Prolonged Exposure Therapy in the Treatment of PTSD Based on Virtual Reality and Smartwatch Utilization: A Case Study in a Private Mental Health Clinic in Peru

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ABSTRACT

Post-Traumatic Stress Disorder (PTSD) derived from sexual violence represents a critical public health challenge in Peru, where more than 42,000 cases were treated in 2022. Conventional therapies present limitations in recreating controlled exposure environments and objectifying clinical monitoring. This study presents Synapse, a platform that integrates Prolonged Exposure Therapy (PET) with immersive Virtual Reality (VR) and biometric monitoring via a smartwatch. The development comprised four phases: (i) PET selection through benchmarking, (ii) design of three therapeutic scenarios with progressive exposure levels, (iii) implementation of the environment in Unity, and (iv) development of a web application with cloud architecture. Validation was conducted in a private clinic in Lima with 30 patients diagnosed with PTSD, divided into a control group (traditional PET) and an experimental group (PET with Synapse), evaluated over three weekly sessions using Subjective Units of Distress (SUDS), heart rate (BPM), and the PCL-5 Scale. The results demonstrated the superiority of the experimental group with a 21.3% reduction in PCL-5 compared to 11.8% in the control group. Furthermore, the system evidenced greater initial emotional activation and superior reductions in anxiety, with more robust physiological habituation. The usability evaluation obtained 84.67 points on the System Usability Scale (SUS), classified as "Excellent". These findings establish that Synapse constitutes an effective tool to improve the efficacy of PET in PTSD, with great potential for implementation in public health systems.

Keywords-Post-Traumatic Stress Disorder (PTSD); Virtual Reality (VR); exposure therapy; wearable devices; biometric monitoring; IoT; mental health

I. INTRODUCTION

Post-Traumatic Stress Disorder (PTSD) is a psychological condition derived from traumatic experiences and manifests in a set of negative symptoms, such as intrusive memories or avoidance, that seriously affect patients' lives. Although conventional therapies have demonstrated efficacy, they also present critical limitations such as difficulty in recreating controlled exposure environments, subjectivity in clinical monitoring, and access barriers that restrict appropriate and, above all, personalized care, especially in contexts where highly specialized personnel are required [1]. In Peru, this problem acquires alarming dimensions that transcend the individual clinical scope, constituting a public health challenge. Ministry of Health establishments treated more than 42,000 cases of acute and post-traumatic stress reaction in 2022 [2], while the WHO reports that PTSD can affect up to 3.9% of the world population annually [3].

To mitigate this problem, the current literature has applied different technologies such as Virtual Reality (VR), Internet of Things (IoT), and Machine Learning (ML). In [4], it was confirmed that VR therapy combined with physiological monitoring provides an effective treatment with objective metrics for PTSD. Similarly, in [5], a review was conducted on the use of wearable biosensors in immersive VR experiences. In the context of wearable devices, in [6], a mobile application was developed that used smartwatches to monitor anxiety and depression by applying cognitive behavior therapy techniques, while in [7], the effectiveness of VR was demonstrated with Peruvian students, obtaining 22% increase in academic performance. In [8], the feasibility of intensive VR-augmented exposure therapy programs in first responders was confirmed, validating their applicability in controlled clinical environments. In [9], it was explored how ML can expand access and improve PTSD treatments by personalizing and monitoring interventions. In [10], an open-access VR platform was presented for exposure therapy. In [11], an auditory generative system in VR was proposed, which created dynamic environments for therapy in patients with PTSD. In [12], a VR adaptation algorithm in exposure therapy was developed based on the Rescorla-Wagner model. In [13], a technological solution was developed, using wearables and VR, demonstrating its efficacy in two test patients. This study presents the validation of this solution in a private mental clinic in Peru.

II. MATERIALS AND METHODS

A. *Selection of Prolonged Exposure Therapy*

According to [13], benchmarking was carried out for four therapies: Prolonged Exposure (PE), Trauma-Focused Cognitive Behavioral Therapy (TF-CBT), Eye Movement Desensitization and Reprocessing (EMDR), and Cognitive Processing Therapy (CPT). The evaluation was based on five key criteria: (T1) effectiveness, (T2) adaptability to virtual reality environments, (T3) duration and feasibility of the intervention protocol, (T4) complexity of technical requirements for implementation, and (T5) compatibility with biometric monitoring systems. PET reached the highest score (4.8/5.0), positioning it as the optimal therapeutic approach for integration with VR+IoT architectures oriented towards PTSD treatment (See Table I).

