VR Stress Response Trainer

Project Number 26 1 D 18

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Abstract

The increasing number of emergency situations and extreme stress events, particularly in the context of multi stage incidents such as the events of 7/10, together with the growing awareness of the need for effective cognitive functioning under stress, highlight the critical need for developing training tools that can enhance individuals, self regulation abilities and expand the available knowledge on physiological responses to stress.

At present, traditional training methods do not provide personalized stress monitoring nor data driven feedback, making it challenging for many individuals to improve their performance under pressure. With the advancement of Virtual Reality (VR) technologies, it is now possible to create immersive environments capable of replicating realistic, stress inducing scenarios while maintaining full psychological safety. These technologies allow us to observe user behavior under controlled pressure conditions and analyze changes in physiological indicators such as heart rate and HRV, both considered key markers of stress regulation capacity.

This project focuses on the user's physiological self regulation ability, as reflected through variations in heart rate and HRV during exposure to VR simulations that mimic emergency situations. The simulations integrate critical tasks inspired by real events, such as gathering essential supplies during an alarm and providing basic first aid in a kibbutz courtyard.

The system features an automated data pipeline where physiological metrics are streamed from a smartwatch to a dedicated Android application and transmits the data to the Unity environment for real time monitoring and subsequent retrospective analysis, based on the physiological changes and performance quality, the system generates a personalized stress profile, presents the user with clear and accessible feedback regarding their experienced stress level, and provides recommendations for improving regulation skills and resilience in future scenarios. This feedback is integrated into an interactive VR interface, allowing users to track their progress across multiple simulations.

1. Introduction

In recent decades, emergency events, particularly acts of terrorism and warfare, have led to a significant increase in civilians' exposure to extreme stress situations. Events such as the October 7 attack highlighted the existing gap between the need for immediate and effective performance in life threatening situations and the lack of practical tools capable of training civilians to cope with emotional and physiological load in real time.

Managing an emergency requires a combination of cognition, composure, emotional regulation, decision making under pressure, and the ability to perform tasks while exposed to threatening stimuli. While security and medical personnel receive specialized training, the majority of the population does not have access to such rigorous preparation.

Research in physiological psychology indicates that measures such as heart rate, heart rate variability (HRV), and blood pressure serve as clear indicators of the ability to cope with stress and maintain optimal performance under load. However, traditional training programs rarely include physiological monitoring or personalized feedback, and therefore do not allow for quantitative assessment of an individual's stress response or the conscious development of self regulation skills.

Significant advancements in virtual reality (VR) in recent years are transforming the way trainees can be prepared for extreme situations. VR headsets can create immersive and realistic environments that combine audio, movement, interaction, and spatial tasks, while maintaining complete psychological and emotional safety. These technologies allow users to be exposed to scenarios simulating real life situations, with full control over stimulus intensity, task type, and difficulty level. These features make VR an ideal tool for behavioral training under stress.

This project proposes an innovative VR simulator for stress regulation training in emergency situations, utilizing an automated biofeedback integration system. Unlike traditional approaches that rely on subjective assessments, the proposed system implements a continuous wireless data pipeline. Physiological metrics are captured by a smartwatch and transmitted via Bluetooth to a dedicated Android gateway application, where the data are processed and relayed over Wi-Fi to the Unity-based VR environment. This architecture enables non-intrusive, near real-time monitoring of the user's autonomic nervous system without interrupting the training flow or restricting user mobility.

2. Related Work
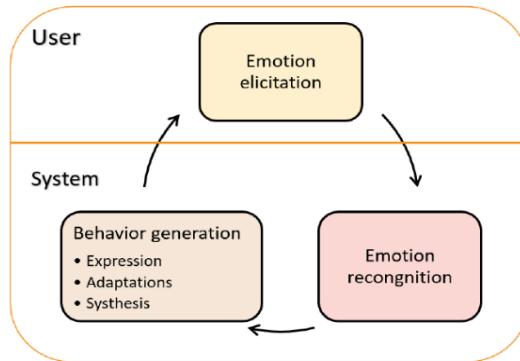
Research on stress regulation training has increasingly focused on the integration of Virtual Reality (VR) with biofeedback technologies. VR provides immersive, controllable environments where users can be exposed to realistic stress inducing scenarios in a safe and gradual manner, while biofeedback enables the observation and interpretation of physiological responses, allowing users to better understand and improve their self regulation capabilities [5].

Several studies have demonstrated the effectiveness of VR based biofeedback for improving Heart Rate Variability (HRV) and enhancing resilience to stress [7]. VR supported HRV biofeedback significantly reduces psychological stress and increases cardiac coherence, with immersive head mounted display setups outperforming desktop based environments in both user engagement and physiological outcomes [1]. Similarly, slow paced breathing exercises performed within immersive VR environments led to increased relaxation self efficacy, reduced perceived stress, and improved attentional focus [2].

Interventions combining VR with HR or HRV biofeedback consistently produced positive effects, including reductions in anxiety, improved motivation, and stronger user immersion [3,8]. In addition, randomized controlled trials have shown that VR relaxation experiences significantly decrease subjective stress in individuals with high baseline stress levels across various conditions, underscoring VR's potential as a personalized stress management tool [4].

Unlike traditional passive elicitation methods, where users are mere observers of emotional stimuli (e.g., viewing image), VR acts as an active mechanism for emotion induction [9]. Active methods are superior because they foster self relevance, the user is a participant, not an observer. This participation leads to more realistic and intense emotional experiences [9].

Recent reviews emphasize the emergence of Affective Computing. A core concept is the Affective Loop, which consists of emotional elicitation, recognition, and behavior generation [9].

Affective Loop theory

Our project utilizes this loop by eliciting stress through VR tasks and recognizing it via automated HRV monitoring.

Studies have shown that VR games and interactive tasks are particularly effective at inducing discrete emotions such as fear, joy, and anger, as well as dimensional states like valence and arousal [9]. The success of VR in these domains is attributed to its ability to produce a strong sense of presence and isolation from external stimuli, allowing for synchronous physiological changes throughout the body [9].

