Genre-Sensitive Prediction of Emotional Arousal in Virtual Reality: A Neural Modeling Approach Using Skin Conductance Peaks

Demián Velasco Gómez Llanos, Santiago Arreola Munguía, Marco Antonio Manjarrez Fernandez, Juan Pablo Villaseñor Navares, Violeta Corona, Jesus GomezRomero-Borquez, José Varela-Aldás, *Senior Member, IEEE*, and Carolina Del-Valle-Soto, *Senior Member, IEEE*

***Abstract*—Understanding how different virtual reality (VR) game genres modulate physiological arousal is crucial for designing emotionally adaptive immersive systems. This study introduces a novel experimental framework combining high-resolution Skin Conductance Response (SCR) data and neural predictive modeling to compare emotional activation across horror, skill-based, and exercise VR games. Using Galvanic Skin Response (GSR) sensors, we recorded phasic peaks in SCR from 25 university-aged participants during gameplay sessions with controlled exposure times and standardized transitions. However, given the minimal difference relative to the large variability, this observation should be considered preliminary and specific to the tested games and cohort. A feed-forward neural network was developed to forecast individual arousal levels based solely on genre-induced features, achieving strong predictive performance. This dual contribution—empirical genre comparison and lightweight predictive modeling—offers a scalable tool for integrating emotional responsiveness into VR systems without continuous biosignal monitoring. The findings not only advance the state of the art in affective computing but also open new avenues for therapeutic, educational, and entertainment applications grounded in physiological adaptation.**

Link to graphical and video abstracts, and to code: https://latamt.ieeer9.org/index.php/transactions/article/view/10067

***Index Terms*—Galvanic Skin Response, Virtual Reality Games, Emotional Arousal, Skin Conductance Response, Predictive Modeling.**

I. Introduction

THE increasing use of immersive environments in entertainment and therapeutic applications has raised important questions about how to quantify users' physiological responses to emotionally salient stimuli. VR, with its multisensory and interactive features, creates unprecedented opportunities for real-time measurement of affective states [1]. However, VR developers still lack standardized physiological metrics to inform experience design, especially regarding emotional arousal provoked by different game genres.

The rapid expansion of immersive environments in both entertainment and therapeutic domains has underscored the urgent need for reliable, objective indicators of emotional engagement [2]. As VR technologies become increasingly embedded in daily life, their potential to influence users' affective states—through multisensory stimulation, embodiment, and real-time interactivity—has raised critical questions about how such experiences modulate physiological arousal [3].

Among the most promising tools for assessing emotional arousal is the SCR, captured through GSR sensors, which provides a validated proxy of autonomic nervous system activity [4]. However, most studies using SCR in VR contexts have focused on isolated genres, heterogeneous populations, or narrowly scoped scenarios—limiting generalizability and actionable insights for developers and researchers. Furthermore, the dynamic and genre-dependent nature of emotional engagement in VR remains poorly understood, particularly in homogeneous youth populations such as university students, who constitute a primary user base for immersive technologies [5].

II. Related Work

The integration of psychophysiological sensors in VR for monitoring emotional arousal has advanced rapidly. Pop et al. [6] first established a robust connection between electrodermal activity (EDA) and limbic system activation in response to emotional stimuli. Building on that, Mateos et al. [7] confirmed the feasibility of detecting intense emotional episodes via SCR during urban VR simulations, underscoring the reliability of EDA as an emotion proxy. Meinel et al. [8] later focused on GSR responses in horror-oriented VR settings, identifying distinctive phasic peaks tied to sudden fear-inducing events; meanwhile, Marin et al. [9] explored physiological arousal during VR fitness tasks, demonstrating sustained tonic SCR changes associated with physical exertion. However, most existing studies are limited to single-genre evaluations or heterogeneous adult populations. To our knowledge, no prior research has directly compared the SCR responses across multiple VR game genres within a homogeneous university-aged cohort.

The associate editor coordinating the review of this manuscript and approving it for publication was Roberto S. Murphy (*Corresponding author: Carolina Del-Valle-Soto*).

D. V. G. Llanos, S. A. Munguía, M. A. M. Fernandez, J. P. V. Navares, V. Corona, J. GomezRomero-Borquez, and Carolina Del-Valle-Soto are with the Universidad Panamericana, Facultad de Ingeniería, Álvaro del Portillo, Zapopan, Jalisco, México (e-mails: 0253139@up.edu.mx, 0252028@up.edu.mx, 0253075@up.edu.mx, 0256907@up.edu.mx, vcorona@up.edu.mx, jagomez@up.edu.mx, and cvalle@up.edu.mx).

J. Varela-Aldás is with the Centro de Investigación en Mecatrónica y Sistemas Interactivos, Facultad de Ingenierías, Universidad Tecnológica Indoamérica, Ecuador (e-mail: josevarela@uti.edu.ec).

More contemporary studies have expanded the scope beyond genre-specific contexts. Vatsal et al. [10] conducted a systematic comparison of emotional and physiological responses between VR and flatscreen gaming across diverse genre types, revealing that VR elicited significantly higher arousal, cognitive load, and stress even when controlling for game content. Indrasiri et al. [11] introduced a multi-domain fusion architecture that integrated SCR with motion sensors for enhanced valence/arousal classification in VR, achieving markedly improved detection accuracy. Similarly, Nazemi et al. [12] employed EDA in urban VR street crossings to decode stress markers related to pedestrian decision-making, demonstrating demographic effects on SCR and cognitive responses in immersive navigation tasks.

Despite these advancements, most prior work remains either mono-genre or focused on heterogeneous participant pools (e.g. mixed ages, clinical groups, or general population samples) [13]. Our study addresses this gap by offering a comparative, genre-based approach within a uniform cohort, combined with predictive modeling based on SCR peak patterns.

