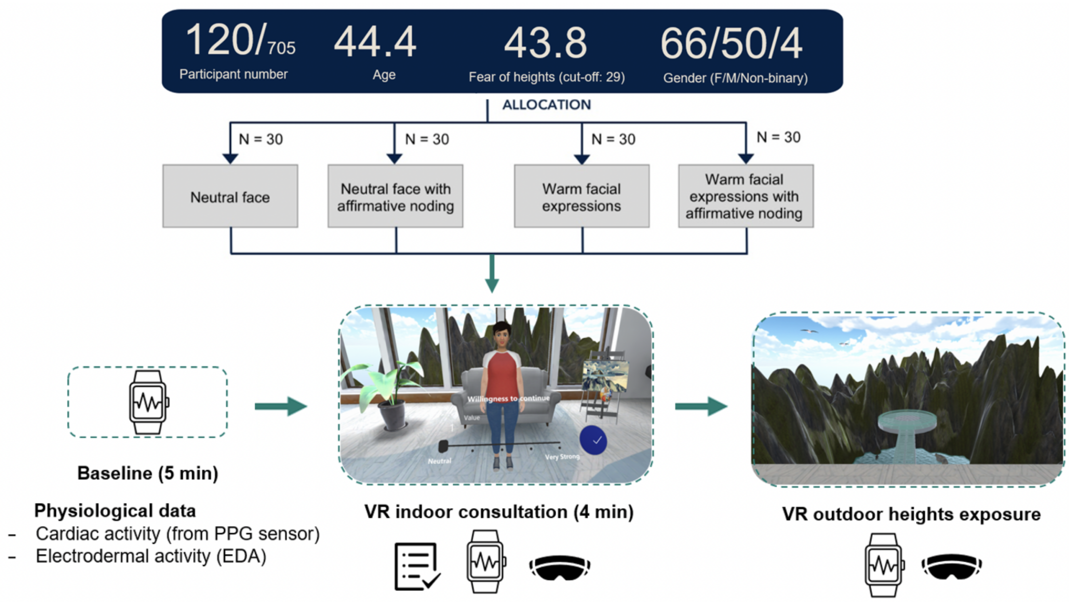

Fig. 2. Physiological response during indoor VR consultation.

3.6 Physiological Data Processing

3.6.1 Data pre-processing. Raw cardiac (from a photoplethysmography sensor) (64 Hz) and EDA (4 Hz) data were cleaned via visual inspection, filtering, and outlier screening. Participants were excluded if >15% of their data were missing, and EDA data were removed if >15% contained zero or negative values, indicating poor sensor contact. To minimise edge artifacts, the first and last 3 seconds of all signals were trimmed. Cardiac signals were processed using a 2nd-order Butterworth bandpass filter (0.6875–10 Hz) and Stationary Wavelet Transform (SWT) with a 7th-level Daubechies mother wavelet [30]. EDA signals underwent 2nd-order low-pass filtering (0.25 Hz) for noise reduction [9].

3.6.2 Feature Extraction. We used Neurokit2 [22] to extract key physiological features commonly used in affective VR research [9, 21, 25, 47].

- **Cardiac metrics**: Mean **HR**, HRV indices (**RMSSD**, **LF/HF ratio**).
- **EDA metrics**: Continuous decomposition analysis [2] was applied to separate tonic **SCL** (baseline activity) from phasic **SCR** (stimulus-driven peaks). We calculated mean **SCL**, **PeaksPerMin** (average SCR occurrences), and **PeakAmp** (SCR peak amplitude).

4 Results

4.1 RQ1: Physiological Responses in Indoor vs. Outdoor VR

For within-subject comparisons, data were excluded if one session was missing, leaving 104 out of 120 valid pairs. Pairwise differences between indoor and outdoor VR sessions were analysed using the Wilcoxon Rank Sum Test following the non-normally distributed results of a Shapiro-Wilk test (p < 0.01). Table 2 summarises the results.