VR has gained traction as a platform for emergency preparedness training and high pressure task simulation. Systematic reviews on VR based stress management and emergency response simulations indicate that VR environments can effectively replicate complex, multi stage scenarios such as alarms, evacuation procedures, or first aid interventions, while maintaining complete psychological safety [10]. Such simulations allow to measure user performance, behavioral decision making, and physiological stress responses under controlled yet realistic conditions.

From an implementation perspective, modern VR simulators are commonly developed using game engines such as Unity, which provides robust support for 3D world building, physics based interactions, and cross platform VR deployment. Unity's XR Interaction Toolkit and the OpenXR framework enable natural movement, object manipulation, and spatial interaction, allowing developers to create training simulations that closely resemble real world physical behavior [6]. Studies suggest that high interaction fidelity, such as accurate grab mechanics, spatial audio cues, and realistic locomotion, enhances user presence and emotional engagement, which are crucial when inducing stress in training environments [11].

The hardware used in VR simulations also plays a significant role in shaping user experience. Head mounted displays (HMDs) deliver high resolution stereoscopic visuals, spatial audio,enabling users to navigate virtual spaces naturally and interact with objects in a way that mirrors real world emergency tasks. Research demonstrates that HMD based VR yields significantly higher presence and physiological arousal compared to flat screen simulations, making it especially suitable for stress inducing tasks that require situational awareness, rapid decision making, and cognitive load management [11].

Another essential technological component is the use of smartwatches and wearable sensors for physiological monitoring [12]. Modern smartwatches rely on photoplethysmography (PPG) sensors to measure heart rate and HRV, and numerous studies support their reliability in detecting stress related changes in autonomic nervous system activity [7]. Although clinical grade equipment provides greater precision, consumer grade wearables are widely accepted in behavioral research due to their accessibility, ecological validity, and ability to capture physiological data in naturalistic contexts [8].

Overall, combining VR with physiological stress assessment creates a powerful training environment capable of increasing resilience, enhancing self regulation skills, and enabling safe exposure to challenging scenarios. The proposed project builds directly on these findings by applying VR assisted stress training methods to multi stage emergency simulations inspired by real world events, while employing retrospective HR/HRV analysis to generate personalized stress profiles and actionable feedback for users.

3. Background

This section is dedicated for description of terms and tools used in this book.

3.1 Stress and Heart Rate Variability (HRV)

Stress is a complex physiological response to perceived threats, significantly impacting cognitive functioning and decision making capabilities. A key objective marker for the autonomic nervous system's state is Heart Rate Variability (HRV) the variation in time intervals between consecutive heartbeats [7]. Research indicates that HRV serves as a clear indicator of the balance between the sympathetic (fight or flight) and parasympathetic (rest and digest) nervous systems [7]. High HRV is associated with better emotional regulation, cardiovascular health, and resilience to stressors, whereas low HRV often indicates acute stress, fatigue, or over stimulation [7, 8]. In training environments, monitoring HRV allows for a quantitative assessment of a trainee's physiological response to pressure [7].

3.2 How to Improve HRV & Manage Stress

Improving HRV is directly linked to enhanced stress management and emotional resilience. According to [8], maintaining a healthy balance between different lifestyle factors is crucial.

- Regulated Breathing: Techniques such as slow paced, rhythmic breathing can increase parasympathetic activity and boost HRV [2, 8].
- Self Regulation Training: Exposure to controlled stress environments, combined with immediate physiological feedback, allows individuals to consciously develop coping strategies and improve their physiological "recovery" speed after a stress event [1, 8].

3.3 Virtual Reality (VR) as an Active Stimulant

VR is a computer aided design providing an interactable 3D environment [9]. It is considered an "empathy machine" because it allows for Active Elicitation. Unlike passive videos, VR allows users to interact with avatars and environments, triggering more natural feelings [9]. This is crucial for our project, as the user must perform tasks (first aid, equipment gathering) under pressure, creating a motivational tendency to succeed that directly impacts physiological markers.

3.4 Virtual Reality (VR) and Emergency Training

Virtual Reality technology creates a simulated environment through the use of high resolution stereoscopic visuals and spatial audio, providing a deep sense of "presence" [5]. In the context of emergency preparedness, VR offers several unique advantages:

- Ecological Validity: It allows for the replication of high risk scenarios (e.g., sirens, casualties) that would be impossible or unsafe to recreate in real life [5].
- Controlled Exposure: Instructors can adjust the intensity of stressors, such as time pressure or environmental noise, to match the trainee's level [5].
- Safe Failure: Users can experience the consequences of their decisions under pressure without real world risks, facilitating better retention of life saving protocols.

3.5 Unity Engine

Unity is a cross platform game engine widely utilized for professional VR simulations and interactive 3D environments [6]. It serves as the primary development platform for this project due to several key features:

- XR Interaction Toolkit: A high level library that simplifies the implementation of VR locomotion and object manipulation [6].
- Cross Platform Integration: Unity allows for seamless communication between various hardware components, including PC, VR headsets, and external sensors [6].
- Scripting and Logic: Using C#, Unity enables the creation of complex triggers for emergency tasks and real time processing of incoming data.
- Audio: Unity includes a comprehensive audio system that allows developers to add sound effects and music.

3.6 Smartwatch and Android Integration

The modern wearable market has popularized Photoplethysmography (PPG) sensors, which are now standard in most smartwatches for tracking HR and HRV. While these devices are primarily consumer grade, their reliability in detecting autonomic shifts is well supported [1]. Our system utilizes an automated data pipeline to bridge the hardware gap:

- Android Gateway: A dedicated mobile application acts as a central hub, fetching physiological metrics from the watch via Bluetooth.
- WIFI Communication: To ensure a stable, low latency connection required for simulation, the Android device transmits the data via a WIFI to the Unity engine. This setup allows the system to correlate specific virtual stress events with physiological spikes in near real time.