TABLE I. BENCHMARKING OF THERAPEUTIC APPROACHES

3	Weight	PE	TF-CBT	EMDR	CPT
		A	A	A	A
T1	40%	5	4	5	4
T2	30%	5	3	2	3
T3	10%	4	3	3	3
T4	10%	4	3	2	3
T5	10%	5	4	3	4
Average	100%	4.8	3.5	3.4	3.5

B. *Selection of Therapeutic Scenarios to Use Derived from Sexual Violence*

The selection of the sexual violence scenarios to be treated in this project was based on the study conducted in [13]. Table II presents the details of the three scenarios with their respective exposure level.

TABLE II. THERAPEUTIC SCENARIOS

ID	Scenario	Exposure Level
S1	Home	Medium-High
S2	Public Transport	High
S3	Bus Stop	High

C. *Virtual Reality Environment Design*

The Autodesk Maya 3D modeling tool was used for the VR design. The entire 3D modeling process of the elements present in the scene was carried out considering the initial relaxation environment and the three therapeutic scenarios. To model in 3D, five steps were considered: Conceptualization, Base Mesh, Modeling, UV Mapping plus Texturing, and Rendering, which are described below:

1. Conceptualization. Definition of what object is to be modeled, such as, for example: character, doors, lamps. Figure 1(a) shows an example of modeling a lamp.
2. Base Mesh. Creation of base shapes using primitives such as cubes, spheres, and planes, which were then modified with extrusion, smoothing, and sculpting tools to achieve greater detail and realism (Figure 1b).
3. Modeling. Refinement of geometry by adding more polygons (Figure 1c).
4. UV Mapping plus Texturing. Application of textures and materials, adjusting lighting parameters to obtain an appearance consistent with the proposed virtual environment (Figure 1d).
5. Render. The modeled elements were exported from Maya to Unity for their subsequent implementation. The export process employed specific formats according to their type: .OBJ for the environment geometry, .JPG for textures, and .FBX for models with animation (Figure 1e).

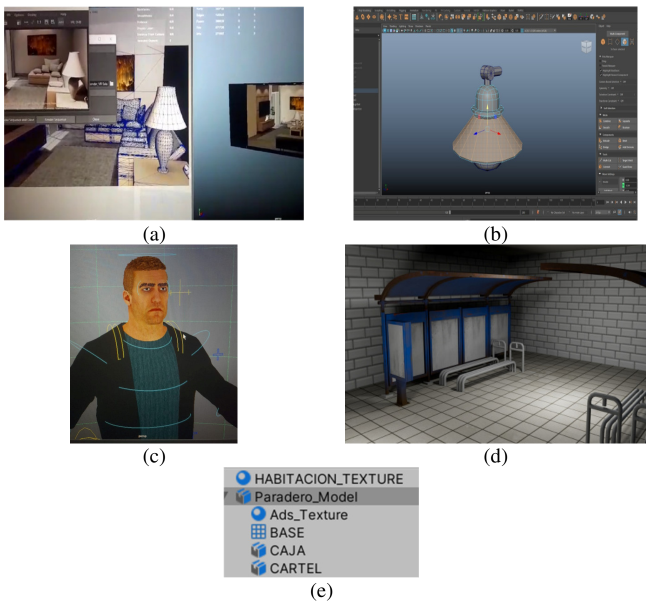

Fig. 1. VR scenario.

D. Technical Implementation of VR Scenarios

The three therapeutic scenarios were implemented in Unity 2021.3 LTS using the Universal Render Pipeline (URP) for optimized mobile VR performance compatible with VR Box headsets.

1. S1 (Home): 35m² apartment with 47 3D assets (furniture, doors, lamps). Spatial audio with household sounds at 48 kHz stereo. Patient remains stationary in first-person POV while an aggressor approaches, performs threatening gestures, and delivers pre-recorded verbal aggression dialogue.
2. S2 (Public Transport): 12-meter bus with 24 seats and one male NPC aggressor with animated behaviors (staring, approaching, physical contact). Dynamic audio includes Lima traffic ambience and engine sounds. Patient experiences from the seated victim's POV as the aggressor initiates eye contact, approaches gradually, and executes touch-and-retreat animation sequences, simulating real sexual harassment incidents in Lima's public transport.
3. S3 (Bus Stop): 80m² outdoor urban environment simulating a Lima bus station at night (19:00-20:00 lighting). Features city soundscape, distant traffic, and NPC aggressor with slow-approach animation. Patient observes from the standing victim's POV as the aggressor maintains prolonged eye contact while advancing, replicating high-risk evening scenarios from patient trauma narratives.