For cardiac responses, HR was significantly higher in outdoor VR than indoor VR (N = 104, W = 1639, p < 0.001, r = 0.347), and HRV (RMSSD) was greater outdoors (N = 105, W = 1912, p = 0.005, r = 0.272). For EDA, SCL was significantly higher in outdoor VR (W = 1848, p = 0.003, r = 0.292), while PeaksPerMin was lower (W = 3124, p = 0.013, r = 0.244) and PeakAmp was higher (W = 1859, p = 0.005, r = 0.277).

Table 2. Physiological data in indoor and outdoor VR, including mean, median, and interquartile range (IQR = Q3 − Q1).

Physiological Measures	**Indoors**			**Outdoors**			**Stats**	
	Mean	*Median*	*IQR*	*Mean*	*Median*	*IQR*	*p*	*r*
HR (% Baseline)	105%	104%	9%	106%	106%	8%	< 0.001	0.347
RMSSD (% Baseline)	106%	94%	58%	122%	105%	57%	0.005	0.272
LF/HF (% Baseline)	224%	102%	151%	166%	86%	120%	0.052	0.192
SCL (% Baseline)	297%	153%	157%	414%	215%	262%	0.003	0.292
PeaksPerMin (% Baseline)	124%	105%	87%	108%	79%	70%	0.013	0.244
PeakAmp (% Baseline)	191%	76%	140%	349%	103%	223%	0.005	0.277

4.2 RQ2: Physiological Responses Towards the VR coach

A Shapiro-Wilk test showed all the physiological responses (HR, RMSSD, LF/HF, SCL, PeaksPerMin, PeakAmp) as not normally distributed (p < 0.01). We therefore conducted Aligned Rank Transform (ART) [45] test to analyse the effects of warm facial expressions, affirmative head nods, and their interaction, by comparing values from different virtual coach condition groups. Full results are shown in Supplementary Material A.

Indoor VR: For cardiac responses, no significant effects were found for HR, RMSSD, or LF/HF. For EDA, warm facial expressions significantly increased PeakAmp ($F(1, 104) = 4.207, p = 0.043, \eta_p^2 = 0.040$), with significant pairwise differences between the neutral face with nod and warm face (p-adj < 0.001), and between the neutral face with nod and warm face with nod (p-adj $= 0.033$).

Outdoor VR: For cardiac responses, warm facial expressions significantly increased LF/HF ($F(1, 105) = 4.512, p = 0.036, \eta_p^2 = 0.041$). Post-hoc analysis revealed a significant difference between the neutral face with nod and warm face (p-adj $= 0.017$). No significant effects were observed for HR and HMSSD. For EDA, there were no significant effects for SCL, PeaksPerMin, or PeakAmp.

4.3 Correlation between physiological and subjective measures

Table 3 summarises the correlation results between physiological responses during indoor VR consultation and subjective measures. HR was positively correlated with treatment credibility ($\rho = 0.307, p_{\text{adj}} = 0.006$) and expectancy ($\rho = 0.361, p = 0.001$). SCL correlated positively with therapeutic alliance ($\rho = 0.277, p_{\text{adj}} = 0.015$). No significant correlations were found for RMSSD or other subjective measures.

Table 3. Correlation between physiological and subjective measures during Indoor VR.

Subjective Measures	**HR (N = 106)**		**RMSSD (N = 106)**		**SCL (N = 108)**		**PeakAmp (N = 107)**	
	rho	*Adj-p value*	*rho*	*Adj-p value*	*rho*	*Adj-p value*	*rho*	*Adj-p value*
VirtualCoachAlliance	0.109	1.000	-0.014	1.000	0.277	0.015*	0.158	0.412
Credibility	0.307	0.006**	0.050	1.000	0.070	1.000	-0.052	1.000
Expectancy	0.361	0.001**	-0.034	1.000	-0.005	1.000	-0.106	1.000
PresenceIndoor	0.216	0.107	-0.136	0.667	0.078	1.000	0.122	0.847

5 Discussion

This study examined the physiological effects of VR and VR coach design in mental health therapy, including an indoor consultation and outdoor heights exposure. For **RQ1**, the outdoor heights exposure elicited higher HR and EDA, but also increased HRV (RMSSD) compared to the indoor VR. For **RQ2**, the VR coach's positive emotional attributes heightened physiological arousal, increasing EDA during consultation. However, no significant effects were found during heights exposure, except for higher LF/HF with warm facial expressions. These findings reinforce VR as an affective stimulus and highlight the impact of VH emotional attributes on psychophysiological responses, potentially improving therapeutic outcomes in mental health VR.