3.7 Stress Induction Methods in VR

Designing a training environment that effectively elicits a physiological stress response is a significant challenge.

- Environmental Triggers: The use of sirens, alarms, and low visibility conditions (e.g., smoke or darkness) is a common method to increase cognitive load.
- Time Pressure: Implementing countdowns or urgent task requirements forces the user to make rapid decisions, which is directly reflected in decreased HRV.
- Social/Emotional Triggers: Scenarios involving injured virtual characters or high stakes mission objectives increase the user's emotional engagement and sense of presence.

3.8 Ethical Considerations in Stress Induction

Since VR is highly effective at eliciting genuine emotions, the study in [9] emphasizes the importance of psychological safety.

- Controlled Exposure: While the goal is to induce stress, the environment must be carefully designed to prevent overwhelming trauma, allowing the user to practice coping mechanisms in a "safe to fail" environment [9].
- Gradual Loading: Using VR allows developers to increase the complexity of the stress induction (from simple noise to complex multi hazard scenarios) based on the user's measured HRV levels, ensuring a personalized and safe training progression [9].

4. Expected Achievements & Success Metrics

The success of the project will be evaluated by

4.1 Physiological Analysis Accuracy

- **Baseline Establishment**: The system shall successfully establish a personalized physiological baseline for each user within 60 seconds of rest prior to the start of the scenario.
- **Stress Detection Sensitivity**: The SCI algorithm shall detect at least 80% of intentionally induced stress events (such as alarms or transitions into emergency states) by identifying a significant decrease in HRV relative to the established baseline.

4.2 System and Technical Metrics

- **Real-time Latency**: The end-to-end latency between physiological data acquisition from the smartwatch and its processing within the Unity environment shall not exceed 1,000 milliseconds (1 second).
- **Data Transmission Reliability**: The system shall maintain a data packet delivery rate (Reliability) of over 95% throughout a standard 10-minute training session.
- **System Stability**: The system will be evaluated based on the MTBF (Mean Time Between Failures). A successful implementation will record zero critical crashes during 90% of tested sessions.

4.3 Training Effectiveness & User Experience

- **Physiological Recovery Improvement**: Through longitudinal tracking, returning users will demonstrate at least a 15% improvement in physiological recovery speed, defined as the time required to return to baseline HRV levels following a stressor.
- **Operational Usability**: Users with no prior technical background will be able to complete the physical setup (wearing the watch and headset) and initiate the simulation in less than 3 minutes.
- **Immersion & Presence**: The system shall achieve an average score of 80% on a standardized Presence Questionnaire, confirming that the "Active Elicitation" method effectively engages the user.

5. Research/Engineering Process

The information gathering and learning process for this project was split into two primary domains: the theoretical understanding of physiological stress markers (specifically HRV) and the practical engineering required to bridge wearable hardware with an immersive VR environment via a low latency serial connection.

5.1 The Process

5.1.1 Research Physiological Stress & HRV Analytics

The research phase began with an in depth exploration of Heart Rate Variability (HRV) as a reliable physiological marker for stress. To establish a solid foundation, we analyzed medical and psychological literature [7, 8] to understand the relationship between the Autonomic Nervous System (ANS) and the Stress Change Index (SCI) algorithm. We concluded that while Heart Rate provides a general view of arousal, the HRV are essential for detecting the subtle shifts in the parasympathetic system during acute stress.

5.1.2 Research Capture physiological data from a smartwatch

A significant portion of our research focused on Photoplethysmography (PPG) technology used in modern smartwatches. We evaluated various WearOS and Tizen based APIs to determine the most efficient way to extract high frequency heart rate data. This research led us to the conclusion that a direct "Watch to PC" connection is often restricted by manufacturer firmware, necessitating the development of an intermediary "Android Gateway."

5.1.3 Research VR Environment

For the virtual environment, we researched the Unity Engine and the XR Interaction Toolkit. Following our advisor's guidance, we integrated the "Active Elicitation" paradigm [11]. Our research showed that unlike passive media, VR can trigger a "Presence" state where the brain treats virtual stressors as real threats, leading to measurable physiological spikes. We focused on spatial audio and lighting optimization to enhance this effect without causing motion sickness.

5.1.4 Research Wireless Communication

A critical technical research area was wireless serial communication using Bluetooth and Wi-Fi. Unlike wired USB connections, wireless protocols introduce challenges related to latency, bandwidth variability, and connection stability, which required careful evaluation and optimization. The research focused on establishing a reliable low-latency wireless data link capable of transmitting physiological signals in near real time. This ensures that when a stressor occurs within the VR environment, the

user's physiological response is captured with sufficiently low latency to preserve temporal alignment between virtual events and measured responses.

5.1.5 Prototype Progress

The idea for the project emerged from the growing need to prepare civilians for high stress emergency situations and the recognition that existing training methods lack objective physiological feedback. Inspired by research on VR based active stress elicitation and HRV biofeedback, we designed a system that combines immersive VR with real time physiological monitoring. In the prototype phase, we focused on validating the core concept and technical feasibility: we built an initial Unity VR scenario with basic emergency stressors (e.g., alarms and time pressure), implemented user interaction and navigation, and established a functional data pipeline from a smartwatch through an Android gateway to the Unity environment. The prototype demonstrates near real time HR/HRV data reception, baseline measurement, and preliminary stress visualization, proving that physiological responses can be synchronized with VR events and forming the foundation for full stress analysis and personalized feedback in later stages.

5.2 Constraints and Challenges

1. API Restrictions: Smartwatch manufacturers restrict access to granular R R interval data. We are currently investigating which SDKs provide the most reliable raw data for high fidelity HRV analysis.
2. Hardware Synchronization: Aligning the VR event (the moment a stressor is triggered) with the data packet arriving via BLUTHOOTH is a major challenge.
3. Unity Game Engine: Using a new game engine will be also challenging due to the need to learn its features and how to implement scenes.