All scenarios maintain patient immobility (no locomotion controls) to prevent motion sickness and ensure focus on emotional processing rather than navigation. Exposure duration is therapist-controlled (target: 4 minutes per scenario with gradual intensity progression across sessions).

E. Web Application Update

The web application (Synapse) developed in the previous study [13] was updated to improve scalability. Figure 2 shows the new architecture of the application, which is structured in four layers: Clients, Frontend, Backend, and Storage.

- The Clients layer defines the patient's interaction point with the therapeutic system. Patients interact with Unity-based VR applications and Samsung Galaxy Fit 3 smartwatches for biometric data capture. The Android mobile application acts as a communication bridge, integrating with Samsung Health via the Samsung Health SDK to receive heart rate data and transmit it to the Backend layer through HTTP requests.
- The Frontend layer provides an interface for therapists to supervise and control therapeutic sessions. Developed with Angular and TypeScript, it provides intuitive dashboards to monitor patient evolution through 5-second polling intervals, visualize real-time biometric metrics, and receive automatic alerts when predefined thresholds are exceeded. Its responsibility is to send requests to the Backend Layer and render data visualizations.
- The Backend layer is the system's heart, responsible for all business logic and data processing. It is significantly modified to optimize information flow through a dual-service architecture: (i) Python/FastAPI biometric ingestion service on Azure Container Instances handles high-throughput IoT telemetry from mobile devices, ensuring scalability for continuous heart rate streams; (ii) Java/Spring Boot service manages core application logic, utilizing native Azure functionalities for data processing, clinical analysis, and report generation. Both backends orchestrate information flow, ensuring traceability from capture to clinical analysis.
- The Storage layer is fundamental for clinical information security and integrity. It was migrated from Amazon RDS to Azure SQL Database for seamless Azure ecosystem integration. It hosts all clinical records (patient demographics, session metadata, PCL-5 scores) and biometric telemetry (timestamped heart rate with *patient_id* and *session_id* associations), enabling structured storage, historical queries, and long-term trend analysis.

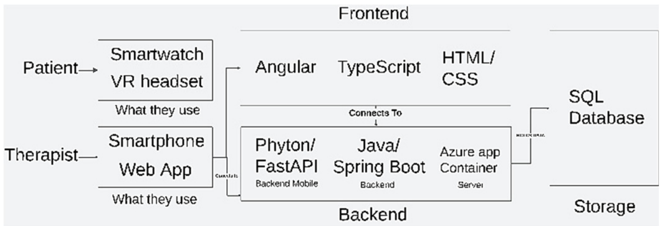

Fig. 2. Proposed architecture.

III. EXPERIMENTATION

The efficacy of the proposed system was corroborated by performing an empirical test in a clinic in Lima, Peru, to comprehensively validate its technical operation, therapeutic efficacy, and usability in patients diagnosed with PTSD derived from sexual violence. The study sample consisted of 30 patients organized into two groups: a control group (receiving traditional PET) and an experimental group (using the Synapse system). In both experiments, three scenarios were considered: Home (S1), Public Transport (S2), and Bus Station (S3). For both experiments, three metrics were considered: Subjective Units of Distress (SUDS), Beats per Minute (BPM), and Post-Traumatic Stress Scale (PCL-5) (see Table III).

TABLE III. EXPERIMENTAL DESIGN

Experiments	Scenarios	Participants	Metrics
Traditional PE (E1)	S1, S2, S3	15 patients with PTSD	SUDS, BPM, PCL-5
PE with Synapse (E2)	S1, S2, S3	15 patients with PTSD	SUDS, BPM, PCL-5

The metrics used are explained below:

- SUDS: Self-administered analog scale where the patient rates its subjective anxiety level in a range of 0 (no anxiety) to 100 (maximum anxiety) [14].

- BPM refers to the heart rate, which indicates the number of times the heart beats in a minute [15].
- PCL-5: A standardized 20-item Likert-type questionnaire that evaluates the severity of PTSD symptoms according to criteria from the Diagnostic and Statistical Manual of Mental Disorders, 5th edition [16].

A. Experiment 1: Traditional Prolonged Exposure Therapy

The first experiment corresponds to the implementation of traditional PET, a standard evidence-based treatment for PTSD [17]. The procedure follows the guided imaginal exposure protocol, where the therapist verbally facilitates the controlled re-experiencing of the traumatic event.