5.1 VR Environments as Affective Stimuli

As a validation test of the outdoor VR scenario, the results of **RQ1** verified that the virtual heights effectively triggered physiological changes, most of which were similar to the fearful responses in real life. Our findings partially align with previous VR studies on acrophobia, where individuals showed immediate physiological arousal, with increased HR and elevated EDA (tonic SCL and phasic SCR) during the exposure [8, 21, 32]. This supports the evidence that VR environments linked to specific phobias can elicit physiological reactions that are compatible with fear and stress, which are common responses to the virtual heights scenario, although contrasting outcomes have been reported in other studies [32, 33].

Notably, we observed an unexpected increase in HRV, specifically RMSSD, during heights exposure. While higher RMSSD typically indicates parasympathetic dominance and relaxation [38], this pattern contrasts with the heightened HR and EDA results, and the expected effects from the heights simulation. Similar findings have been reported when comparing calm VR environments to more stimulating ones [25], suggesting that RMSSD in short-term recordings (<5 minutes) may have more nuanced or non-linear relationships with stress responses. This could reflect a complex interaction within the autonomic nervous system (ANS) under high-stress conditions, where an increased parasympathetic response may act as a protective mechanism against excessive sympathetic activation. Further research is needed to explore the implications of these findings for autonomic flexibility and stress resilience in VR.

Furthermore, we found no significant correlation between participants' fear of heights scores and their physiological responses during either the indoor consultation or outdoor exposure. This finding mirrors results from other studies, where individuals exhibited elevated HR and EDA despite reporting no subjective fear [8] or showing no physiological arousal despite having a fear of heights [46]. In summary, while the VR heights scenario effectively induces physiological responses, the dynamics in HRV patterns and the lack of correlation with subjective fear scores highlight the complexity of psychophysiological responses in VR.

5.2 The Impact of VR coach's Emotional Attributes

To our knowledge, this is the first randomised controlled study to examine the physiological effects of VR coach design. **RQ2** results indicated that the coach's positive emotional attributes increased EDA during the introductory consultation, which provided general information (e.g. rationale behind the fear of height). Warm facial expressions led to fewer but larger SCR peaks, indicating more intense but less frequent arousal bursts, while affirmative nods trended toward higher SCL, suggesting potential sustained arousal. Cardiac responses were unaffected.

Existing research on consultation scenarios has yielded mixed findings. While some studies suggest that positive communication styles (e.g. permissiveness, reassurance) reduce EDA by providing relief [34, 37], our results align with studies where compassionate communication increased arousal (higher SCL, larger SCR amplitude) [10, 24]. This may be because our VR consultation was general and introductory, addressing a less severe condition rather than deep personal concerns (e.g. life-threatening illness). The increased arousal may reflect positive appraisals or excitement from interacting with an empathetic VR character, as indicated by higher therapeutic alliance, confidence in VR treatment, and the positive correlation between SCL and therapeutic alliance (**4.3** results). Another possibility is that the VR coach's enhanced non-verbal behaviours, which were programmed with additional animation and details, heightened attention focus and cognitive engagement, leading to greater physiological activity. Previous research showed that non-verbal cues, such as facial expressions and gestures, increased attention and cognitive load, both of which correlate with heightened physiological responses [41]. The lack of significant effects on HR and HRV may stem from their sensitivity to multiple factors (e.g. respiratory patterns, motion artefacts, individual autonomic differences) [17], whereas EDA, being more directly influenced by emotional and attentional demands, showed significant changes.