5.3 Tools and Technologies
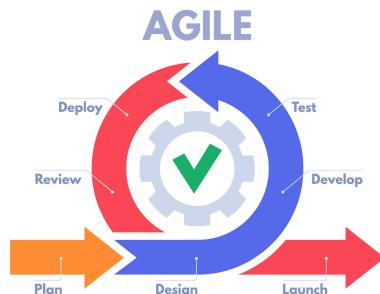
In order to implement the high fidelity data pipeline and the immersive simulation, the following tools and technologies were selected:

Category	Tool / Technology	Role in the Project
Game Engine	Unity 3D	The primary platform for developing the 3D emergency scenarios, calculating the Stress Change Index (SCI), and managing the VR interactions.
VR Hardware	VR Headset	Provides the immersive environment and spatial audio necessary for "Active Elicitation" of stress responses.

Wearable Device	Smartwatch	Captures real time physiological data (Heart Rate and HRV) using Photoplethysmography sensors.
Wearable Interface	Smartwatch Companion App	A dedicated watch side application that accesses raw sensor data and broadcasts it to the mobile gateway.
Mobile Gateway	Android Application	A central hub that receives data from the Smartwatch Companion App and manages the data stream.
Communication Bridge	WIFI/ BLUTHOOTH Protocol	A low latency communication bridge that streams data from the Android device to Unity via a WIFI connection, bypassing wireless jitter.

5.4 Methodology and Development Process

Our project follows the Agile Development Methodology, which allows for an iterative approach to the complex integration of hardware (Smartwatch, Android) and software (Unity VR).

We will be splitting out development into:

1. Research & Algorithm Design: Defining the Stress Change Index (SCI) algorithm and the mathematical logic for stress classification.
2. The Android Gateway (Mobile Development): Developing the Android application. This app acts as a bridge, fetching PPG data from the smartwatch and transmitting it via the WIFI protocol.
3. Unity Integration: Building the Serial Communication interface in Unity. This stage also includes the development of the data synchronization module that marks timestamps for VR triggers.
4. VR Scene Construction: Modeling the 3D environments, implementing spatial audio, and developing the interaction mechanics (using the XR Interaction Toolkit).
5. Analytics & UI: Building the retrospective dashboard that fetches results from the database and displays them as interactive graphs.

6. Product

6.1 Requirements

6.1.1 Requirements Collection

The requirements for the VR Stress Response Trainer were gathered and validated through the following engineering and research methods:

- Literature Review & Academic Research: A thorough analysis of scientific publications was conducted regarding Heart Rate Variability (HRV) as a primary stress marker and the effectiveness of Virtual Reality (VR) as an active emotion elicitation mechanism [9]. This research provided the theoretical foundation for Baseline Measurement and SCI Algorithm Analysis.
- Document & Protocol Analysis: We analyzed existing emergency response protocols and first aid training materials to design realistic scenarios. This helped in defining the specific tasks and environmental triggers (sirens).
- Expert Consultation (Academic Supervision): Our meetings were held with the project advisor to refine the system's technical boundaries.
- Market & Technical Feasibility Analysis: We investigated the SDKs and APIs of modern smartwatches to determine how physiological data could be exported. The discovery of constraints in direct watch to PC streaming led to the architectural decision of building a dedicated Android Gateway Application.
- User Interaction Observation: Through informal observations of users in VR environments, we identified the need for a Safety Exit and Simplified Interactions to prevent cognitive overload during high stress simulations [11].

6.1.2 Functional Requirements (FR)

No.	Requirement
1	The system shall provide an immersive 3D VR environment
2	The system shall capture physiological data from a smartwatch.
2.1	The system shall automatically stream Heart Rate (HR) and HRV data from the watch.
2.2	The system shall utilize an Android gateway application to bridge the data flow.
3	The system shall establish a stable WIFI connection.
3.1	The system shall transmit data from the Android device to Unity
4	The system shall perform a baseline physiological state before starting the simulation to ensure accurate stress analysis.

5	The system includes multiple immersive VR scenarios simulating emergency situations.
5.1	The system shall simulate an "Indoor Survival" scenario (gathering supplies).
5.2	The system shall simulate a "First Aid" scenario in an open area.
6	The system shall analyze data using the Stress Change Index (SCI) algorithm.
7	The system shall display a retrospective feedback dashboard.
7.1	The system shall present visual graphs of stress patterns to the user in VR.
7.2	The system shall provide personalized resilience recommendations based on the profile.
8	The system shall manage user data persistence.
8.1	The system shall save user profiles and simulation results in a database for progress tracking.
9	The system shall provide an emergency exit/pause mechanism.

6.1.3 Non functional Requirements (NFR)

No.	Requirement
1	Data latency between the smartwatch and the VR environment shall not exceed 1 second.
2	The VR interface shall be intuitive and navigable for users with no technical background.
2.1	The system will have three main scenes: Home/Calibration, Training Simulation, and Results Dashboard.
3	The system shall handle WIFI disconnection gracefully with visual alerts.
4	The system shall support common Android mobile devices and standalone VR headsets.
5	The system shall integrate spatial audio cues to increase immersion and provide realistic environmental feedback during stress scenarios.
6	The system shall include simple interaction mechanisms to minimize the user's cognitive load during high stress tasks.

6.2 Architecture overview

The system is based on a Distributed Data Pipeline architecture composed of four primary nodes.

1. Wearable Node (Smartwatch)

This node serves as the initial data source for the system:

- Data Collector: A native application running on the smartwatch that samples raw PPG (Photoplethysmography) sensor data, specifically Heart Rate (HR) and Heart Rate Variability (HRV).
- Bluetooth Low Energy (BLE): Data is transmitted wirelessly via the BLE protocol to the smartphone to maintain user mobility within the VR space.

2. Gateway Node (Android Smartphone)

The smartphone acts as an intermediary relay station consisting of two software layers:

- Watch Companion App: The manufacturer's baseline application that maintains the primary connection with the wearable device.
- Android Gateway App: A custom developed application that intercepts the physiological data stream and prepares it for high speed wired transmission.