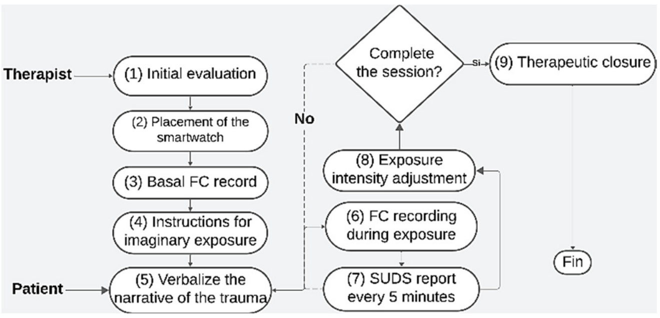

Fig. 3. Activity diagram of traditional PET.

As illustrated in Figure 3, the flow initiates with the clinical evaluation and application of PCL-5 Pre and initial SUDS (step 1). The smartwatch is placed for continuous BPM monitoring (step 2), a device integrated into both groups to guarantee physiological data comparability. After recording basal BPM for 5 minutes at rest (step 3), the therapist instructs the imaginal exposure where the patient verbalizes the trauma narrative in the first person with eyes closed (steps 4-5). During the exposure, the therapist requests SUDS every 5 minutes and monitors BPM in real-time (steps 6-9), adjusting intensity according to individual response per Foa's standard protocol [18]. The session ends when SUDS decreases ≥50% regarding the peak, indicating emotional habituation (step 9), followed by therapeutic closure and application of SUDS Post. This procedure is repeated weekly for three sessions, progressively exposing the patient to the three therapeutic scenarios. At the end of the third session, the post-treatment PCL-5 is applied.

B. Experiment 2: Prolonged Exposure Therapy with the Synapse System

The second experiment implements the proposed Synapse system, integrating immersive VR with real-time biometric monitoring, grounded in the same principles of PET, but mediated by three-dimensional virtual environments. Figure 4 illustrates the differential therapeutic flow. After the initial evaluation identical to experiment E1 (step 1), the therapist authenticates on the system's web dashboard (step 2) and equips the patient with the VR headset and smartwatch (step 3). The patient enters the virtual relaxed environment where the system automatically records basal BPM for 5 minutes (steps 4-5), transmitting data in real-time to the dashboard viewed by the therapist (step 6). Once physiological stability is confirmed, the therapist selects the personalized therapeutic scenario (S1, S2, or S3) according to the patient's specific traumatic context (step 7). The system loads the corresponding virtual environment (step 8), where the patient explores immersively for 4 minutes (step 9). Simultaneously, the system monitors BPM every 30 seconds, updating the dashboard in real-time and generating automatic alerts if BPM > 110 (step 10). The therapist requests SUDS verbally every 5 minutes without removing the headset (steps 11 and 12), triangulating objective physiological data with subjective self-reports for informed adjustment decisions. The session ends when the system detects a need for a pause for safety or the experience ends (step 13), followed by a gradual transition to the relaxed environment, removal of the headset, and structured therapeutic closure. Upon completion of the third session, the post-treatment PCL-5 is applied.

C. System Usability Scale (SUS) Survey Design

The usability evaluation of the Synapse system was performed, applied exclusively to the experimental group (n = 15) using the SUS [19]. The instrument consists of 10 items that evaluate 10 dimensions classified into two valences (see Table IV), using the scale: 1 (Strongly disagree), 2 (Disagree), 3 (Neither agree nor disagree), 4 (Agree), and 5 (Strongly agree).

The evaluation was self-administered at the end of the third session to ensure informed judgments. The final score (0-100) was calculated using the standard algorithm [20], interpreted as: <50 unacceptable, 50-68 below average, 68-80 acceptable, and >80 excellent.

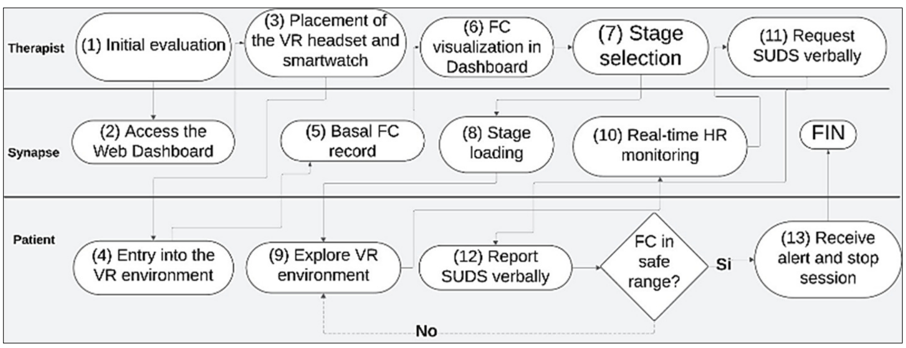

Fig. 4. Activity Diagram of PET with Synapse.