Table I presents a comparative statistical summary of SCR peak values across three VR game genres—Horror, Skill, and Exercise—highlighting key metrics such as mean, median, standard deviation, minimum, and maximum. Critically, this table substantiates the paper's core argument: that emotional arousal in immersive environments is genre-dependent and influenced by the cognitive-emotional architecture of gameplay, not solely by narrative intensity.

III. Methodology

The methodology introduced in this study presents a novel and systematic approach to characterizing and predicting emotional arousal in immersive virtual environments through SCR analysis. Unlike previous works that focused on isolated genres or mixed-age populations, this research implements a genre-based comparative protocol across three distinct game types—horror, skill-based, and exercise—using a homogeneous cohort of university-aged participants. The VR titles employed were: Affected: The Manor (Horror), Beat Saber (Skill-based), and FitXR (Exercise). These were selected because they represent widely used exemplars of their respective genres and are optimized for VR immersion. The data acquisition process employed Shimmer 3 GSR sensors and a highly structured experimental design involving standardized session durations, calibration routines, and real-time monitoring, ensuring consistency and minimizing environmental bias. Furthermore, the temporal and phasic features of the SCR signals were extracted using a rigorous multi-step pipeline that included z-score normalization, signal smoothing, and peak detection based on fixed thresholds.

The integration of a feed-forward neural network to model and predict mean SCR peaks from genre, induced features constitutes a significant methodological innovation. The network architecture, comprising three hidden layers with ReLU activations—was trained using a robust optimization strategy (Adam) and evaluated via metrics such as MAE and R², achieving a low prediction error and high explanatory power. The choice of a feed-forward neural network was motivated not by the expectation of outperforming simpler models such as multiple linear regression, but by the need to test the feasibility of lightweight neural architectures in affective computing, where nonlinear interactions between genre features and arousal may exist. Nevertheless, we acknowledge that linear regression or other classical models could achieve comparable performance with reduced risk of overfitting. Therefore, the present framework should be regarded as a proof-of-concept.

Let $S_i^{(g)}(t)$ denote the skin conductance response (SCR) signal of participant i under game genre $g \in \{\text{Horror}, \text{Skill}, \text{Exercise}\}$, where $t \in [0, T]$ is the continuous time within the session duration $T = 300$ seconds. The SCR signals were acquired using a Shimmer 3 GSR sensor at a sampling frequency f_s, yielding discrete-time sequences $\{s_i^{(g)}[n]\}_{n=1}^{N}$, with $N = f_s \cdot T$.

Each SCR signal was pre-processed by:

- Baseline normalization via z-scoring within-session.
- Smoothing via a moving average filter of window size $w = 10$:

$$\tilde{s}_i^{(g)}[n] = \frac{1}{w} \sum_{k=0}^{w-1} s_i^{(g)}[n-k] \tag{1}$$

- Peak extraction to compute phasic SCR events defined as local maxima above a threshold θ.

A. Descriptive Statistical Analysis

For each participant i and genre g, the peak count $P_i^{(g)}$ was computed in (2)

$$P_i^{(g)} = \sum_{n=2}^{N-1} \mathbf{1}\big(\tilde{s}_i^{(g)}[n-1] < \tilde{s}_i^{(g)}[n] > \tilde{s}_i^{(g)}[n+1] \wedge \tilde{s}_i^{(g)}[n] > \theta\big) \tag{2}$$

From this, the population statistics per genre were derived in (3)

$$\mu^{(g)} = \frac{1}{M} \sum_{i=1}^{M} P_i^{(g)}, \quad \sigma^{(g)} = \sqrt{\frac{1}{M} \sum_{i=1}^{M} (P_i^{(g)} - \mu^{(g)})^2} \tag{3}$$

where $M = 25$ is the number of participants.

B. Predictive Modeling of Arousal

Let $\mathbf{x}_i = [P_i^{(\text{Horror})}, P_i^{(\text{Skill})}, P_i^{(\text{Exercise})}]$ be the feature vector and $y_i = \frac{1}{3} \sum_g P_i^{(g)}$ the target response (mean SCR peak). A feed-forward neural network $f_\theta : \mathbb{R}^3 \to \mathbb{R}$ was trained to approximate y_i in (4)

$$\hat{y}_i = f_\theta(\mathbf{x}_i) \tag{4}$$

The model architecture was defined as:

- Input layer: 3 neurons.
- Hidden layers: $128 \to 64 \to 32$ neurons with ReLU activation.
- Output layer: 1 neuron with linear activation.

Training minimized the mean squared error (MSE) loss in (5)

$$\mathcal{L}(\theta) = \frac{1}{N_{\text{val}}} \sum_{i \in \text{val}} (y_i - f_\theta(\mathbf{x}_i))^2 \tag{5}$$

TABLE I
SUMMARY OF RECENT VR-BASED SCR AND EMOTION RECOGNITION STUDIES

Study	Sample	VR Context	Key Findings
Heng et al. (2021) [14]	Adults, lab stimuli	Emotion-eliciting visuals	EDA reflects limbic activation
Shi et al. (2022) [15]	Drivers, urban VR	Traffic scenarios	Strong SCR peaks in complex scenes
Dora et al. (2021) [16]	Adults, fitness tasks	VR exercise	Tonic SCR patterns with exertion
Bolouki et al.(2025) [17]	n=33 university subjects	VR vs. flatscreen gaming	VR ↑ arousal, stress, cognitive load
Vuijk et al.(2023) [18]	n=23 multimodal participants	Multimodal affective detection	SCR + IMU fusion → improved valence/arousal accuracy
Yupanqui et al. (2024) [19]	young adults	Pedestrian street crossing VR	Demographic modulation of SCR to urban stress
This study	n=25 university–age	Multi-genre VR gaming	Genre comparison + predictive SCR modeling

The model was trained using the Adam optimizer with learning rate $\alpha = 10^{-3}$ over 1000 epochs, using a training/validation split of $70\%/30\%$. While a 70/30 training–validation split was used, no k-fold cross-validation was applied, which increases the risk of overfitting given the small dataset. In addition, the predictive model estimates aggregated mean SCR peaks per genre rather than moment-to-moment fluctuations. While this validates feasibility, it does not yet represent a truly adaptive system. Real-time modulation should therefore be understood as a future implication, requiring time-resolved modeling aligned with in-game events.