Interestingly, positive non-verbal behaviours had no significant effect on physiological responses during outdoor heights exposure, except for an increase in the LF/HF ratio associated with warm facial expressions. Governed by the ANS, physiological signals reflect the balance between the sympathetic nervous system (SNS) ('fight or flight') and parasympathetic nervous system (PNS) ('rest and digest') [26]. The observed LF/HF increase suggests greater sympathetic activation, linked to heightened emotional arousal. However, HR and EDA remained unaffected by the positive emotional attributes. This discrepancy may be due to the brief consultation duration and the absence of coach support during outdoor exposure, limiting sustained effects. Another explanation lies in the SNS-PNS interaction. In highly stressful scenarios such as heights exposure, SNS dominance may override the influence of positive non-verbal cues from the consultation. This effect was most pronounced in participants who interacted with a VR coach displaying warm facial expressions.

To further apply these insights in digital health and human-computer interaction, future research could explore how a VR coach might adapt in real-time to users' physiological changes to offer personalized therapy. Integrating machine learning algorithms could enable the VR coach to modify its responses based on real-time physiological data, enhancing user engagement and therapeutic outcomes. Additionally, intersecting these objective measures with subjective assessments, such as self-reported anxiety and nervousness, could provide a comprehensive understanding of the interplay between physiological and psychological responses during phobia exposure. Such insights are crucial for optimising VR scenarios and character design to improve therapeutic effectiveness.

5.3 Limitations

This study has several limitations. Measuring arousal without valence limits our ability to fully interpret physiological changes, especially during the consultation where tension and relief may coexist [1, 5, 42]. Although therapeutic alliance served as a proxy for positive emotions, subjective stress or fear measures after heights exposure were not collected. We also did not look at moment-to-moment physiological changes during the consultation or responses to specific coach dialogue, hindering a detailed analysis of affective shifts [13]. Lastly, the absence of post-task physiological recovery measures limits insights into the after-effects of the coach design. These limitations highlight the complexity of physiological data and the potential for misinterpretation, underscoring the need for cautious analysis of our results.

6 Conclusions

We explored the effects of a VR coach's design on participants' physiological responses. We found that specific positive non-verbal cues, such as affirmative nods and warm facial expressions, significantly increased EDA, which was potentially linked to heightened emotional engagement during the VR consultation. However, the positive cues did not sustain their influence during the subsequent VR heights exposure apart from the HRV-LF/HF. These results highlight the psychophysical impacts of carefully considering the VR coach's emotional attributes in automated VR therapy. Future research should systematically examine the physiological impact of VH design in VR-based interventions to better leverage physiological data for personalised VR experiences and therapies.

Acknowledgments

The authors would like to thank all participants for their involvement. The study was supported by the OCAP Research Fund and a research internship grant from Centrum Wiskunde & Informatica. S.W. would also like to thank Yale XR Pediatrics for conference support.

References

[1] Ebrahim Babaei, Benjamin Tag, Tilman Dingler, and Eduardo Velloso. 2021. A critique of electrodermal activity practices at chi. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–14.

[2] Mathias Benedek and Christian Kaernbach. 2010. A continuous measure of phasic electrodermal activity. *Journal of neuroscience methods* 190, 1 (2010), 80–91.

[3] Willem-Paul Brinkman, Wim Veling, Emily Dorrestijn, Guntur Sandino, Vanessa Vakili, and Mark Van Der Gaag. 2011. Virtual reality to study responses to social environmental stressors in individuals with and without psychosis. *Annual Review of Cybertherapy and Telemedicine 2011* (2011), 86–91.

[4] Francesco Chiossi, Yagiz Turgut, Robin Welsch, and Sven Mayer. 2023. Adapting visual complexity based on electrodermal activity improves working memory performance in virtual reality. *Proceedings of the ACM on Human-Computer Interaction* 7, MHCI (2023), 1–26.

[5] F. M. M. Citron, M. A. Gray, H. D. Critchley, B. S. Weekes, and E. C. Ferstl. 2014. Emotional valence and arousal affect reading in an interactive way: Neuroimaging evidence for an approach-withdrawal framework. *Neuropsychologia* 56, 100 (2014), 79–89. https://doi.org/10.1016/j.neuropsychologia.2014.01.002

[6] Lidia Del Piccolo and Arnstein Finset. 2018. Patients' autonomic activation during clinical interaction: A review of empirical studies. *Patient Education and Counseling* 101, 2 (2018), 195–208.