3. Workstation / Processing Node (PC)
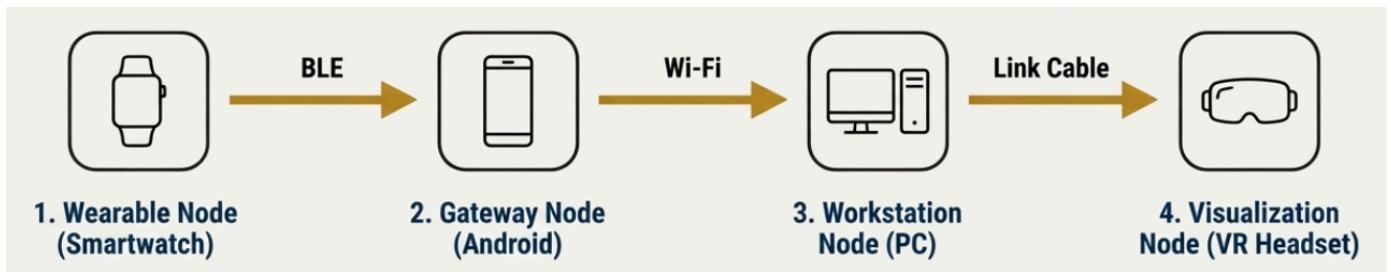
This is the "brain" of the system, where central data processing occurs within the Unity Engine:

- WIFI Connection: Data is streamed from the phone to the PC via WIFI protocol.
- Serial Listener Script: A script within Unity that monitors the Serial port, parses the incoming data strings, and converts them into numerical values for analysis.
- SCI Algorithm (Stress Calc): The core processing logic is implemented as a script within Unity. It calculates the Stress Change Index by comparing real time metrics against the user's recorded baseline.
- Unity Engine: The engine manages the simulation logic and synchronizes the calculated stress levels with virtual events and triggers.

4. VR Headset (Visualization Node)
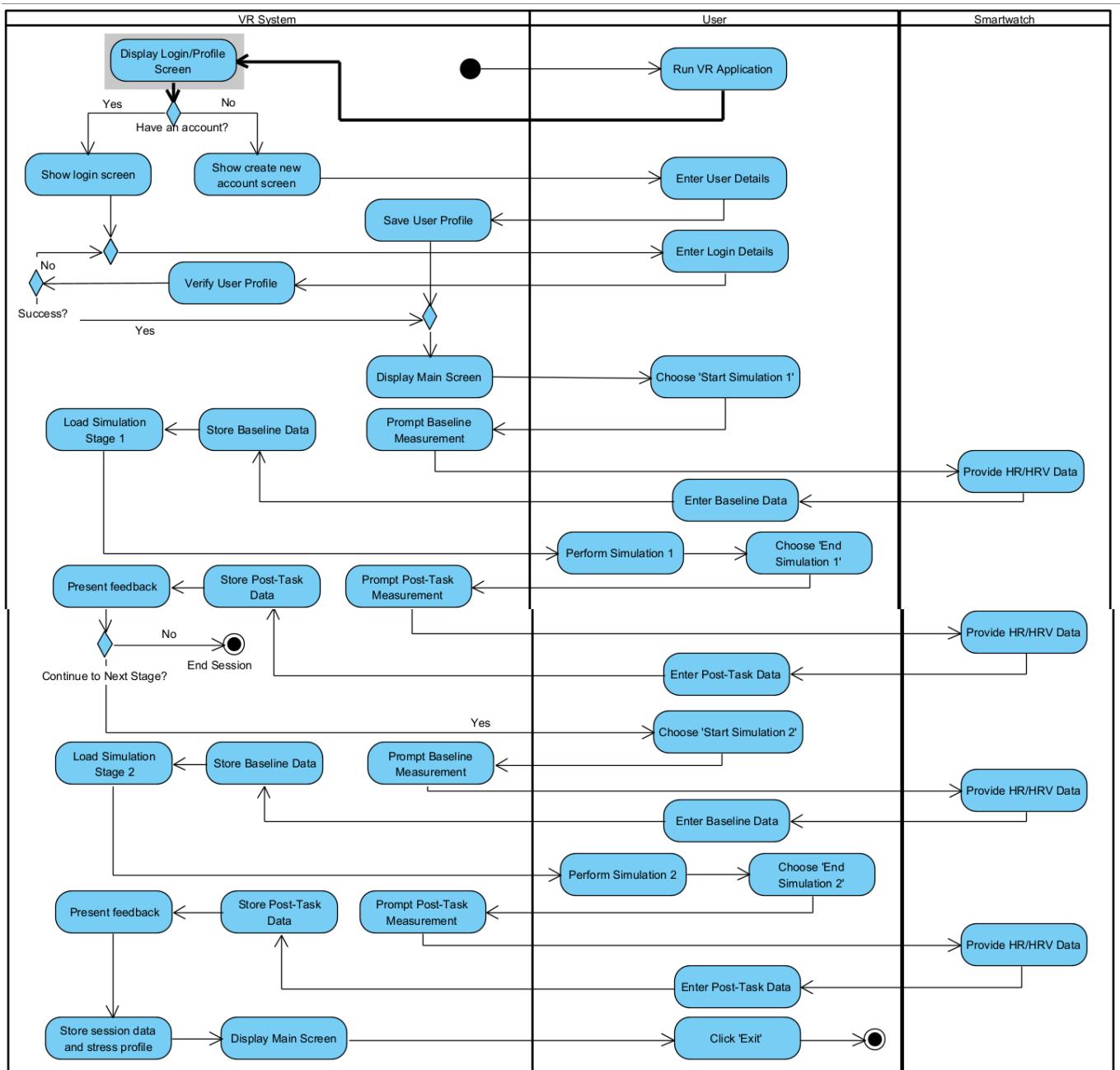
The final node in the pipeline, connected to the workstation via a Link Cable:

- Visual Stress Feedback: The headset renders the 3D environment and provides real time visual feedback to the user based on the physiological analysis performed in Unity.