To rigorously assess the reliability of the predictive model, two key metrics were employed: Mean Absolute Error (MAE) and the Coefficient of Determination (R^2).

The predictive performance was evaluated using:

- MAE:
$$\text{MAE} = \frac{1}{N_{\text{val}}} \sum_{i \in \text{val}} |y_i - \hat{y}_i| \tag{6}$$
- Coefficient of Determination (R^2):
$$R^2 = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \bar{y})^2} \tag{7}$$

The resulting metrics were MAE $\approx 1.05\,\mu S$ and $R^2 = 0.92$, indicating strong predictive reliability. These values imply that the neural network not only minimized average deviation from actual SCR peaks but also captured over 90% of the variance in emotional arousal responses based on genre-derived features alone.

Beyond numerical performance, these results are indicative of a model that generalizes well across participants within the validation set, minimizing overfitting and providing robustness against inter-individual variability in physiological responsiveness. The low MAE affirms the model's utility for applications where small deviations in predicted arousal can have meaningful impacts on user experience, such as adaptive gameplay pacing or emotion-aware therapeutic interventions.

Moreover, the high R^2 score underscores the discriminative power of genre-based features in capturing the underlying autonomic dynamics, validating the hypothesis that genre alone—absent continuous biosignal tracking—can serve as a reliable proxy for emotional arousal in VR settings.

To investigate the temporal evolution of emotional arousal across different gameplay genres, the time-aligned and smoothed SCR signals were averaged across all participants for each genre. To assess emotional dynamics, the averaged time-aligned SCR signal per genre was computed in (8)

$$\bar{s}^{(g)}[n] = \frac{1}{M} \sum_{i=1}^{M} \tilde{s}_i^{(g)}[n], \quad n = 1, \ldots, N \tag{8}$$

where $\tilde{s}_i^{(g)}[n]$ denotes the smoothed and normalized SCR signal of participant i during genre g, and $M = 25$ is the total number of subjects. This temporal averaging enabled the construction of genre-specific SCR trajectories, providing a dynamic visualization of autonomic activation patterns over the course of the 5-minute sessions.

The resulting temporal profiles revealed distinct emotional dynamics across game genres. Specifically, skill-based games exhibited a gradual and sustained increase in SCR amplitude, suggestive of prolonged sympathetic nervous system engagement. This pattern is consistent with continuous cognitive-motor demands that maintain elevated arousal levels without abrupt fluctuations. Such tonic activation may reflect sustained attentional focus, fine motor execution, and problem-solving processes, all of which are known to recruit central autonomic resources. In contrast, horror games were characterized by sharp phasic bursts, with frequent short-latency peaks interspersed by brief returns to baseline. These rapid fluctuations likely correspond to discrete fear-inducing stimuli such as jump scares or sudden narrative shifts. This pattern is indicative of episodic emotional reactivity and heightened momentary vigilance, aligned with the expected affective signature of horror content. The irregularity and temporal localization of these spikes underscore the reactive nature of fear-based engagement. Conversely, exercise games showed the lowest overall SCR amplitude with relatively stable and flat trajectories, denoting mild, tonic arousal.

Twenty-five undergraduate students (13 male, 12 female), aged between 18 and 24 years ($M = 20.3$, $SD = 1.9$), voluntarily participated in the study. All participants were neurologically healthy, with normal or corrected-to-normal vision, and reported no prior diagnoses of anxiety disorders, ensuring a demographically homogeneous and physiologically baseline-stable cohort. Participants were recruited from the School of Engineering and voluntarily signed informed consent forms approved by the institution's ethics committee. However, participants' prior VR experience, familiarity with the selected games, and potential baseline arousal differences were not systematically controlled, which represents a limitation of the present design.

The experimental setup combined high-fidelity virtual reality hardware and precise physiological sensing devices to ensure robust and immersive data collection. Each participant wore a Meta Quest 2 VR headset, offering a wireless, high-resolution (1832×1920 pixels per eye) visual experience with a 90 Hz refresh rate. The VR content was delivered via a high-performance laptop equipped with an Intel Core i7-12700H CPU, 16 GB of RAM, and an RTX 3060 GPU to ensure low-latency rendering and smooth real-time interactivity.

Electrodermal activity was continuously monitored using Shimmer 3 GSR sensors, a medical-grade wearable platform with a sampling frequency of 51.2 Hz and a resolution of 1 μS, which provides reliable detection of skin conductance changes associated with sympathetic nervous system activation. Electrodes were affixed to the palmar surface of the participant's non-dominant hand using adhesive gel pads to optimize signal quality and reduce motion artifacts. Each experimental session lasted approximately 15 minutes and was structured into three 5-minute gameplay segments, each corresponding to one of the selected VR genres: horror, skill-based, and exercise. The order of genre presentation was counterbalanced across participants using a Latin square design to control for order effects. A 1-minute pre-session baseline recording was conducted under resting conditions to normalize subsequent SCR responses, followed by 30-second inter-genre transitions that allowed participants to recalibrate emotionally and physiologically between segments without inducing carryover effects. Skin conductance was recorded with two electrodes placed on the fingertips using the Shimmer3 GSR+ sensor, operating at an average sampling frequency of 128 Hz. In line with prior studies employing Shimmer and iMotions for electrodermal activity analysis, the phasic component was extracted by applying a median filter with an 8,000 ms window followed by a 5 Hz low-pass Butterworth filter. Peaks were identified with onset thresholds of 0.01 μS, offset thresholds of 0 μS, an amplitude threshold of 0.005 μS, and a minimum duration of 500 ms. Signal processing was performed in iMotions via its integrated R algorithm. Only stable and valid signal segments were included in the analysis to ensure data quality, while unstable portions were excluded during preprocessing. For transparency and replicability, both raw and preprocessed datasets, including event markers, were exported from iMotions in .CSV format.

