

Article

Virtual Reality Exposure Therapy for Driving Phobia Disorder: System Design and Development

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Abstract: Driving phobia is an anxiety disorder. People are greatly impaired in their daily lives when suffering from driving phobia disorders. The anxieties can be triggered under various conditions, such as driving over bridges, driving at high speeds, or driving in close proximity to large trucks. Traditional cognitive behavioral therapy (CBT) and exposure therapy are the most common approaches used in the treatment of psychological disorders, such as anxiety disorder (AD) and panic disorder (PD). This research focuses on virtual reality (VR)-based exposure therapy, called VRET, and describes the design and development of a system which uses alternating levels of fear-based driving scenarios that can be recorded and automatically adjusted to maximize exposure effectiveness without causing the subjects to panic. The proposed VRET integrates an advanced feedback database module for tracing and analyzing the system, along with the user's bio-data to show the valid data collection of the system and its effectiveness for future use in clinical trials. The research conducts a system's pre-test analysis using 31 subjects to demonstrate the effectiveness of the system. This research demonstrates the systematic development of the VRET for driving phobia disorder by depicting the system framework, key system modules, system integration, bio-database management, and pre-test data analysis to support our next research efforts in hospital-based clinical trials and for additional VRET development applications for clinical psychology.

Keywords: virtual reality exposure therapy; driving phobia; post-traumatic stress disorder; physiological signal

1. Introduction

Post-traumatic stress disorder (PTSD) is a general term for any mental health issue that is triggered by a traumatic event experienced or witnessed by the patient. Many types of assaults can result in PTSD, such as physical or mental abuse, sexual assault, and serious physical accidents. People that suffer from PTSD have problems with daily, societal, and work-related activities. The condition interferes with one's ability to deal with normal life tasks. In 1980, PTSD was officially recognized as a mental illness by the American Psychiatric Association after the analysis of soldiers injured and exposed to traumatic experiences during the Vietnam war [1].

Cognitive behavioral therapy (CBT) and exposure therapy (ET) are the most common approaches for treating PTSD, anxiety disorder (AD), and panic disorder (PD) [2]. The goal of therapies is to change

patterns of thinking or behavior that cause mental disorders. CBT works by changing people's attitudes and their behaviors by focusing on the thoughts, images, beliefs and attitudes. Because there is no invasive treatment or psychoactive drugs used while conducting CBT, it is generally recommended by medical institutions [3]. The challenges of CBT are that it requires patient cooperation, is time consuming, and is difficult to execute as a standard procedure.

An emerging treatment approach for PTSD takes advantage of immersive-based information technology to advance exposure therapy using virtual reality (VR) and more sophisticated physical measuring devices (called VR-based exposure therapy (VRET)). VRET allows patients to slowly expose themselves to different levels of traumatic stimuli using immersions of vision, sound and tactile feedback, which matches the principle of systematic desensitization (SD). SD is evaluated by researchers to be as effective as CBT [2,4]. Using VRET, patients interact and are exposed to a simulation of the phobic surroundings, but do not physically encounter the feared situations and the immersive condition can be immediately adjusted to reduce additional harm that can be caused by stress and panic attacks resulting from overexposure. The curative effects of VRET are more significant (and more realistic) than CBT [5]. There are some issues to be considered when designing VRET as a therapeutic treatment [6]. First, VRET is an evolving technology, psychiatrists and psychotherapists have to experiment with designs and configurations of therapy, develop base scenes, changing scenarios, and integrate complex monitoring equipment while demonstrating that the treatment is effective, reliable, and valid. The development costs and design thresholds of VRET are considerably more challenging than traditional CBTs. Further, researchers must consider the realism of the immersive environments. If the immersive environment is not realistic, the patients will lack exposure and the curative effect (or an effective meta-analytic effect size for clinical trials) will be compromised. If the immersive environment is too realistic, it could trigger severe phobic reactions during the experiments and endanger the subject's safety. Finally, some patients may not be familiar with VR hardware and software settings. Thus, severe dizziness during the experiment may hinder the VRET results. Thus, patients' physical conditions and their suitability for VRET need to be carefully investigated to ensure the effectiveness of VRET implementations and applications [6].

