Using Skin Conductance to Predict Awe and Perceived Vastness in Virtual Reality

Melissa Steininger[1], Monica Perusquía-Hernández[2], Alexander Marquardt[1], Hiromu Otsubo[2],
Marvin Lehnort[1], Felix Dollack[2], Kiyoshi Kiyokawa[2], Ernst Kruijff[1] and Bernhard Riecke[3]
1 *University of Applied Sciences Bonn-Rhein-Sieg (H-BRS)*
2 *Nara Institute of Science and Technology (NAIST)*
3 *Simon Fraser University*

***Abstract*—Awe is an emotion characterized by the perception of vastness and the need to accommodate this vastness into one's mental framework. We propose an elicitation scene to induce awe in Virtual Reality (VR), validate it through self-report, and explore the feasibility of using skin conductance to predict self-reported awe and vastness as labeled from the stimuli in VR. Sixty-two participants took part in the study comparing the awe-eliciting space scene and a neutral scene. The space scene was confirmed as more awe-eliciting. A k-nearest neighbor algorithm confirmed high and low-awe score clusters used to label the data. A Random Forest algorithm achieved 65% accuracy $(F1 = 0.56, AUC = 0.73)$ when predicting the self-reported low and high awe categories from continuous skin conductance data. A similar approach achieved 55% accuracy $(F1 = 0.59, AUC = 0.56)$ when predicting the perception of vastness. These results underscore the potential of skin-conductance-based algorithms to predict awe.**

***Index Terms*—Virtual Reality, Awe, Skin Conductance, Machine Learning**

I. INTRODUCTION

Awe is a complex emotional experience characterized by the perception of vastness and the need to accommodate this vastness into one's existing mental frameworks [1]. Given the immersive and controlled nature of virtual reality (VR), this technology has emerged as a promising tool for eliciting and studying awe [2]. Among the various aspects of awe, vastness is particularly well measurable in the environment. This makes it a practical focus for our research despite the limitation that actual vastness does not always equate to perceived vastness [3]. Awe has been linked to positive psychological outcomes, such as increased humility, connectedness, and life satisfaction. It is the only positive emotion shown to reduce inflammation [4]. Higher levels of awe self-reports have also been associated with higher skin conductance response [5], [6]. However, these studies used stationary screens, while recent work shows that head-mounted display (HMD)-based stimuli are more effective at eliciting awe [2], [6], [7]. Furthermore, the predictive power of skin conductance responses (SCR) and skin conductance levels (SCL) to identify self-reported awe has not been tested. Therefore, we explored these skin conductance features using VR-based stimuli and analyzed how behavioral markers, such as time spent in a vast space, relate to SCR, SCL, and the subjective experience of awe. The contributions of this study are:

- Awe elicitation using a VR scene depicting vastness, validated through self-report AWE-S questionnaire [1].
- Unsupervised clustering of the AWE-S scores to determine high awe versus low awe.
- Exploration of the relationship between skin conductance, the experience of vastness, and self-reported awe and the development of predictive models for awe and vastness from skin conductance using Random Forests.

II. RELATED WORK

VR can transport users to otherwise unattainable experiences, such as viewing the Earth from space or exploring vast natural landscapes [8], [9], making this technology particularly suitable for inducing awe. Several studies have explored the potential of VR to evoke awe using various types of scenes. For instance, research on the *Overview Effect* allowed participants to view the Earth from space [9], [10], while other studies used natural landscapes like mountains, forests, and waterfalls to elicit awe [2], [11]. Additionally, researchers have investigated the impact of different awe-inducing stimuli, including vast natural scenes and grand architectural structures [7], in VR. Following these studies, we utilize a space scene showing an overview of the Earth to induce awe. Awe is associated with distinct physiological responses, including changes in heart rate variability (HRV), skin conductance responses (SCRs) [6], respiration rates [12], and goosebumps/shivers [7]. VR can enhance the subjective experience of awe and facilitate real-time physiological data collection in a controlled setting. Studies have shown that immersive VR environments elicit stronger physiological responses than traditional media, such as increased SCRs and HRV [2], [7]. Participants exposed to awe-inspiring VR content exhibited significant changes in these physiological measures compared to neutral VR content [2], [5].

These findings suggest that VR can effectively induce awe and capture its physiological manifestations. However, no previous work has explored predictive models to identify awe experiences from skin conductance data.