	BLE		Wi-Fi		Link Cable	
1. Wearable Node (Smartwatch)	→	2. Gateway Node (Android)	→	3. Workstation Node (PC)	→	4. Visualization Node (VR Headset)

6.2 Activity Diagram

This diagram illustrates the interaction between the VR System, the User, and the Smartwatch node. The process begins with the user running the VR application and interacting with the Login/Profile screen. Once the user initiates "Simulation 1," the system enters a baseline measurement. During this rest period, the Smartwatch provides real time HR/HRV data. As the user performs the simulation tasks, the system continuously monitors physiological changes. The system calculates the Stress Change Index (SCI) and presents immediate visual feedback to the user. At the end of the session, the system compiles the overall stress profile and simulation data.

7. Verification and Evaluation

This chapter describes the methods used to evaluate the effectiveness of the VR Stress Response Trainer and to verify that the system meets its functional and non-functional requirements. The evaluation focuses on physiological stress detection accuracy, system performance, and training effectiveness, while verification ensures technical correctness, stability, and usability of each system component.

7.1 Evaluation

The evaluation of the system is based on its ability to accurately detect stress responses, analyze physiological changes, and provide meaningful feedback to the user during and after VR-based emergency simulations.

The primary evaluation objective is to assess whether the system can correctly identify stressful events by analyzing Heart Rate (HR) and Heart Rate Variability (HRV) relative to a personalized baseline. This classification is achieved using the Stress Change Index (SCI) algorithm, which compares real-time physiological data against baseline measurements collected prior to the simulation.

The system is evaluated according to the following criteria:

- Physiological Stress Detection Accuracy:
   The system should correctly identify induced stress events (e.g., alarms, time pressure, emergency tasks) through measurable reductions in HRV and elevations in HR. A successful evaluation is defined as detecting at least 80% of known stress-inducing triggers during a session.

- Baseline Stability and Recovery Analysis:
   The system evaluates each user's ability to return to baseline HRV levels following a stressor. Improvement in physiological recovery time across repeated sessions is used as an indicator of training effectiveness.

- System Responsiveness:
   The end-to-end latency between physiological signal acquisition (smartwatch) and its processing inside the Unity VR environment must remain under 1 second, ensuring accurate temporal alignment between VR events and physiological responses.

- User Experience and Immersion:
   User immersion and presence are evaluated using standardized presence questionnaires and qualitative feedback. High presence scores validate the use of Active Elicitation as an effective stress induction method.

A successful evaluation indicates that the system can serve as a training and self-assessment tool, allowing users to understand their stress responses and improve regulation skills over time.

7.2 Verification

Verification ensures that the system was built correctly according to specifications, validating both software functionality and system integration across hardware components.

7.2.1 Testing Plan

Due to the system's distributed and iterative development process, testing is conducted across three main modules:

1. VR Application (Unity & XR Interaction Toolkit)

2. Physiological Data Pipeline & Analysis (Smartwatch + Android Gateway + SCI Algorithm)

3. Results Dashboard & Data Management

Testing includes a combination of automated tests, manual quality assurance (QA), and performance validation.

- VR Application Testing:
  Unit tests are implemented using the Unity Test Framework, supplemented by manual QA to validate interaction mechanics, immersion quality, and usability under stress.

- Physiological Data & Analysis Testing:
  Data integrity and algorithm correctness are verified by analyzing known stress scenarios and comparing expected physiological patterns against measured HR/HRV values. Detection accuracy is evaluated using controlled stress triggers.

- System Integration Testing:
  Communication reliability between the smartwatch, Android gateway, and Unity engine is verified under real usage conditions, including network instability scenarios.

7.2.2 Test Cases

Test No.	Module	Tested Function	Expected Result
1	VR Application	Scene loading	Scene loads smoothly without noticeable delay
2	VR Application	Frame rate stability	Minimum 30 FPS during simulation
3	VR Application	Scene transitions	Transition time < 2 seconds
4	VR Application	Head & controller tracking	Accurate tracking with no noticeable lag
5	VR Application	User calibration	Environment adapts correctly to user height
6	VR Application	Controller input	Inputs handled correctly and intuitively
7	VR Application	Object interaction	Correct object proportions and positioning
8	VR Application	Data storage	Simulation and physiological data stored correctly
9	Data Pipeline	Physiological data reception	Correct HR and HRV data packets received
10	Data Analysis	Stress detection accuracy	≥80% correct identification of stress events

| 11	Data Analysis	Baseline computation	Stable baseline generated within 60 seconds
12	System	End-to-end latency	Latency < 1 second
13	System	Network reliability	≥95% packet delivery during session
14	Dashboard	Data visualization	Graphs and summaries displayed correctly
15	Dashboard	Session comparison	Accurate comparison across multiple sessions
16	Dashboard	User profiles	Correct loading and saving of user data
17	System	Safety exit	Immediate pause/exit without system crash