Section 2 presents a literature review of immersive applications in PTSD, including traditional ET, CBT, and VRET. Section 3 introduces the methodology framework and the approaches used in this research. Section 4 demonstrates the system architecture and the hardware and software components that are adopted and integrated to build the immersive environment. Section 5 performs statistical analysis to the pre-test data, using the correlation coefficients between system and bio-data, nonparametric testing for gender difference and anxiety group difference, and an ANOVA test for ET level effects. A Shewhart control chart was applied to monitor the subjects' emotional arousal. Section 6 summarizes the VRET systematic research, describes the research contributions, and highlights the next phase VRET research for controlled clinical trials.

In principle, this research focuses on VRET design and development using seven increasingly frightening driving scenario levels. The proposed VRET integrates with an advanced system and bio-database module for tracing and analyzing the system and user's bio-data. The research conducts the system's pre-test analysis to demonstrate the effectiveness of the system. The main objectives of this research are to present the systematic development of the VRET for driving phobia disorder, including the VRET system framework, key system modules, system design theory, bio-feedback database management, and pre-test data analysis. The research outcomes will support our next efforts in using VRET for hospital based clinical trials for driving phobia disorders, and potentially extending VRET development to other applications in clinical psychology.

2. Literature Review

In this section, the literature review focuses on the latest state of immersive technologies and applications in PTSD-related psychotherapies. Publications from the American Psychological Association (APA), the Institute of Electrical and Electronics Engineers (IEEE) Xplore, and the Web of

Science (WoS) digital library are searched using keywords Cognitive Behavior Therapy, Post Traumatic Stress Disorder, and Exposure Therapy. The results were further refined to include Virtual Reality Exposure Therapy and Driving Phobia. The two groups of literature are simply divided into VRET and traditional treatments. The traditional treatment types are further divided into CBT and ET.

CBT and ET are commonly used to treat PTSD, depression, anxiety, and panic disorders. CBT reduces cognitive anxiety by letting patients understand the causes of their reactions and how to manage and change reactions that may exacerbate their mental condition. The efficacy of CBT on anxiety-related mental disorders, especially PTSD, has been confirmed by many studies [7–10].

Exposure therapy exposes patients to various levels of stimulating situations and continuously increases the intensity of the exposure to gradually induce a tolerance toward the exposure. Subjects are taught to self-analyze their reactions and change their behavioral response to better adapt to the changing conditions of exposure. Exposure therapy includes both imaginary and in vivo exposure. For imagined exposure, the therapist may ask the patient to imagine what they are afraid of. On the other hand, in vivo exposure allows patients to face the phobia directly. Some clinical trials have confirmed the effectiveness of exposure for treating PTSD. For example, Bryant et al. [11] divided 45 patients with PTSD into three groups—waiting list, exposure or counseling. The results showed that only 14% and 20% of the group members that received prolonged exposure and prolonged exposure plus anxiety management still suffered from symptoms of PTSD after treatment. Fifty-six percent of the supportive counseling group members were not affected by the PTSD treatment. The findings indicated that prolonged exposure may be a critical approach in the treatment of PTSD [11].

Aside from treating phobias, one of the successful applications of virtual reality technology is in the field of education. In one study, researchers have conducted a bibliometric study of the last twenty years from the Scopus database, and conclude that the use of virtual reality in education can improve the quality of the teaching and learning processes [12]. In Jesús López Belmonte's research, he asserted that digital technology has become a part most of people's lives and entered various fields of society. For example, he applies VR to education and reports that VR yields many benefits such as optimizing teaching and learning processes, timely access to new information, greater mobility, ubiquitous access, and adaptable to the uniqueness of each student [13].

At present, there are many studies on the applications of VRET for various kinds of phobias such as acrophobia, arachnophobia, and aviophobia [14]. In one study, a 50-year-old officer who suffered from PTSD caused by the Vietnam War underwent VRET. After 14 treatments of up to 90 min over seven weeks, his PTSD symptoms fell 34% under standard clinical measures. Self-assessment decreased by more than 45% [15]. Another study of flying phobia ET confirmed that VRET and traditional ET have no difference in statistical effect size. Seventy-five patients with fear of flying (FOF) were divided into three groups (25 people in each group): VRET, traditional ET and the waitlist (do nothing). After treatment, the results of VRET and traditional ET were almost equivalent while both groups were superior to those on the waitlist [16]. Another study used meta-analysis to integrate effects from 21 clinical studies with a total of 300 subjects. The analysis results (effect size) demonstrated that VRET effectively reduces anxiety [17]. Finally, our research studied the application of VRET in arachnophobia treatment, incorporating Arduino bio-sensors to collect real-time bio-data from subjects. Bio-data are integrated with the VRET system data and stored in SQL database for data mining and real-time VRET level adjustment is used to minimize over-exposure to the treatment [18].