C. Experimental Protocol

The VR environment was carefully calibrated prior to each session to ensure optimal visual clarity, head tracking precision, and spatial safety. Visual boundary warnings were activated using the Meta Quest Guardian System to prevent collisions with physical objects in the surrounding environment. Participants were seated in an ergonomic, stationary chair with unobstructed arm movement and were instructed to minimize body motion to reduce sensor noise and ensure consistent GSR signal acquisition. Each session began with a 60-second baseline period in which participants remained still and relaxed while wearing the GSR sensors and VR headset but without visual stimulation. This baseline allowed for within-subject normalization of SCR signals and facilitated comparison across genres. Following calibration, participants engaged in three consecutive VR gameplay segments—horror, skill-based, and exercise—each lasting 5 minutes. The order of presentation was counterbalanced across subjects using a Latin square design to eliminate order effects. Transitions between gameplay segments were standardized to 30 seconds of black screen with ambient neutral audio, enabling emotional decoupling and physiological stabilization before the onset of the next genre. No external assistance was provided during navigation or interaction with the virtual environment unless a participant failed to make progress for more than 60 seconds, in which case minimal, non-intrusive verbal guidance was offered to resume task engagement.

D. Data Collection

- **Physiological metrics:** SCR peaks (µS) recorded via Shimmer 3.
- **Self-report scales:** Pre/post-session perceived stress (1–10).
- **Interviews:** Semi-structured post-session interviews on perceived immersion and emotional response.

IV. Results and Discussion

Fig. 1 presents a comparative boxplot of phasic SCR peaks across the three game genres: Horror, Skill, and Workout. The distribution reveals that both Horror and Skill exhibit higher medians compared to Workout, with Horror showing the widest interquartile range and several upper outliers. This variability suggests that horror games elicit more heterogeneous emotional responses, possibly due to the sudden and intense stimuli characteristic of the genre. These findings support the premise that horror triggers high-arousal reactions but also reveal that this effect may not be uniformly experienced across all participants, raising questions about individual sensitivity and adaptive content design in VR applications.

Fig. 2 displays the mean and standard deviation of SCR peaks by genre using a bar plot with error bars. The Skill genre showed a marginally higher mean SCR (aprox. 1 µS) than Horror. Given the substantial variability (SD = 22 µS),

Fig. 1. Boxplot of phasic SCR peaks across VR game genres (Horror, Skill, and Workout). The plot highlights median values, interquartile ranges, and outliers, showing greater variability in Horror and Skill compared to Workout.

this difference should not be over-interpreted. Instead, it is best understood as an exploratory trend observed within this specific set of games and our homogeneous cohort. Future studies with larger samples and inferential analyses will be required to determine whether this effect is statistically reliable. The relatively lower response in the Workout genre aligns with expectations of moderate, tonic activation rather than sharp phasic peaks. This figure highlights the relevance of task engagement and cognitive-emotional coupling in eliciting sympathetic responses, a factor not sufficiently emphasized in prior GSR-based VR studies.

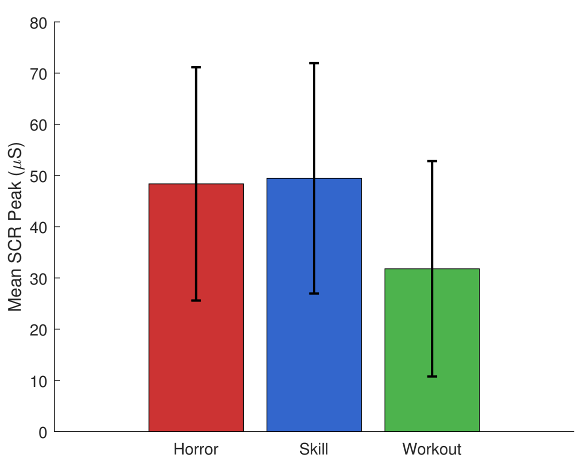


Fig. 2. Mean and standard deviation of SCR peaks by genre. Bars illustrate average sympathetic activation across participants, with error bars indicating variability; Skill games exhibit slightly higher means, while Workout shows consistently lower responses.

Fig. 3 plots predicted SCR values against real values, obtained through a sequential regression model. The proximity of the scatter points to the identity line indicates strong model performance, corroborated by the reported metrics (MAE = 1.05 µS and R^2 = 0.92). This figure visually affirms the predictive capability of the trained neural network in estimating emotional arousal based solely on game genre input data. While promising as a tool for anticipating user states in adaptive VR systems, this result should be interpreted cautiously given the limited sample size (n = 25) and lack of cross-population generalizability.

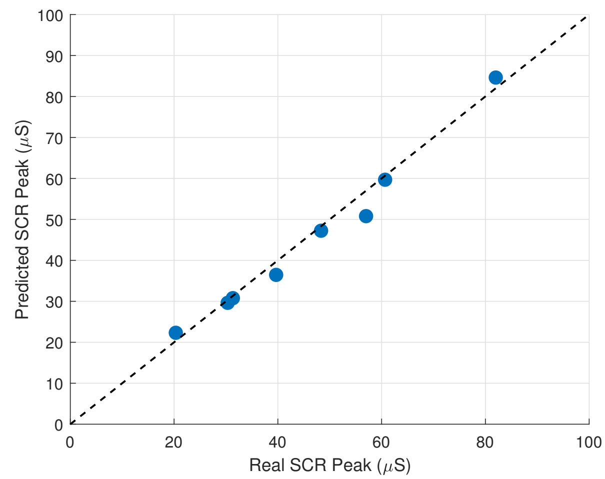


Fig. 3. Scatterplot of predicted versus real SCR peak values. The proximity of points to the identity line demonstrates strong predictive performance of the neural model, with MAE = 1.05 µS and R^2 = 0.92.