TABLE IV. SUS DIMENSIONS

Item	Dimension	Description
Valence: Positive		
1	Desired frequency of use	"I think I would like to use this system frequently"
2	Ease of use	"I thought the system was easy to use"
3	Function integration	"I found the various functions of this system were well integrated"
4	Learning curve	"I imagine that most people would learn to use this system quickly"
5	Confidence in use	"I felt very confident using the system"
Valence: Negative		
6	Need for technical support	"I think I would need the support of a technical person to be able to use this system"
7	Perceived inconsistencies	"I thought there was too much inconsistency in this system"
8	Difficulty of use	"I found the system very complicated to use"
9	Perceived complexity	"I found the system unnecessarily complex"
10	Need for prior learning	"I needed to learn many things before I could use this system"

IV. RESULTS AND DISCUSSION

A. Experiment 1: Traditional Prolonged Exposure Therapy

The first group (n = 15) received traditional PET through guided imaginal exposure. Table V presents the results obtained in the three evaluated therapeutic scenarios. The data show the average BPM during the session, the reduction in SUDS from the beginning to the end of each exposure, and the PCL-5 scores before and after the complete treatment.

TABLE V. RESULTS OF EXPERIMENT I

	Scenario S1			Scenario S2		Scenario S3		
ID	BPM	ΔSUDS	PCL-5 Pre	BPM	ΔSUDS	BPM	ΔSUDS	PCL-5 Post
P01	72	13	32	71	11	70	10	28
P02	70	11	34	69	10	68	9	30
P03	74	12	30	72	12	71	11	27
P04	71	10	36	70	11	69	10	32
P05	73	11	31	71	9	70	8	28
P06	69	12	35	68	10	67	9	31
P07	75	10	33	73	11	72	10	29
P08	82	11	47	80	11	78	10	41
P09	85	12	49	83	12	81	11	44
P10	84	11	46	82	11	80	10	40
P11	83	13	52	81	12	79	11	46
P12	86	12	54	84	11	82	11	47
P13	81	11	49	79	10	77	9	43
P14	98	10	65	95	9	93	8	57
P15	100	9	68	97	10	95	9	60
Avg.	80.2	11.2	44.9	78.3	10.7	76.8	9.7	39.6

The results show that the treatment is consistent with habituation principles (Figure 5). The mean BPM decreased from 80.2 (S1) to 76.8 (S3), a reduction of 4.24% that suggests progressive physiological stabilization. The SUDS reduction decreased between scenarios (11.2 to 9.7), indicating that patients with higher initial anxiety showed greater absolute reductions at the beginning, subsequently reaching gradual stabilization. The PCL-5 evidenced an average reduction of 5.2 points (11.8%), a response consistent with brief therapies (range 10-15%). PET maintained efficacy independent of initial severity, with patients with mild and severe symptomatology achieving similar percentage reductions.

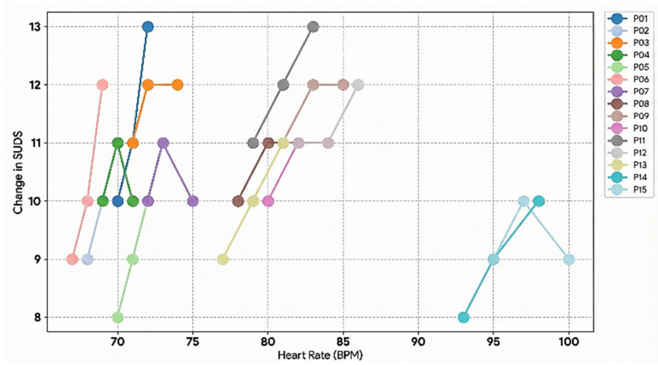

Fig. 5. BPM and SUDS trajectory in Experiment 1.

B. Experiment 2: Therapy with Synapse VR+IoT System

The second experimental group (n = 15) used the Synapse system. After the initial evaluation, each patient was equipped with a VR Box headset and a Samsung Fit 3 smartwatch. The patient entered the virtual relaxed environment (Figure 6a) for basal BPM recording (5 min), and then the therapist selected the scenario corresponding to the session (Figures 6b-d).