Driving is an essential skill that facilitates independence and mobility of individuals in modern society and is often a requirement of employment. Being diagnosed with a driving phobia limits an individual's work options and creates issues associated with social interaction when mass transportation or transportation for hire is not available or unaffordable. According to emotional processing theory, successful exposure therapy leads to new and more neutral memory structures that overrule old memories that provoke and heighten anxiety [19]. In a VRET for driving phobia pilot study, 14 subjects with serious driving phobia were placed into a series of experimental conditions, including psychotherapeutic, medical examination, psychotherapy sessions, VRET sessions, and a final behavioral

avoidance test (BAT) when driving in traffic. The therapy session for each subject required 10 days to complete the experiment. After 6 to 12 weeks, follow-up tracking of the subjects was performed to access the subjects' driving performance and evaluate the effectiveness of the treatment for each subject. The follow-up tracking indicated that 13 out of the 14 patients maintained successful treatment results [20]. Another VRET experiment for driving phobia used eight females who were willing to try VRET but unwilling participants used *in vivo* exposure. The VRET exposure environment consisted of eight sessions which gradually exposed participants to increasingly uncomfortable exposure over 50-minute intervals. Factors, such as mean mood, anxiety, cognitive evaluation, quality of life, sense of presence, subjective discomfort, and heart rate were recorded during the experiment. The result showed that the sense of presence decreased as the session progressed while subjects' subjective discomfort scores and heart rate increased. After the experiment, subjects were determined to be more confident with their driving ability. Six out of eight subjects were willing to conduct *in vivo* exposure after VRET [21]. A VRET experiment for driving phobia related to fear of driving in tunnels was conducted. In the virtual reality environment, the car passes through a tunnel with lighting adjusted to resemble natural daylight on entry and exit, with increasing darkness and increasing lightness upon exit. The sound of traffic was also included to enhance the realism of the simulations [22]. The above driving phobia VRET studies provide a solid basis for continued research. The numbers of subjects in these studies are generally too small to draw a decisive conclusion or provide suggestions for future VRET refinement. Moreover, most of the literature evaluated their VRET system based on subjects' driving performance, and few focused on the subjects' biological senses and system recorded data analysis. Therefore, this pre-test experiment will examine the feasibility of using biological sensors and system-data collection and analyses to measure subjects' driving performance to ensure the safety and effectiveness of VRET toward phobia treatment. Further, to ensure the VRET is scientifically conducted, collecting real-time bio-data of patients is vital during the ET sessions. Matured bio-sensor solutions, such as the Arduino micro-controller, can transmit bio-data to a remote computer or cloud database using an XBee wireless network [23].

3. Methodology Applied in This Research

Figure 1 presents the research flow of this study for the driving phobia VRET design and development. The project formulation made at the beginning was to decide how to implement the research, perform risk assessment, and hypothesize expected results. Literature related to VRET, driving phobia, CBT, and PTSD were reviewed and referenced before designing the exposure treatment scenario. The virtual reality immersive environments were constructed to model different fear levels of scenarios. The constructed VRET prototype has been examined by psychologists and an iterative modification process was executed until the psychologists were confident that the system matched the needs of ethical and medically acceptable driving phobia treatments.