III. DATA COLLECTION EXPERIMENT

The following section describes the study design and procedures used to gather and analyze data.

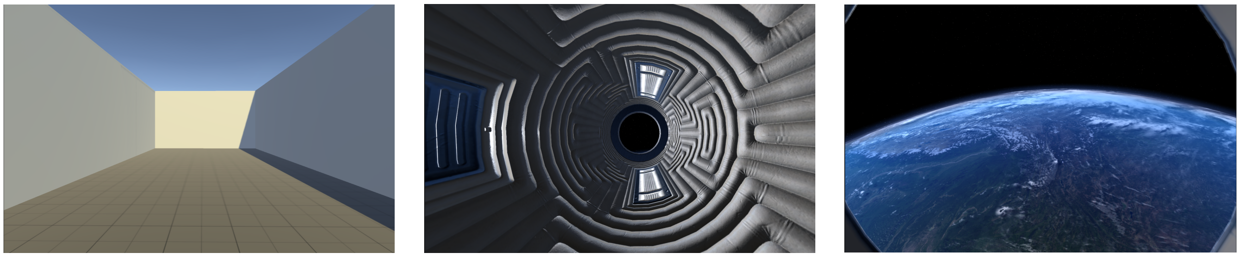

Fig. 1. Left: neutral scene, middle: narrow area of the space scene, right: vast area of the space scene.

A. *Participants*

Sixty-two volunteers (18 females, 44 males, aged 18-64) recruited from three Universities in Jordan, Japan, and Germany participated in the study. This experiment was approved by our local IRB (2023-I-5). Due to excessive artifacts in the biological signals, only the data of 52 participants (15 females, 37 males, aged 18-64) was used for analysis.

B. *Experiment Design*

A within-subjects design was used. Participants experienced two interactive VR scenes in a counterbalanced order: one designed to elicit a high level of awe (space scene) and the other serving as a neutral control (neutral scene).

C. *VR Stimuli and Apparatus*

The awe-eliciting scene depicted a **narrow spaceship corridor** that ended in an opening to **the vastness of space**, providing a view of the earth (Figure 1, middle and right). Participants navigated the scene using the controllers to experience first the spaceship corridor and then the open space. The design aimed to create a contrasting impression of vastness, inspired by Burke's concept of the sublime [13]. The view of the Earth was intended to convey the user's smallness within a larger space. These two characteristics were aimed to provide an increased sense of awe. An invisible trigger was placed at the opening of the spaceship corridor to mark the transition point from the narrow corridor to the vast space. The trigger logged the number of times and timestamp when participants passed through it. It served as a threshold to label data samples when the participant was observing vastness. The neutral scene depicted a **narrow, non-vast, empty corridor** to avoid eliciting awe (see Figure 1, left). The scenes were implemented using Unity 2021.3.6f1 and presented on a Meta Quest 2 (90Hz refresh rate, 1832 x 1920 pixels per eye).

D. *Measures*

Awe was self-reported using the AWE-S questionnaire [1]. Participants completed a demographic questionnaire assessing age, gender, nationality, dominant hand, VR experience, and current well-being. Skin conductance was measured with a Gtec $g.GSRsensor^2$ sensor sampled at 10 Hz, placed on the middle and ring fingers of the non-dominant hand. The non-dominant hand was chosen to potentially reduce noise in the measurements as it is used less frequently.

Additionally, the Igroup Presence Questionnaire (IPQ) [14], Ten Item Personality Inventory (TIPI) [15] and respiration rates were measured. However, their analysis is left for future work.

E. *Procedure*

Participants were briefed, signed a consent form, and wore the biosensors and VR HMD. They explored each scene for two minutes, filling out the AWE-S and IPQ questionnaires afterward. The demographics questionnaire was completed once at the beginning of the experiment.

IV. ANALYSIS AND RESULTS

A. *Awe elicitation check*

We compared the AWE-S scores for the two scenes to confirm that the space scene elicited stronger awe than the neutral scene. AWE-S questions were answered on a 7-point Likert scale, and the overall mean score was converted to a scale from 0 (no awe) to 100 (high level of awe). The scores did not follow a normal distribution $(W = 0.945, p < .001)$ as tested with the Shapiro-Wilk test for normality. Therefore, a Wilcoxon signed rank test was used. The participants reported significantly higher awe in the space scene $(M = 53.7, SD = 18.7)$ than the neutral scene $(M = 19.1, SD = 18.1, Z = 2, p < .001, r = -0.997)$ – see Figure 2 (A).