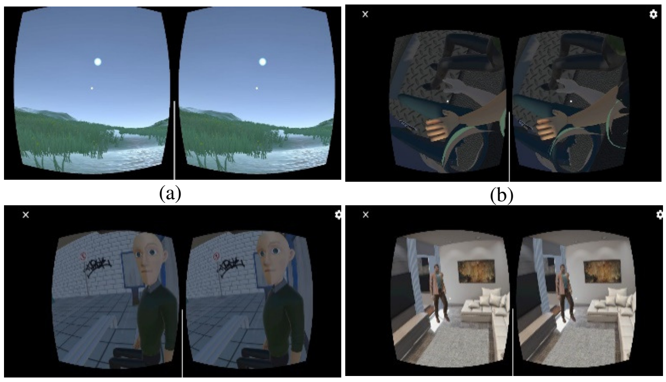

Fig. 6. Scenario images.

During immersive exposure (4 min), the system monitored BPM every 30 s (Figure 7) and generated automatic alerts if BPM exceeded 110. The therapist requested SUDS verbally every 5 minutes without removing the headset, visualizing physiological data in real-time through the web dashboard. Subsequently, the data were visualized for later analysis (Figure 8). Table VI presents the results of the experimental group.

The results of the experimental group demonstrate an explicit behavior of greater initial physiological activation and greater depth in emotional processing (Figure 9). The average BPM in S1 reached 94.1, confirming that VR immersion provokes significant emotional activation. SUDS reductions were substantial, with 21.1 points in S1, demonstrating that the 3D virtual environment provides contextual cues that facilitate the broad activation of associative neural networks. The PCL-5 reduction was 10.1 points, going from an average of 47.9 to 37.7, equivalent to a 21.3% decrease in symptomatic severity. This magnitude of change exceeds the clinical significance threshold established in the literature for populations with PTSD.

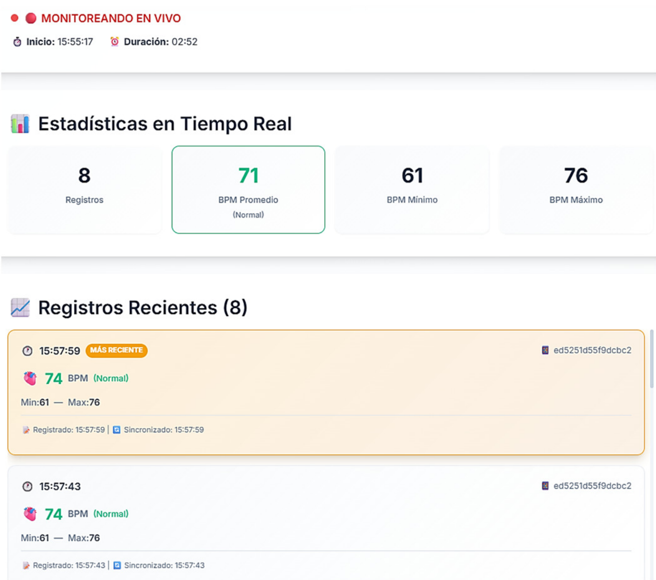

Fig. 7. Real-time monitoring section.

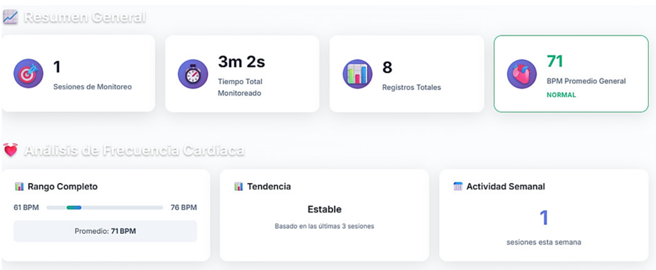

Fig. 8. Results section

TABLE VI. RESULTS OF EXPERIMENT II

ID	Scenario S1 BPM	Scenario S1 ΔSUDS	Scenario S1 PCL-5 Pre	Scenario S2 BPM	Scenario S2 ΔSUDS	Scenario S3 BPM	Scenario S3 ΔSUDS	PCL-5 Post
P16	78	16	33	72	10	70	9	26
P17	81	18	35	74	11	72	8	27
P18	79	17	31	73	11	71	9	24
P19	82	16	37	75	12	73	10	29
P20	80	17	32	71	10	69	8	25
P21	83	19	38	76	12	74	9	30
P22	94	20	48	85	14	82	10	38
P23	97	22	46	88	16	85	12	36
P24	95	21	51	86	15	83	11	40
P25	96	20	47	87	14	84	10	37
P26	98	21	53	89	16	86	11	42
P27	109	26	55	98	18	92	13	43
P28	112	28	66	101	20	96	13	52
P29	115	27	64	100	19	94	12	51
P30	113	29	68	102	21	97	14	54
Avg.	94.1	21.1	47.9	85.1	14.6	81.9	10.6	37.7