[7] Grant J Devilly and Thomas D Borkovec. 2000. Psychometric properties of the credibility/expectancy questionnaire. *Journal of behavior therapy and experimental psychiatry* 31, 2 (2000), 73–86.

[8] Julia Diemer, Nora Lohkamp, Andreas Mühlberger, and Peter Zwanzger. 2016. Fear and physiological arousal during a virtual height challenge—effects in patients with acrophobia and healthy controls. *Journal of anxiety disorders* 37 (2016), 30–39.

[9] Abdallah El Ali, Ekaterina R Stepanova, Shalvi Palande, Angelika Mader, Pablo Cesar, and Kaspar Jansen. 2023. BreatheWithMe: Exploring Visual and Vibrotactile Displays for Social Breath Awareness during Colocated, Collaborative Tasks. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–8.

[10] Arnstein Finset, Tonje L Stensrud, Erik Holt, William Verheul, and Jozien Bensing. 2011. Electrodermal activity in response to empathic statements in clinical interviews with fibromyalgia patients. *Patient education and counseling* 82, 3 (2011), 355–360.

[11] Daniel Freeman, Polly Haselton, Jason Freeman, Bernhard Spanlang, Sameer Kishore, Emily Albery, Megan Denne, Poppy Brown, Mel Slater, and Alecia Nickless. 2018. Automated psychological therapy using immersive virtual reality for treatment of fear of heights: a single-blind, parallel-group, randomised controlled trial. *The Lancet Psychiatry* 5, 8 (2018), 625–632.

[12] Daniel Freeman, Sinéad Lambe, Thomas Kabir, Ariane Petit, Laina Rosebrock, Ly-Mee Yu, Robert Dudley, Kate Chapman, Anthony Morrison, Eileen O'Regan, et al. 2022. Automated virtual reality therapy to treat agoraphobic avoidance and distress in patients with psychosis (gameChange): a multicentre, parallel-group, single-blind, randomised, controlled trial in England with mediation and moderation analyses. *The Lancet Psychiatry* 9, 5 (2022), 375–388.

[13] Jonathan Giron, Jelena Mladenovic, Maxine Hanrieder, Yulia Golland, and Doron Friedman. 2023. Physiological correlates of stress induced by virtual humans in a naturalistic virtual reality scenario. In *2023 11th International Conference on Affective Computing and Intelligent Interaction Workshops and Demos (ACIIW)*. IEEE, 1–8.

[14] Andreas Halbig and Marc Erich Latoschik. 2021. A systematic review of physiological measurements, factors, methods, and applications in virtual reality. *Frontiers in Virtual Reality* 2 (2021), 694567.

[15] Masashi Inoue, Toshio Irino, Nobuhiro Furuyama, and Ryoko Hanada. 2021. Observational and accelerometer analysis of head movement patterns in psychotherapeutic dialogue. *Sensors* 21, 9 (2021), 3162.

[16] Allison Jing, Theophilus Teo, Jeremy McDade, Chenkai Zhang, Yi Wang, Andrei Mitrofan, Rushil Thareja, Heesook Shin, Yongho Lee, Youn-Hee Gil, et al. 2024. Superpowering Emotion Through Multimodal Cues in Collaborative VR. In *2024 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, 160–169.

[17] Yuwon Kim, Jinseok Park, Hojin Choi, Martin Loeser, Hokyoung Ryu, and Kyoungwon Seo. 2024. Decoding Behavior: Utilizing Virtual Reality Digital Marker and Machine Learning for Early Detection of Mild Cognitive Impairment. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems*. 1–8.

[18] Oswald D Kothgassner, Andreas Goreis, Johanna X Kafka, Marlene Kaufmann, Katharina Atteneder, Leon Beutl, Kristina Hennig-Fast, Helmut Hlavacs, and Anna Felnhofer. 2019. Virtual social support buffers stress response: An experimental comparison of real-life and virtual support prior to a social stressor. *Journal of behavior therapy and experimental psychiatry* 63 (2019), 57–65.