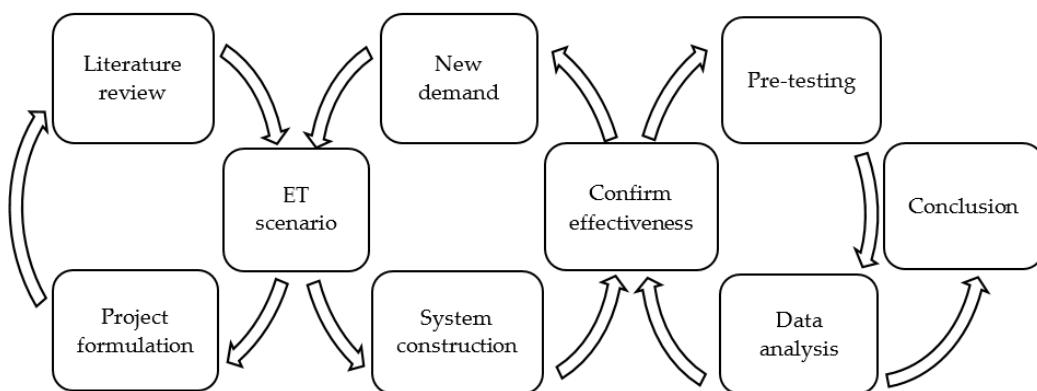


Figure 1. The research flow of the virtual reality-based exposure therapy (VRET) system design and development.

The VRET system is constructed using a seven-level exposure therapy design as shown in Figure 2. Since some patients are extremely afraid of car crashes, pedestrians and other driving vehicles do not appear in the immersive environment for the initial test runs. All of the simulation scenes follow a single route map. Subjects drive a specified distance to reach a destination before advancing to a higher level. Each level has its unique simulation environment, time, and treatment objectives. The details of each level are highlighted as follows.

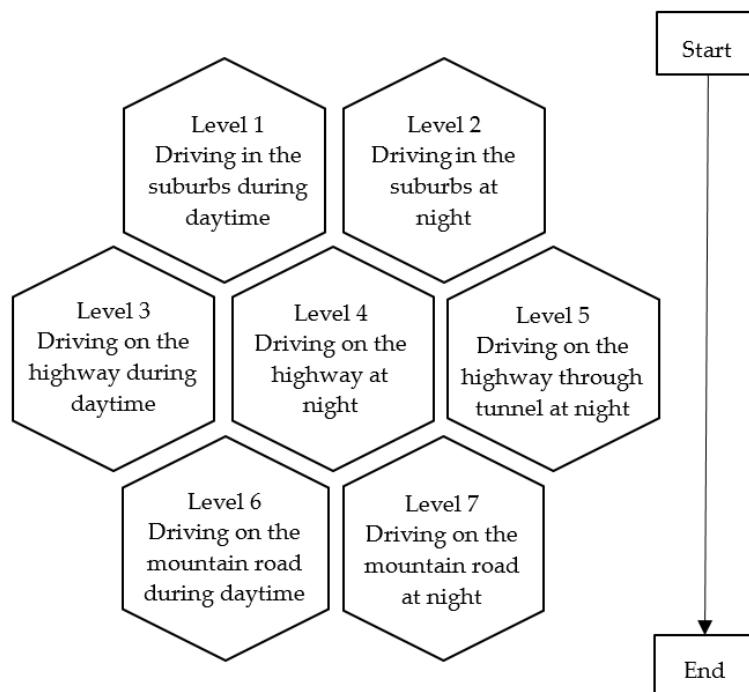


Figure 2. Scenario design level chart.

- Level 1 Driving in the suburbs during the daytime, the speed limit is 40 km/h.
- Level 2 Driving in the suburbs at night, the speed limit is 40 km/h.
- Level 3 Driving on the highway during the daytime, the speed limit is 110 km/h, and the system will ask subjects to drive faster if the driving speed is less than 90 km/h.
- Level 4 Driving on the highway at night, the speed limit is 110 km/h, and the system will ask subjects to drive faster if the driving speed is less than 90 km/h.
- Level 5 Driving on the highway at night, the speed limit is 110 km/h, and the system will ask subjects to drive faster if the driving speed is less than 90 km/h. Subjects will be expected to traverse a tunnel.
- Level 6 Driving on a mountain road during the daytime, the speed limit is 50 km/h.
- Level 7 Driving on the mountain road at night, the speed limit is 50 km/h.