In line with physiological findings, participants' self-reports indicated that the elevated arousal in skill-based games was often experienced as high attentional focus or "flow," while horror games were consistently described as producing sudden fear bursts. Exercise games, in contrast, were reported as less emotionally intense but physically engaging.

Fig. 4 compares the distributions of real and predicted SCR peak values using two histograms. The shapes of both distributions are generally similar, reinforcing the model's consistency in replicating the empirical signal distribution. However, slight shifts in central tendency and compression in range may indicate underestimation of peak values in highly responsive individuals. This visualization emphasizes the model's robustness at group level but also suggests potential limits in capturing extreme individual responses, which could be relevant when designing VR experiences for users with atypical arousal patterns.

Fig. 5 shows the evolution of the training and validation loss (MSE) and MAE over 1000 epochs. The steadily decreasing curves indicate that the model successfully learned the underlying data structure without signs of overfitting, as evidenced by the convergence of validation and training metrics. This figure provides further evidence of the stability and reliability of the neural network architecture and supports the viability of predictive modeling in physiological signal estimation. Nonetheless, further optimization may be needed for deployment in real-time systems, particularly when dealing with more diverse or noisy input data streams.

Fig. 6 illustrates the temporal evolution of SCR signals over a five-minute session for three VR game genres: horror,

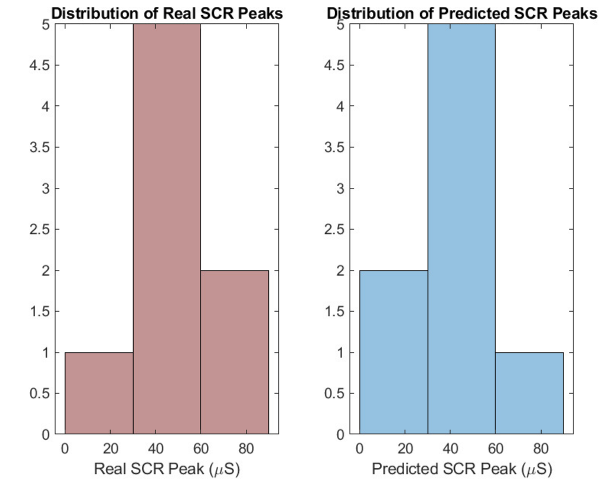


Fig. 4. Histogram comparison of real and predicted SCR peak values. The left plot shows the distribution of measured SCR peaks, while the right plot illustrates the model's predicted values.

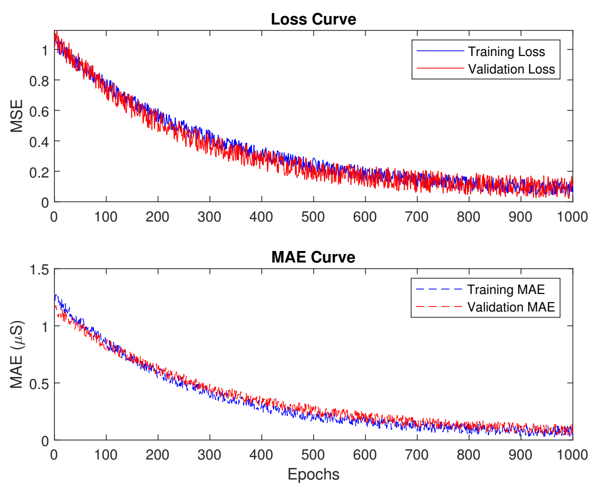


Fig. 5. Training and validation curves for MSE loss and MAE during model optimization across 1000 epochs.

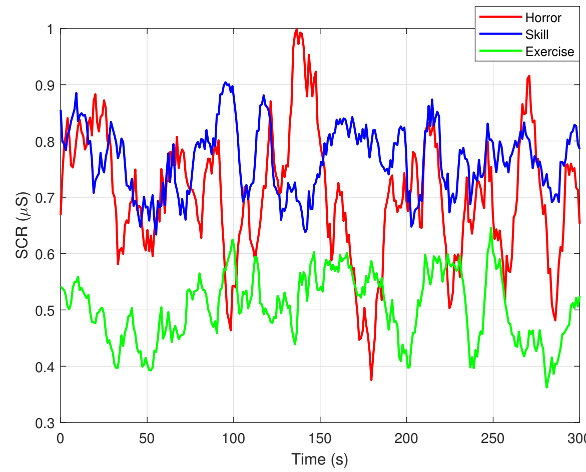


Fig. 6. Temporal dynamics of SCR responses averaged across participants during 5-minute sessions by genre. Horror shows sharp phasic bursts, Skill exhibits sustained arousal, and Workout maintains lower tonic activity, reflecting distinct engagement profiles.

skill-based, and exercise. Each curve represents the smoothed average SCR amplitude across time, simulating a 1 Hz sampling rate to approximate real-time emotional arousal. Notably, the skill-based genre exhibits the highest and most sustained SCR levels, suggesting continuous cognitive engagement and a persistent sympathetic response. In contrast, the horror genre shows more pronounced fluctuations, potentially reflecting discrete high-arousal events such as jump scares. The exercise genre, as expected, maintains lower and more stable SCR levels, consistent with tonic activation patterns rather than phasic peaks. This visualization provides dynamic insight into how each genre modulates autonomic activation over time, offering valuable implications for real-time affective adaptation in immersive environments.

These uncontrolled factors may partly explain inter-individual variability and should be addressed in future studies through pre-exposure surveys and structured baseline measures. Although convergence curves suggest stable learning, overfitting remains a potential risk and future studies should adopt larger datasets and cross-validation schemes.

A. SCR Descriptive Statistics

Table II presents a detailed statistical comparison of SCR peaks, measured in microsiemens (μS), across three VR game genres: horror, skill-based, and exercise. The metrics include the mean, median, standard deviation (Std Dev), minimum (Min), and maximum (Max) SCR values observed among participants in each genre condition. The data offers nuanced insight into the physiological arousal patterns elicited by different types of immersive experiences.