[19] Michael Kotlyar, Christopher Donahue, Paul Thuras, Matt G Kushner, Natalie O'Gorman, Erin A Smith, and David E Adson. 2008. Physiological response to a speech stressor presented in a virtual reality environment. *Psychophysiology* 45, 6 (2008), 1034–1037.

[20] Leon OH Kroczek and Andreas Mühlberger. 2023. Public speaking training in front of a supportive audience in Virtual Reality improves performance in real-life. *Scientific Reports* 13, 1 (2023), 13968.

[21] Tiffany Luong and Christian Holz. 2022. Characterizing physiological responses to fear, frustration, and insight in virtual reality. *IEEE Transactions on Visualization and Computer Graphics* 28, 11 (2022), 3917–3927.

[22] Dominique Makowski, Tam Pham, Zen J Lau, Jan C Brammer, François Lespinasse, Hung Pham, Christopher Schölzel, and SH Annabel Chen. 2021. NeuroKit2: A Python toolbox for neurophysiological signal processing. *Behavior research methods* (2021), 1–8.

[23] Jessica L Maples-Keller, Sheila AM Rauch, Tanja Jovanovic, Carly W Yasinski, Jessica Morgan Goodnight, Andrew Sherrill, Kathryn Black, Vasiliki Michopoulos, Boadie W Dunlop, Barbara Olasov Rothbaum, et al. 2019. Changes in trauma-potentiated startle, skin conductance, and heart rate within prolonged exposure therapy for PTSD in high and low treatment responders. *Journal of Anxiety Disorders* 68 (2019), 102147.

[24] Carl D Marci, Erin K Moran, and Scott P Orr. 2004. Physiologic evidence for the interpersonal role of laughter during psychotherapy. *The Journal of nervous and mental disease* 192, 10 (2004), 689–695.

[25] Marieke AG Martens, Angus Antley, Daniel Freeman, Mel Slater, Paul J Harrison, and Elizabeth M Tunbridge. 2019. It feels real: physiological responses to a stressful virtual reality environment and its impact on working memory. *Journal of Psychopharmacology* 33, 10 (2019), 1264–1273.

[26] Laurie Kelly McCorry. 2007. Physiology of the autonomic nervous system. *American journal of pharmaceutical education* 71, 4 (2007).

[27] Gaëtan Mertens, Patrick Wagensveld, and Iris M Engelhard. 2019. Cue conditioning using a virtual spider discriminates between high and low spider fearful individuals. *Computers in Human Behavior* 91 (2019), 192–200.

[28] Alexander Miloff, Per Carlbring, William Hamilton, Gerhard Andersson, Lena Reuterskiöld, and Philip Lindner. 2020. Measuring alliance toward embodied virtual therapists in the era of automated treatments with the Virtual Therapist Alliance Scale (VTAS): Development and psychometric evaluation. *Journal of medical Internet research* 22, 3 (2020), e16660.

[29] Andreas Mühlberger, Martin J Herrmann, Georg Wiedemann, Heiner Ellgring, and Paul Pauli. 2001. Repeated exposure of flight phobics to flights in virtual reality. *Behaviour research and therapy* 39, 9 (2001), 1033–1050.

[30] Guy P Nason and Bernard W Silverman. 1995. The stationary wavelet transform and some statistical applications. In *Wavelets and statistics*. Springer, 281–299.

[31] Xueni Pan and Antonia F de C Hamilton. 2018. Why and how to use virtual reality to study human social interaction: The challenges of exploring a new research landscape. *British Journal of Psychology* 109, 3 (2018), 395–417.

[32] Steven M Peterson, Emily Furuichi, and Daniel P Ferris. 2018. Effects of virtual reality high heights exposure during beam-walking on physiological stress and cognitive loading. *PloS one* 13, 7 (2018), e0200306.

[33] Tiphanie E Raffegeau, Bradley Fawver, William R Young, A Mark Williams, Keith R Lohse, and Peter C Fino. 2020. The direction of postural threat alters balance control when standing at virtual elevation. *Experimental brain research* 238 (2020), 2653–2663.