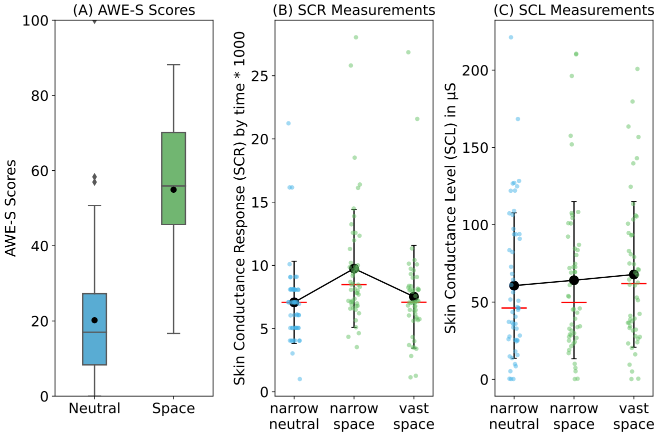

Fig. 2. From left to right: (A) Boxplots showing self-reported AWE-S questionnaire scores for neutral and space scenes. (B) and (C) show SCR and SCL measurements, respectively, of the narrow neutral, narrow space, and vast space conditions. Black dots show means, and red lines show medians. Whiskers depict standard errors.

B. GSR features in narrow vs. vast areas

We analyzed differences in physiological data when experiencing narrow versus vast areas. GSR features were compared during three states: **narrow neutral**, **narrow space**, and **vast space**. GSR data of each participant was split into three windows: all data of the neutral scene (**narrow neutral**), data from the space scene when participants were in the narrow corridor before the trigger (**narrow space**), and data from the space scene when participants were in the vast space after the trigger (**vast space**). We calculated SCR by time, which represents the peaks in skin conductance, and SCL, which reflects the overall skin conductance level in μS, for each of the three windows using the neurokit2 python library [16]. As tested with the Shapiro-Wilk test, data was not normally distributed $(SCRbytime : W = 0.779p < .001, SCL : W = 0.911, p < .001)$. Thus, we used non-parametric methods. Friedman test showed significant differences in both SCR and SCL, between vast versus narrow windows $(SCRbytime : X^2 = 18.5, df = 2, p < .001, SCL : X^2 = 19.1, df = 2, p < .001)$. Durbin-Conover corrected pair-wise comparisons revealed a significant decrease in SCR between the **narrow space** $(M = 9.75, SD = 4.66)$ to **vast space** $(M = 7.52, SD = 4.07)$ windows – see Figure 2 (B). The results revealed significant differences in SCL between all windows, **narrow neutral** $(M = 61.2, SD = 47.0)$, **narrow space** $(M = 64.1, SD = 50.8)$ and **vast space** $(M = 67.8, SD = 47.1)$ – see Figure 2 (C).

C. Awe and vastness prediction from skin conductance

We aimed to predict awe and vastness from GSR data using subject-independent models. Self-reported AWE-S scores were split into classes using k-means clustering, and the data was annotated based on these results. The results showed two clusters centered on 61 and 18 points of the AWE-S scale. Therefore, we labeled them as high and low awe, respectively. A Random Forest classifier was chosen due to its robustness against overfitting, ability to handle non-linear relationships, and proven performance on physiological data [17]. A test set was prepared with 20% of the data with random sampling. Hyperparameters were optimized using grid search in the train set. Due to an imbalance between classes (more data in the **narrow** class versus the **vast** class), the Synthetic Minority Oversampling Technique (SMOTE) [18] was applied to oversample the minority classes in the test sets. We tested two approaches to epoch the input data: (1) 2.5-second skin conductance data windows, as suggested by previous works for analyzing GSR data [19], (2) SCL and SCR feature extraction from 30-second windows. The 2.5-second window size was too short for feature extraction due to sparse SCR peaks per participant. Thus, we chose the larger 30 s window. Each model's performance results can be seen in Table I.