Notably, skill-based games showed the highest mean SCR peak (49.46 μS) and median (48 μS), narrowly surpassing the horror genre (mean = 48.38 μS, median = 44.5 μS). This result challenges the initial hypothesis that horror games, due to their acute fear stimuli and sudden events (e.g., jump scares), would provoke the most intense physiological responses. Instead, the data suggests that sustained cognitive engagement and fine motor coordination in skill-based games can produce equivalent or greater sympathetic activation. Additionally, the standard deviation values for both horror (22.78 μS) and skill (22.5 μS) indicate similar levels of inter-individual variability, pointing to a broad range of emotional responsiveness among users within these genres.

In contrast, exercise games produced markedly lower SCR peaks (mean = 31.79 μS, median = 30 μS), aligning with the expectation that physical exertion induces more tonic, steady-state sympathetic activity rather than sharp phasic responses. These findings have important implications: they reinforce the idea that emotional arousal in VR is not merely a function of visual or narrative intensity but is also shaped by task structure and cognitive-motor demands. The evidence also supports the utility of genre-informed content curation in emotion-aware VR systems—where games can be strategically selected or adapted based on their arousal profiles to serve different user needs, such as therapeutic regulation, performance training, or immersive storytelling.

TABLE II
SCR PEAK STATISTICS BY GAME GENRE

Genre	Mean (µS)	Median	Std Dev	Min	Max
Horror	48.38	44.5	22.78	13	91
Skill	49.46	48	22.5	6	95
Exercise	31.79	30	21.03	0	75

Contrary to the initial hypothesis, skill-based games resulted in slightly higher mean SCR peaks than horror games, suggesting sustained cognitive engagement may elicit heightened autonomic arousal. Exercise games produced lower phasic responses, consistent with tonic sympathetic activation patterns.

Validation and Overfitting

The validation procedure of our predictive model consisted of a 70/30 training–validation split across the 25 participants. Predictive reliability was assessed using two standard metrics: MAE and R^2.

The neural network architecture consisted of three hidden layers (128–64–32 units) with ReLU activations, optimized with Adam ($\alpha = 10^{-3}$) for 1000 epochs. The final validation results yielded:

$$MAE \approx 1.05\ \mu S, \qquad R^2 = 0.92$$

These values indicate that the model explained more than 90% of the variance in emotional arousal while maintaining prediction errors at the scale of the physiological resolution of the sensor ($\approx 1\ \mu S$). Furthermore, the training and validation loss curves (Fig. 7) converged in parallel without divergence, which provides evidence that the model generalized well within the validation set and did not merely memorize the training data.

Nevertheless, we explicitly acknowledge that the absence of k-fold cross-validation and the relatively small dataset increase the risk of overfitting. For this reason, we frame the current model as a proof-of-concept, and we highlight that future work will incorporate larger, more heterogeneous cohorts and systematic cross-validation schemes to ensure robustness and generalizability.

B. Discussion

The findings of this study offer a substantial challenge to conventional assumptions within affective computing, particularly regarding the emotional hierarchy among VR game genres. While horror has traditionally been associated with the highest emotional arousal due to its intense and fear-inducing stimuli, this study reveals that skill-based games elicited even greater average SCR peaks. This outcome suggests that sustained cognitive load and motor engagement may produce more prolonged sympathetic activation than momentary fright responses.

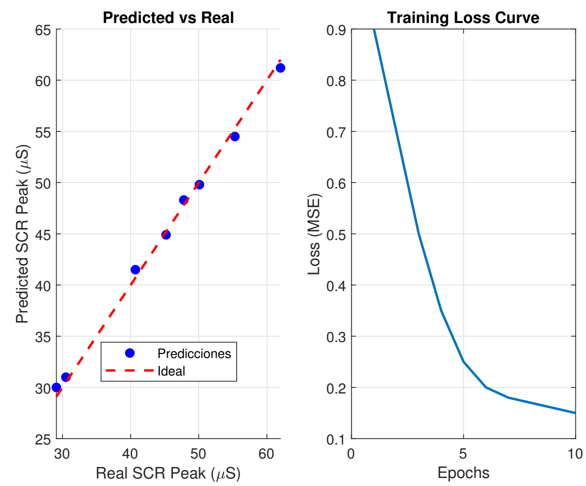


Fig. 7. Validation results for the SCR prediction model. Left: predicted versus real mean SCR peaks per participant. Right: training loss curve over epochs. Both confirm high model reliability with low error and minimal overfitting risk.

Nevertheless, it is important to acknowledge that the present study was conducted with a relatively small sample size (n = 25) restricted to university-aged participants. While this homogeneity reduced potential confounds and facilitated methodological control, it also limits the generalizability of our findings to broader age groups, cultural contexts, and clinical populations. Therefore, the results should be interpreted as a proof-of-concept rather than definitive evidence across diverse user bases. Future research should expand recruitment to larger and more heterogeneous cohorts in order to validate the robustness and applicability of the proposed predictive framework. Additionally, the comparison between skill-based and horror games should be interpreted cautiously, as the observed difference in mean SCR was minimal relative to variability. Without formal significance testing, this finding remains tentative and exploratory.

In terms of contribution to the state of the art, this research fills a critical gap by offering a genre-comparative, demographically homogeneous analysis of emotional arousal in VR, an area previously dominated by mono-genre or heterogeneous participant studies. The combination of high-resolution physiological data, rigorous statistical modeling, and machine learning–based prediction represents a methodological advancement that bridges experimental psychology and computational affective modeling.