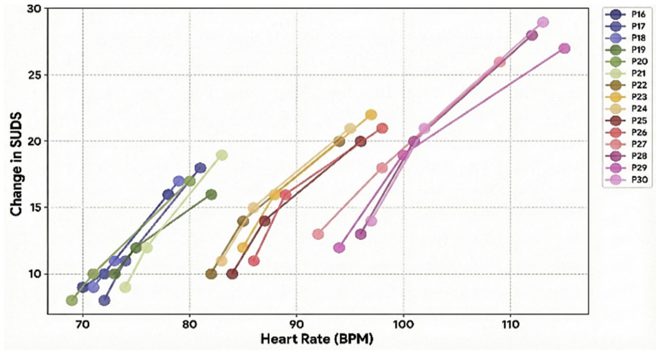

Fig. 9. BPM and SUDS trajectory in Experiment 2.

C. Comparative Analysis

Table VII synthesizes the averages obtained in both groups, allowing a direct comparison of differential efficacy. The comparative analysis confirms the superiority of the Synapse system in all indicators. The most relevant difference is observed in PCL-5: the experimental group achieved an improvement of 21.3% versus 11.8% for the control group. This difference of 9.5 percentage points reaches clinical significance according to the criteria from [20]. Furthermore, Figure 10 presents a bar chart comparing the PCL-5 percentage reduction for both experiments. Synapse achieved these results through greater initial emotional activation (BPM: 94.1 in S1), evidencing that VR immersion generates deeper emotional processing. This greater controlled activation translated into substantially larger anxiety reductions (ΔSUDS: 21.1), confirming that intense physiological activation favors fear extinction more effectively than imaginal exposure.

TABLE VII. COMPARISON OF EXPERIMENTS

Group	Scenario S1 BPM (%)	Scenario S1 ΔSUDS (%)	Scenario S2 BPM (%)	Scenario S2 ΔSUDS (%)	Scenario S3 BPM (%)	Scenario S3 ΔSUDS (%)	PCL -5 % Red.
Control (E1)	80.2	11.2	78.3	10.7	76.8	9.7	11.80
Experimental (E2)	94.1	21.1	85.1	14.6	81.9	10.6	21.30

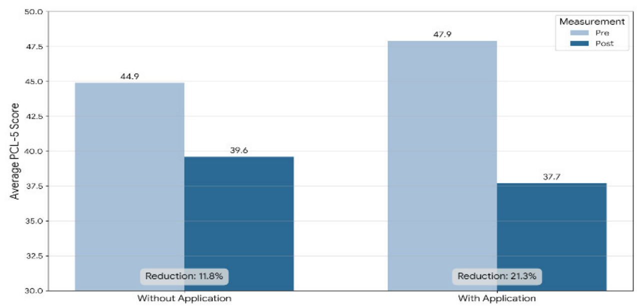

Fig. 10. Bar chart comparing percentage reduction in PCL-5.

D. Comparison with Related Work

Table VIII presents a comparative analysis of Synapse against similar VR-enhanced PTSD interventions reported in literature.

TABLE VIII. COMPARISON WITH RELATED VR-PTSD STUDIES

Study	Approach	Sample	Sessions	Trauma type	PCL reduction	Usability (SUS)
[21]	VRET (combat)	6	6-11	Combat PTSD	74.0% (PCL-M)	N/R
[22]	VRET (MST)	15	6-12	Military sexual trauma	d=1.14	N/R
[23]	VRET (firefighters)	4	5	Occupational trauma	26.9%	N/R
Synapse (this)	VRET+IoT	30	3	Sexual violence	21.3%	84.67

N/R = Not Reported; PCL-M = PCL Military version; MST = Military Sexual Trauma

Synapse achieved a clinically significant 21.3% PCL-5 reduction, comparable to military VRET programs like McLay (73% in 6-11 sessions) [21] and Firefighters (26.9% in 5 weeks) [23], but in substantially fewer sessions (3 vs. 5-12). This efficiency is attributed to three innovations: (i) culturally-adapted scenarios reflecting Peruvian contexts (Lima transport and residential settings) for higher environmental validity, (ii) real-time smartwatch-to-dashboard biometric monitoring for precise therapist-controlled dosing, and (iii) integration of evidence-based PET protocols combining imaginal exposure with 3D environmental cues.