The VRET experiment flow is illustrated in Figure 3. The treatment begins with a detailed introduction about the experimental objective, method, procedure, expected risk, and relevant disclaimer information. A pre-test questionnaire is completed by the subject before the experiment to measure the subject's mental state. The questionnaire asks about the subject's behavior, thoughts, and emotions in regard to previous driving experiences. During the experiment, bio-data including heart rate, skin conductance, body temperature, respiration, and head movement are recorded in the computer database for statistical analysis. If virtual reality vertigo or other motion sickness symptoms occur to the subject during the VRET session, an emergency stop is triggered and the experiment is terminated. After the immersive treatment is finished, subjects are asked to complete a post-test feedback form.

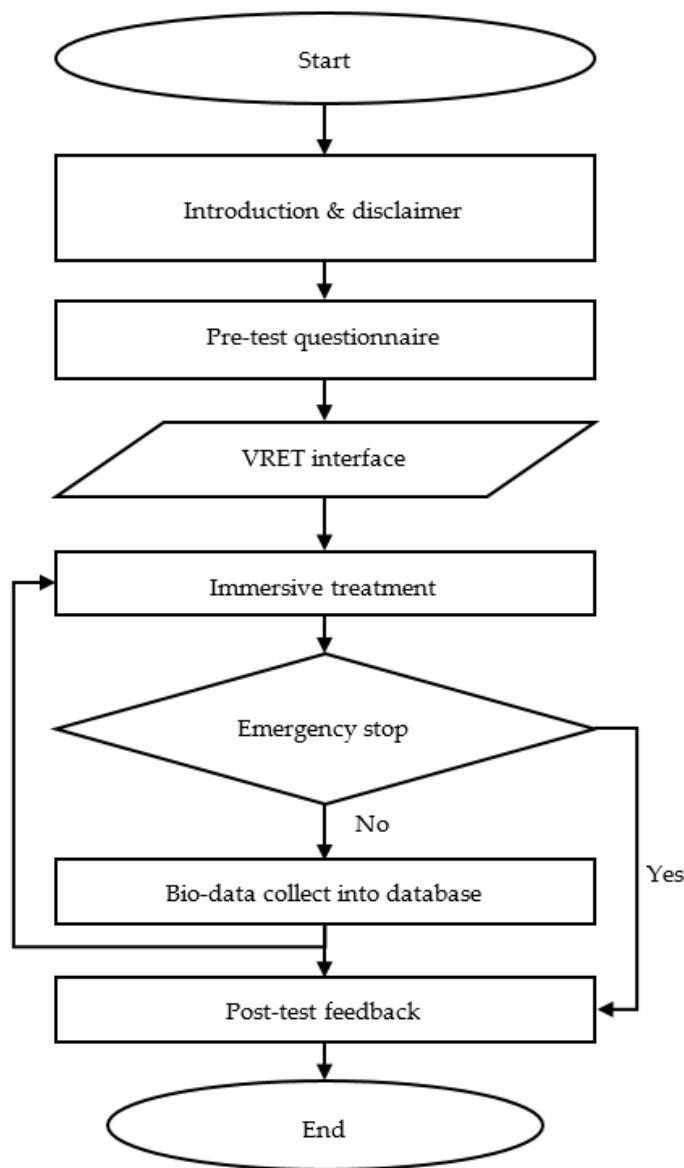


Figure 3. The driving phobia VRET experiment flow.

A total of thirty-one subjects including 14 males and 17 females at the university participated in the pre-test of the VRET prototype. The inclusion criteria are aged between 20 and 25 years old, possession of a valid driving license, and described a fear of at least one type of driving phobias such as driving on highways, mountain roads, or congested traffic.

4. System Architecture

The overview system architecture of this VRET research is presented in Figure 4. The VRET system (software) consists of four modules: the exposure therapy (ET) scenario module (7 scenario levels), the VR environment module, the data collection module, and the data analysis module. The VR-User interface (hardware) includes a VR headset, steering wheel, and bio-sensors. A database management system is developed to collect and integrate system and bio-data from the VRET system and the VR-User interface. The system's hardware, software, and database designs are described in the following paragraphs. For more technical details, please refer to [16].