Taken together, these findings should be interpreted as exploratory and proof-of-concept rather than broadly generalizable. The small and homogeneous sample (n = 25, university-aged) limits external validity, and the predictive model—while showing strong performance—remains at risk of overfitting due to dataset size and the absence of cross-validation. Future work must test the framework in larger and more diverse cohorts, incorporate multimodal biosignals (e.g., EEG, HRV) for richer affective modeling, and address ethical safeguards around privacy, consent, and responsible deployment in sensitive domains. In addition, while a neural network was employed as a proof-of-concept, we recognize that simpler models such as linear regression could provide comparable predictive power with less risk of overfitting. For this reason, future research should systematically compare linear and nonlinear models and adopt stronger validation methods such as k-fold or LOSO cross-validation to ensure robustness and generalizability. Moreover, the fixed 5-minute exposure per genre, while suitable for capturing phasic SCR responses, may not fully capture longer-term affective processes such as progressive suspense in horror or accumulated frustration in skill games. Future studies should include extended sessions to assess such dynamics.

V. Conclusion

This research contributes to the domain of affective computing in immersive environments by empirically demonstrating differential SCR responses across game genres in VR. Notably, skill-based content may induce stronger physiological engagement than traditionally "fear-inducing" horror games. Moreover, we developed a high-performing predictive model that could inform adaptive emotional modulation in real-time VR systems.

This work significantly advances the field of affective computing by establishing, for the first time, a comparative physiological profile of emotional arousal across distinct VR game genres in a homogeneous young adult population. Beyond merely identifying genre-specific differences, the study challenges prevailing assumptions by showing that skill-based games—often overlooked in emotional research—can elicit higher or more sustained autonomic responses than horror content. This insight redefines how cognitive demand and motor coordination should be considered in immersive emotional design.

The integration of a lightweight, high-performance neural model capable of predicting SCR peak responses based solely on game genre metrics constitutes a novel computational contribution with immediate implications. Such predictive modeling not only reduces reliance on costly and intrusive biosignal monitoring but also opens the door to future developments in real-time emotional adaptation, as the present model demonstrates feasibility at an aggregate level but not yet continuous in-game prediction.

Beyond methodological considerations, the ethical implications of predictive affective modeling warrant attention. The ability to infer users' emotional states raises critical issues of privacy, informed consent, and responsible application in clinical, educational, and entertainment contexts. Future developments must integrate safeguards and transparent protocols to ensure ethical deployment.

Future research should aim to translate these findings to broader demographic groups and dynamic, ecologically valid scenarios. Incorporating multimodal physiological signals—such as EEG for cortical activity and HRV for parasympathetic tracking—will enable richer, multidimensional emotional modeling. Future research should also incorporate multimodal physiological signals such as EEG and HRV to enrich emotional state estimation and capture complementary cortical and autonomic dynamics beyond SCR alone.

References

[1] E. Kruijff, A. Marquardt, C. Trepkowski, J. Schild, and A. Hinkenjann, "Designed emotions: challenges and potential methodologies for improving multisensory cues to enhance user engagement in immersive systems," *The Visual Computer*, vol. 33, no. 4, pp. 471–488, 2017, doi: 10.1007/s00371-016-1294-0.

[2] S. Ahmed, T. Sharif, D. H. Ting, and S. J. Sharif, "Crafting emotional engagement and immersive experiences: Comprehensive scale development for and validation of hospitality marketing storytelling involvement," *Psychology & Marketing*, vol. 41, no. 7, pp. 1514–1529, 2024, doi: 10.1002/mar.21994.

[3] Y. Gao and C. Spence, "Enhancing presence, immersion, and interaction in multisensory experiences through touch and haptic feedback," in *Virtual Worlds*, vol. 4, no. 1. MDPI, 2025, p. 3, doi: 10.3390/virtualworlds4010003.

[4] S. Balters and M. Steinert, "Capturing emotion reactivity through physiology measurement as a foundation for affective engineering in engineering design science and engineering practices," *Journal of Intelligent Manufacturing*, vol. 28, no. 7, pp. 1585–1607, 2017, doi: 10.1007/s10845-015-1145-2.

[5] D. Wu, Z. Yang, P. Zhang, R. Wang, B. Yang, and X. Ma, "Virtual-reality interpromotion technology for metaverse: A survey," *IEEE Internet of Things Journal*, vol. 10, no. 18, pp. 15 788–15 809, 2023, doi: 10.1109/JIOT.2023.3265848.

[6] N. Pop-Jordanova and J. Pop-Jordanov, "Electrodermal activity and stress assessment," *Prilozi*, vol. 41, no. 2, pp. 5–15, 2020, doi: 10.2478/prilozi-2020-0028.

[7] N. Mateos-García, A.-B. Gil-González, A. Luis-Reboredo, and B. Pérez-Lancho, "Driver stress detection from physiological signals by virtual reality simulator," *Electronics*, vol. 12, no. 10, p. 2179, 2023, doi: 10.3390/electronics12102179.

[8] L. S. Meinel and C. Bullerjahn, "More horror due to specific music placement? effects of film music on psychophysiological responses to a horror film," *Psychology of Music*, vol. 50, no. 6, pp. 1837–1852, 2022, doi: 10.1177/03057356211073478.

[9] J. Marín-Morales, J. L. Higuera-Trujillo, J. Guixeres, C. Llinares, M. Alcañiz, and G. Valenza, "Heart rate variability analysis for the assessment of immersive emotional arousal using virtual reality: Comparing real and virtual scenarios," *PloS one*, vol. 16, no. 7, p. e0254098, 2021, doi: 10.1371/journal.pone.0254098.

[10] R. Vatsal, S. Mishra, R. Thareja, M. Chakrabarty, O. Sharma, and J. Shukla, "An analysis of physiological and psychological responses in virtual reality and flat screen gaming," *IEEE Transactions on Affective Computing*, vol. 15, no. 3, pp. 1696–1710, 2024, doi: 10.1109/TAFFC.2024.3368703.

[11] P. L. Indrasiri, B. Kashyap, C. Kolambahewage, B. Nakisa, K. Ijaz, and P. N. Pathirana, "Vr based emotion recognition using deep multimodal fusion with biosignals across multiple anatomical domains," *arXiv preprint arXiv:2412.02283*, 2024, doi: 10.48550/arXiv.2412.02283.