[34] Maija Reblin, Lee Ellington, Seth Latimer, Bert N Uchino, Debra Roter, and Amiee Maxwell. 2012. Communication style affects physiological response in simulated cancer risk reduction interactions. *Journal of Applied Biobehavioral Research* 17, 2 (2012), 129–156.

[35] Jonas Reichenberger, Theresa F Wechsler, Julia Diemer, Andreas Mühlberger, and Swantje Notzon. 2022. Fear, psychophysiological arousal, and cognitions during a virtual social skills training in social anxiety disorder while manipulating gaze duration. *Biological psychology* 175 (2022), 108432.

[36] Laina Rosebrock, Jason Freeman, Aitor Rovira, Andre Lages Miguel, Rupert Ward, Matthew Bousfield, Ludovic Riffiod, Roya Kamvar, Thomas Kabir, Felicity Waite, et al. 2024. Developing an Automated Virtual Reality Therapy for Improving Positive Self-Beliefs and Psychological Well-Being (Phoenix VR Self-Confidence Therapy): Tutorial. *JMIR Serious Games* 12, 1 (2024), e51512.

[37] Milou SC Sep, Mara Van Osch, Liesbeth M Van Vliet, Ellen MA Smets, and Jozien M Bensing. 2014. The power of clinicians' affective communication: how reassurance about non-abandonment can reduce patients' physiological arousal and increase information recall in bad news consultations. An experimental study using analogue patients. *Patient education and counseling* 95, 1 (2014), 45–52.

[38] Fred Shaffer and Jay P Ginsberg. 2017. An overview of heart rate variability metrics and norms. *Frontiers in public health* 5 (2017), 258.

[39] Lina Stallmann, Michel Tran, David Rudrauf, Daniel Dukes, and Andrea Samson. 2023. Simulating Social Emotion Regulation in Virtual Reality: Effect of Virtual Social Support Following Ostracism in a Cyberball Game. *International Journal of Emerging Technologies in Learning (iJET)* 18, 7 (2023), 4–27.

[40] Shari A Steinman and Bethany A Teachman. 2011. Cognitive processing and acrophobia: validating the Heights Interpretation Questionnaire. *Journal of anxiety disorders* 25, 7 (2011), 896–902.

[41] Matias Volonte, Yu-Chun Hsu, Kuan-Yu Liu, Joe P Mazer, Sai-Keung Wong, and Sabarish V Babu. 2020. Effects of interacting with a crowd of emotional virtual humans on users' affective and non-verbal behaviors. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 293–302.

[42] Liisa Voutilainen, Pentti Henttonen, Mikko Kahri, Niklas Ravaja, Mikko Sams, and Anssi Peräkylä. 2018. Empathy, challenge, and psychophysiological activation in therapist–client interaction. *Frontiers in psychology* 9 (2018), 530.

[43] Shu Wei, Daniel Freeman, Victoria Harris, and Aitor Rovira. 2024. A randomised controlled test in virtual reality of the effects on paranoid thoughts of virtual humans' facial animation and expression. *Scientific Reports* 14, 1 (2024), 17102.

[44] Shu Wei, Daniel Freeman, and Aitor Rovira. 2023. A randomised controlled test of emotional attributes of a virtual coach within a virtual reality (VR) mental health treatment. *Scientific Reports* 13, 1 (2023), 11517.

[45] Jacob O Wobbrock, Leah Findlater, Darren Gergle, and James J Higgins. 2011. The aligned rank transform for nonparametric factorial analyses using only anova procedures. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 143–146.

[46] Max Wuehr, Katharina Breitkopf, Julian Decker, Gerardo Ibarra, Doreen Huppert, and Thomas Brandt. 2019. Fear of heights in virtual reality saturates 20 to 40 m above ground. *Journal of neurology* 266, Suppl 1 (2019), 80–87.

[47] Tong Xue, Abdallah El Ali, Tianyi Zhang, Gangyi Ding, and Pablo Cesar. 2021. CEAP-360VR: A Continuous Physiological and Behavioral Emotion Annotation Dataset for 360° VR Videos. *IEEE Transactions on Multimedia* 25 (2021), 243–255.