1) **Vast-narrow classification from small skin conductance data windows.** We annotated 2.5-second windows of the skin conductance data with **vast** or **narrow** depending on the participant's location in the VR scenes at that time. This model achieved a score of 55%.
2) **Vast-narrow classification from SCL and SCR features of large skin conductance data windows.** SCR and SCL were calculated in 30-second windows. The data was annotated based on the participant's location in the VR scenes. The achieved accuracy was 50%, indicating a performance at chance level.
3) **Self-reported awe classification from small skin conductance data windows.** The skin conductance data was partitioned into 2.5-second windows and annotated based on the AWE-S score of the participant. This model achieved 65% accuracy.
4) **Self-reported awe classification from SCL and SCR features of large skin conductance data windows.** SCR and SCL were calculated in 30-second windows and annotated based on the AWE-S score of the participant. This model achieved an accuracy of 63%.

TABLE I
OVERVIEW OF RANDOM FOREST MODEL PREDICTION RESULTS

Model	Accuracy	F1	AUC
1) Vast-narrow / small GSR data windows	55%	0.59	0.56
2) Vast-narrow / SCL and SCR	50%	0.54	0.49
3) Self-reported awe / small GSR data windows	65%	0.56	0.73
4) Self-reported awe / SCL and SCR	63%	0.56	0.63

V. DISCUSSION AND FUTURE WORK

Our results confirmed that the space and neutral scenes worked as intended in eliciting high and low awe experiences, consistent with previous research [2], [6], [11]. The analysis of skin conductance features revealed significant differences in physiological responses between experiencing narrow and vast areas. Specifically, we observed a decrease in SCR and an increase in SCL when transitioning from narrow to vast space, suggesting a distinct physiological signature indicative of an awe response in VR. This observation is partly supported by previous work. While studies using awe-inspiring 2D videos transitioning from closed to open areas found an overall increase in SCRs [6], our study in VR observed a decrease in SCR. This difference might be attributed to VR's more immersive and engaging nature, which can lead to different patterns of engagement and arousal compared to 2D media [20]. The elevated SCRs in the **narrow space** area may indicate anticipatory arousal, while the subsequent decrease in SCR and increase in SCL in **vast space** could represent physiological adaptation to the awe-inspiring environment [21]. These findings are consistent with recent research, which suggests that awe experiences involve fluctuations in sympathetic nervous system activation, highlighting its complex nature [6].

Using Random Forest classifiers to predict awe and vastness from skin conductance data yielded mixed results. We achieved moderately good results for predicting the experience of awe: 2.5 s windows of continuous skin conductance data provided superior predictions (65% accuracy) as opposed to using SCL and SCR features of 30 s windows (63% accuracy). Predictions of vastness perceptions showed more modest results: the 2.5 s window approach achieved 55% accuracy compared to 50% for the 30 s window approach.

These results are close to chance level, indicating that predicting vastness perception from GSR data alone remains challenging. The awe prediction models' better performance than the narrow/vast models shows that experiencing awe depends on more than just vastness perception. Awe is a complex emotional experience involving both cognitive and physiological components [6]. In contrast, the perception of vastness may elicit more varied individual responses, making it harder to predict based solely on physiological data. Additionally, the awe experience in our VR environment involved a temporal component, with physiological responses changing as participants moved from narrow to vast space. This dynamic nature of the awe experience may have provided more variability in the data for the machine learning models, compared to the more static spatial perceptions of narrow or vast environments.

There are several limitations to this study. First, we had a low percentage of female participants, and most of our participants were young, with 72% under the age of 24. Second, we recorded GSR on the non-dominant hand to reduce motion artifacts when interacting with the VR controller. GSR is known to be asymmetrical [22], hence, future research should investigate the differences when using GSR measured from different body locations. In future research, we will explore a larger variety of awe stimuli, including natural landscapes and abstract scenes, and how different factors influence the experience of awe. We will look at respiration patterns, presence using the IPQ, personality traits through the TIPI, and cultural influences based on participants' country of origin. This investigation aims to reveal the interplay between physiological responses, psychological factors, and demographics in shaping the sensation of awe. We will also explore improved techniques for extracting awe and vastness information from skin conductivity data, considering personalized models to enhance performance. Further, we will look more into confounding variables for GSR measurements as well as other potential confounding factors in our experimental setup, such as how VR proficiency might influence the experience of awe.

VI. ETHICAL IMPACT STATEMENT

This research was approved by our local committee for research with human data. All participant data was anonymized. The subjective experience of awe was labeled through self-report. However, this annotation's granularity is coarse compared to the skin conductance measurements. The labels of vastness were derived from the user's behavior. Therefore, they might not accurately describe the subjective experience. Because of the different time scales of self-report and the behavioral markers, the results presented here should be interpreted carefully.

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