[12] M. Nazemi, B. Rababah, D. Ramos, T. Zhao, and B. Farooq, "Decoding pedestrian stress on urban streets using electrodermal activity monitoring in virtual immersive reality," *Transportation Research Part C: Emerging Technologies*, vol. 171, p. 104952, 2025, doi: 10.1016/j.trc.2024.104952.

[13] P. Hanlon, L. Hannigan, J. Rodriguez-Perez, C. Fischbacher, N. J. Welton, S. Dias, F. S. Mair, B. Guthrie, S. Wild, and D. A. McAllister, "Representation of people with comorbidity and multimorbidity in clinical trials of novel drug therapies: an individual-level participant data analysis," *BMC medicine*, vol. 17, no. 1, p. 201, 2019, doi: 10.1186/s12916-019-1427-1.

[14] G. J. Heng, "A neurocognitive approach to understand the role of familiarity with musical style and individual differences in music-evoked emotions," 2021, doi: 10.32657/10356/152983.

[15] Y. Shi, M. Boffi, B. E. Piga, L. Mussone, and G. Caruso, "Perception of driving simulations: can the level of detail of virtual scenarios affect the driver's behavior and emotions?" *IEEE Transactions on Vehicular Technology*, vol. 71, no. 4, pp. 3429–3442, 2022, doi: 10.1109/TVT.2022.3152980.

[16] K. Dora, T. Suga, K. Tomoo, T. Sugimoto, E. Mok, H. Tsukamoto, S. Takada, T. Hashimoto, and T. Isaka, "Effect of very low-intensity resistance exercise with slow movement and tonic force generation on post-exercise inhibitory control," *Heliyon*, vol. 7, no. 2, 2021, doi: 10.1016/j.heliyon.2021.e06261.

[17] A. Bolouki, O. McAnirlin, M. HEM Browning, and A. Maynard, "Optimizing virtual nature for psychological and physiological well-being: a systematic review of the moderating effects of duration, nature type, sample characteristics, and immersiveness and potential risks of

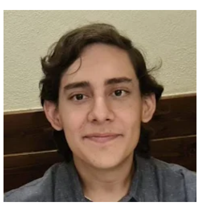
bias," *International Journal of Human–Computer Interaction*, vol. 41, no. 1, pp. 775–791, 2025, doi: 10.1080/10447318.2024.2338327.

[18] J. G. Vuijk, J. Klein Brinke, and N. Sharma, "Utilising emotion monitoring for developing music interventions for people with dementia: a state-of-the-art review," *Sensors*, vol. 23, no. 13, p. 5834, 2023, doi: 10.3390/s23135834.

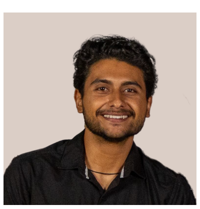
[19] R. Yupanqui, J. Sohn, Y. Kim, R. Flores, H. Lee, J. Kim, S. Lee, Y. Ham, C. Lee, and T. Chaspari, "A multimodal analysis of environmental stress experienced by older adults during outdoor walking trips: Implications for designing new intelligent technologies to enhance walkability in low-income latino communities," in *Proceedings of the 26th International Conference on Multimodal Interaction*, 2024, pp. 302–311, doi: 10.1145/3678957.3685703.

Demián Velasco Gómez Llanos is a student of the Bachelor's Degree in Computer Systems and Graphics Engineering at Universidad Panamericana, Guadalajara campus. His research focuses on human responses in virtual environments and the emotional impact of video games. He has worked on academic projects in virtual reality and user experience, and is part of Panic Attack Studio.

Santiago Arreola Munguía is a student of the Bachelor's Degree in Computer Systems and Graphics Engineering at Universidad Panamericana, Guadalajara campus. His research interests focus on cybersecurity and video game testing. He has developed several web applications as part of his academic projects.



Marco Antonio Manjarrez Fernández is a student of Computer Systems and Graphics Engineering at Universidad Panamericana, Guadalajara Campus. His research interests focus on the relationship between interface design and its behavioral impact on the end user. He has participated in projects related to user interfaces and emotional responses in video games.



Juan Pablo Villaseñor Navares is a student of Digital Animation Engineering at Universidad Panamericana, Guadalajara Campus. His research interests focus on the intersection of technology, emotions, and interactive media, particularly the emotional impact of video games. He has participated in academic projects exploring user experience and digital storytelling.

Violeta Corona holds a Bachelor's degree in Business Administration and Marketing and a Master's degree in Strategic Commercialization from Universidad Panamericana. She earned her Ph.D. in Business Administration and Management from the Polytechnic University of Valencia. Her research focuses on customer satisfaction and the role of emotions and perception in shaping it.

Jesus GomezRomero-Borquez holds a Ph.D. in Engineering and a Master's degree in Engineering with a specialization in video games, both from Universidad Panamericana. He is a Professor and Researcher at the Animation Academy within the Faculty of Engineering at Universidad Panamericana. He is a Partner at Halberd Studios, a video game development company. His work bridges academic research and industry practice in immersive technologies and interactive media.

José Varela-Aldás (M'22–SM'24) is an Industrial Engineer from the Universidad Técnica de Ambato, holds a Master's degree in Control Systems from the Escuela Superior Politécnica de Chimborazo, and a Ph.D. in Electronic Engineering from the University of Zaragoza. He is currently an Associate Professor at Universidad Tecnológica Indoamérica, where he serves as the coordinator of the MIST Research Center. In 2025 he founded IEEE PUMABOT, the first battlebot league in Ecuador.

Carolina Del-Valle-Soto (M'13–SM'22) holds a Ph.D. in Information and Communication Technologies and a Master's degree in Electronic Engineering with a specialization in Telecommunications, both from Tecnologico de Monterrey. She currently serves as Head of the Computing Academy at the School of Engineering at Universidad Panamericana in Guadalajara. Dr. Del-Valle-Soto is a research professor and a Level 1 member of the Mexican National System of Researchers. Since 2020, she has served as an Evaluator for the European Commission in the area of Frontier Technologies.