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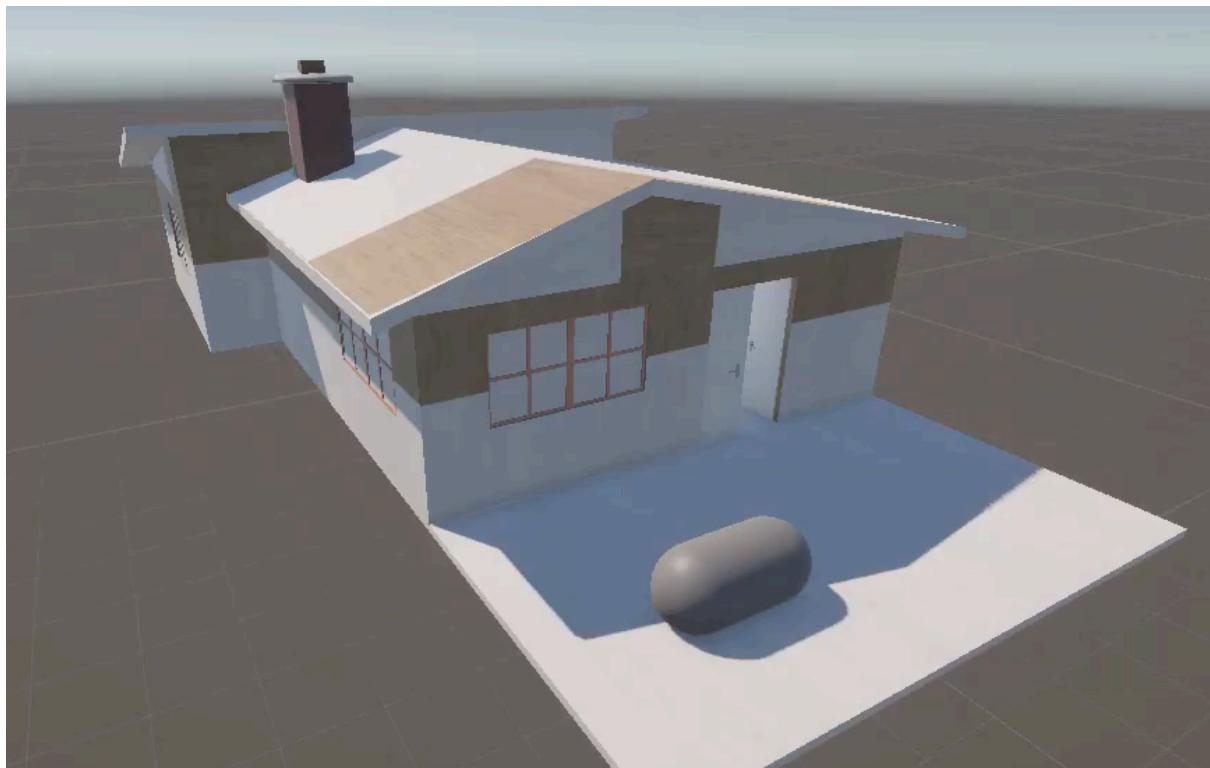
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9. Appendices

9.1 Appendix A

VR Interface Screens - Prototype

Before the simulation begins, the user is presented with an exterior view of the house to establish a sense of "Presence". This transitional phase allows the user to acclimatize to the VR environment and the spatial audio before the high-stress tasks commence.
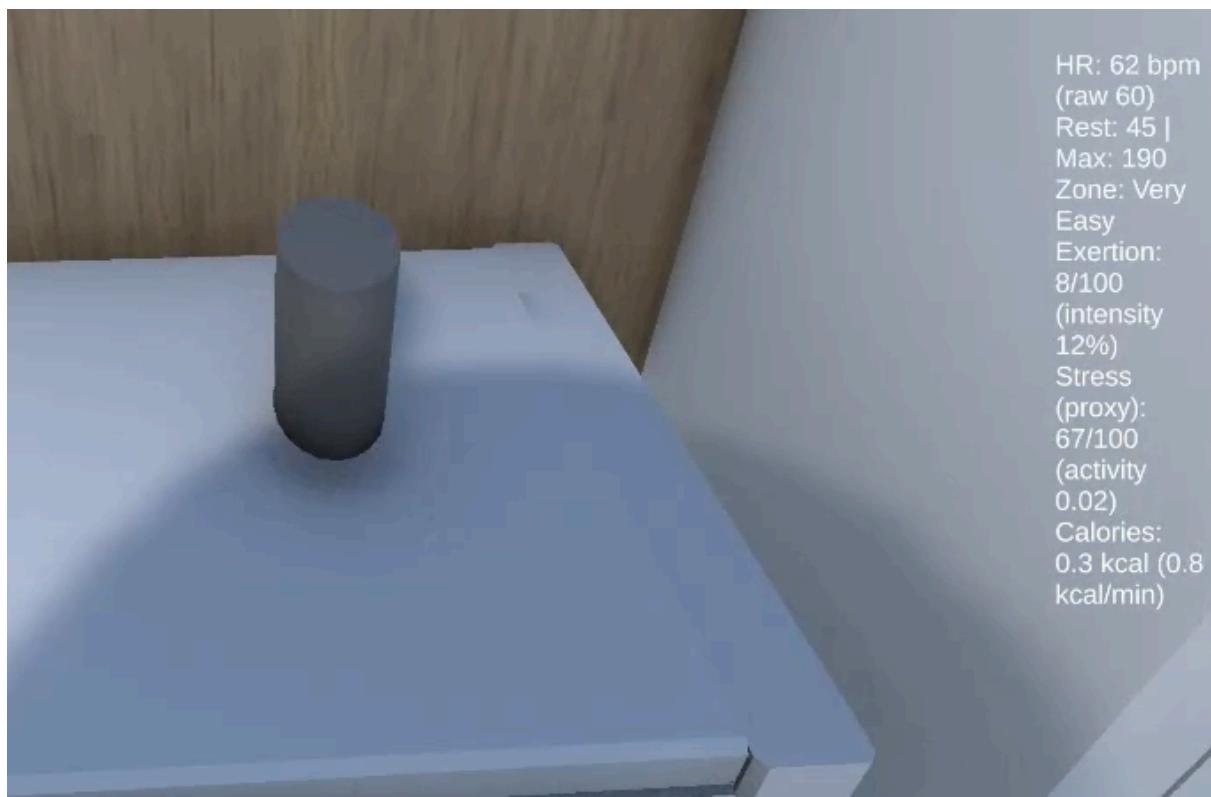

Scenario 1: Emergency Preparedness

The user is placed inside a furnished home and must navigate through various rooms (bedroom, living room, kitchen).

Task Objective: Locate and collect three essential emergency items (represented by 3D cylinders in the prototype).