Compared to Kothgassner's meta-analytic effect size (g = 0.62 vs. waitlist) [8], the 21.3% reduction translates to an approximately 0.88 (d) effect size based on the sample variance, positioning Synapse within the upper quartile of VRET efficacy. The usability score (SUS: 84.67) establishes clinical acceptability, as no comparable VRET-PTSD systems have published usability metrics, representing a novel contribution to implementation science in this domain.

Notably, the proposed 3-session protocol addresses a critical implementation barrier: treatment dropout. Traditional VRET protocols that require 8-12 sessions exhibit 20-30% attrition rates [8], whereas the condensed protocol followed in this study, with strong early symptom reduction (S1: ΔSUDS=21.1), may enhance retention in resource-constrained public health settings.

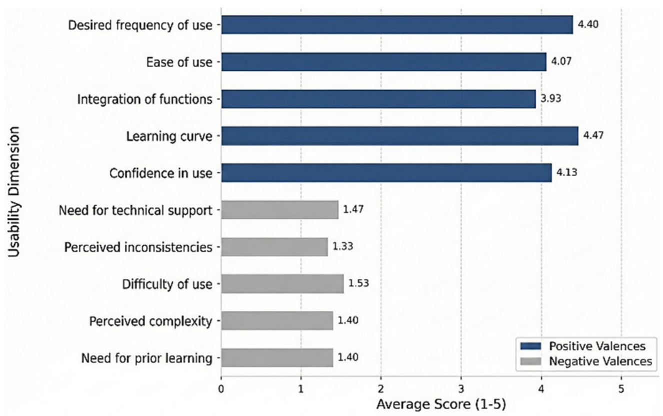

Fig. 11. SUS survey results chart.

E. System Usability Evaluation

After the final intervention, using the SUS, the results revealed a global average score of 84.67, a value considered "Excellent" according to industry standards. Figure 11 shows the average score of the 15 participants per question, where it is evident that the questions related to positive valences have an average of 4.20 (4 = agree) while negative valences show an average value of 1.43 (1 = strongly disagree).

V. CONCLUSIONS AND FUTURE WORK

This study developed and validated the Synapse system for the treatment of PTSD derived from sexual violence, integrating PET with VR and real-time biometric monitoring through a smartwatch. Validation with 30 patients in a private clinic in Lima demonstrated significant superiority of the system, as the experimental group achieved a 21.3% reduction in PCL-5 compared to 11.8% in the control group, achieved in only 3 sessions compared to 5-12 sessions reported in comparable VR-PTSD studies [21-23]. Comparative analysis with state-of-the-art VRET systems (Table VIII) positions Synapse within the upper quartile of efficacy ($d \approx 0.88$ effect size), comparable to McLay's [21] combat PTSD program (73% reduction in 6-11 sessions) and superior to Kothgassner's meta-analytic benchmark (g=0.62) [8]. This efficacy stems from three integrated innovations: (i) culturally-adapted VR scenarios reflecting Peruvian urban sexual violence contexts (home, public transport, bus stop), increasing environental validity for Latin American populations, (ii) Samsung smartwatch-to-Azure cloud architecture enabling therapist-controlled exposure dosing via real-time BPM monitoring (110 BPM alert threshold with 35 s latency), and (iii) structured PET protocol integration within immersive environments, combining imaginal exposure principles with three-dimensional contextual cues. Furthermore, the system generated greater initial emotional activation (BPM: 94.1 vs 80.2) accompanied by superior reductions in subjective anxiety (ΔSUDS: 21.1 vs 11.2), indicating deeper emotional processing of the trauma. Physiological habituation was stronger, showing a 12.96% decrease in BPM across scenarios, compared to 4.24% for traditional PET. The usability evaluation was 84.67 points in SUS, classified as "Excellent". Therefore, clinical viability is confirmed without existing technological barriers prohibiting it. The main contributions include: (i) hybrid cloud architecture optimized for Azure, (ii) clinical validation with objective metrics, and (iii) successful implementation in a private Peruvian clinic, evidencing operational viability. Thus, Synapse constitutes an effective and scalable tool to substantially improve the efficacy of PET in PTSD with potential for implementation in public health systems.

The following are proposed for future work: (i) longitudinal studies with follow-ups at 3, 6, and 12 months to evaluate the durability of therapeutic gains, (ii) multicenter randomized clinical trials with expanded samples ($n \geq 100$) in public and private centers, (iii) integration of ML algorithms for automatic personalization of exposure dosage, (iv) expansion to other trauma typologies prevalent in Peru, and (v) a pilot implementation program in community mental health centers to evaluate cost-effectiveness and scaling in the country.

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