Stress Induction: A loud, continuous siren/alarm is triggered to induce an "Active Elicitation" of stress.
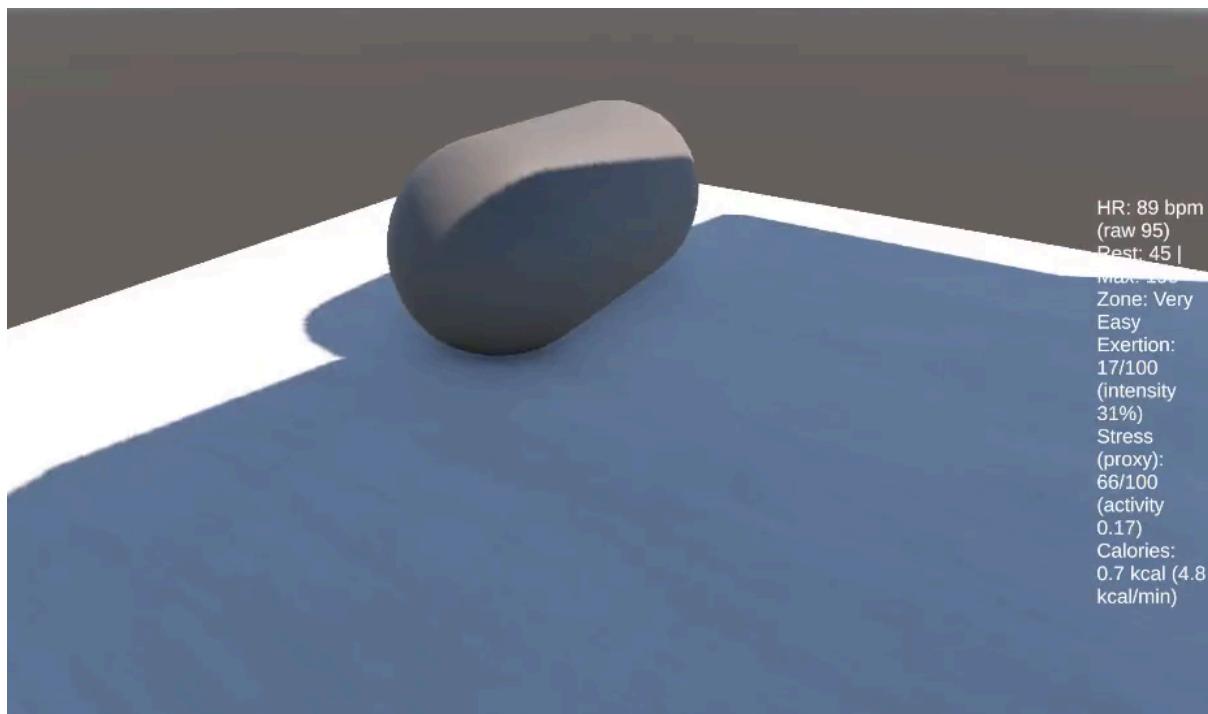
Real-time Monitoring: The interface displays the live stream of HR (Heart Rate) and HRV (Heart Rate Variability) data, which is fed into the SCI algorithm to classify the current stress level.

HR: 87 bpm (raw 98)
Rest: 45 | Max: 190
Zone: Very Easy
Exertion: 13/100 (intensity 29%)
Stress (proxy): 76/100 (activity 0.00)
Calories: 0.1 kcal (4.5 kcal/min)

HR: 62 bpm (raw 60)
Rest: 45 | Max: 190
Zone: Very Easy
Exertion: 8/100 (intensity 12%)
Stress (proxy): 67/100 (activity 0.02)
Calories: 0.3 kcal (0.8 kcal/min)

Scenario 2: Medical Intervention Scenario

- After completing the indoor task, the user transitions to an open-area scenario (a kibbutz courtyard).
- Task Objective: The user must provide basic first aid to a casualty while the alarm continues to sound.
- This scenario tests the user's ability to maintain cognitive functioning and fine motor skills under persistent auditory stressors.

9.2 Appendix B

The Stress Change Index (SCI) Logic

The Stress Change Index (SCI) is the core analytical component of the system. It quantifies the user's physiological shift from a relaxed state to a stressed state by comparing real time Heart Rate Variability (HRV) metrics against a personalized baseline.

Before the simulation starts, the system records the user's physiological data for 60 seconds while they are at rest within the VR environment.

- Baseline HRV: The average variation in time intervals between heartbeats during this rest period.
- Baseline HR: The average heart rate during the same period.

The system continuously samples HRV data and calculates the deviation from the baseline. A significant drop in HRV, combined with an elevation in HR, indicates an activation of the Sympathetic Nervous System (the "Fight or Flight" response).

The Stress Change Index is calculated as follows:

SCI = ((HRV_base - HRV_current)/HTV_base)*100

Low Stress: SCI < 20%

Moderate Stress: 20% =< SCI < 50%

High Stress: SCI >= 50%

The following pseudo-code illustrates the logic implemented in the Unity C# environment to manage this data flow:

```
// PSEUDO-CODE FOR STRESS ANALYSIS

FUNCTION CalculateStressLevel():

    // 1. Check if calibration is complete

    IF (currentTime <= 60 seconds):

        CollectDataForBaseline(currentHRV, currentHR)

        RETURN "Calibrating..."


    // 2. Once baseline is set, start real-time analysis
```

```
    baselineHRV = GetAverage(collectedBaselineData)

    currentHRV = ReceiveDataFromAndroidGateway()


    // 3. Calculate the Stress Change Index (SCI)

    SCI = ((baselineHRV - currentHRV) / baselineHRV) * 100


    // 4. Trigger Environmental Response or Feedback

    IF (SCI >= 50):

        SetStressLevel("High")

        DisplayVisualStressWarning() // Visual feedback in VR

    ELSE IF (SCI >= 20):

        SetStressLevel("Moderate")

    ELSE:

        SetStressLevel("Low")


    SaveToDatabase(SCI, timestamp) // For retrospective analysis

END FUNCTION
```

_____