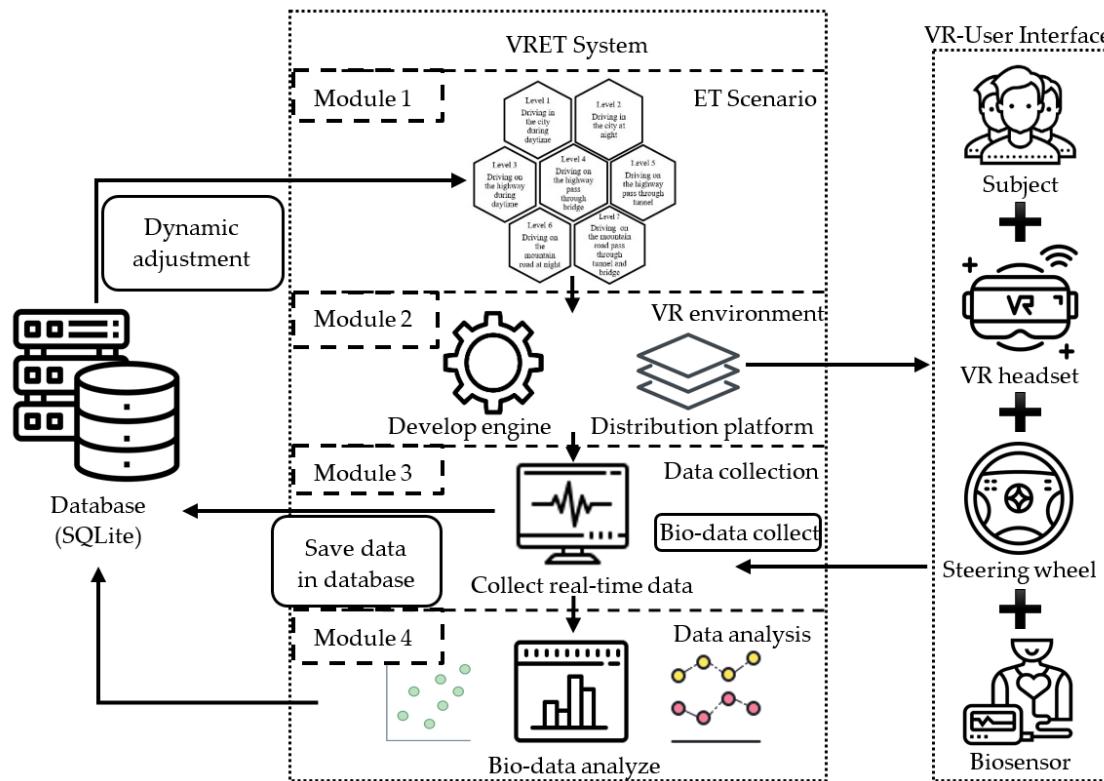


Figure 4. The system architecture for the driving phobia VRET prototype (refer to Figure 2 for Module 1 details).

4.1. Hardware

The hardware components used by the system include the VR headset (HTC, VIVE Pro, Taipei, Taiwan), the steering wheel (Guillemot Co., Thrustmeter T300 RS GT, Carentoir, France), and bio-sensors (Thought Technology Ltd., ProComp Infiniti, Montreal, Canada). The HTC VIVE Pro is a popular virtual reality immersive headset. The kit headset includes VR HMD, two base stations for movement tracking, and two motion controllers for virtual world interaction. The two base stations are able to connect the immersive environment with the subject's reactions to scene objects via motion controllers. The Thrustmeter T300 RS GT Edition is a high-end racing steering wheel equipped with a feedback mechanism, a specialized T3PA acceleration pedal that is integrated with steering wheel motion to provide realistic driving feedback to the subjects. The ProComp Infiniti is an eight-channel biofeedback system for real-time data acquisition that can be used with combinations of sensors including EEG, EKG, RMS EMG, skin conductance, heart rate, blood volume, pulse, respiration, temperature, force, and voltage.

4.2. Software

The software components adopted into the system include the development engine (Unity Technologies, Unity, San Francisco (HQ), CA, USA) and the distribution platform (Valve Corp., Steam, Bellevue, Washington, USA). Unity is a well-known real-time 3D development platform which enables users to develop both 2D and 3D games and models in Windows, iOS, Android, and over twenty types of systems. Microsoft C# is used as the programming language; users are allowed to control actions of virtual objects using specific C# scripts. Unity is compatible with other design software and gaming platforms that have external operating devices also compatible with Unity. Steam is one of the largest video game digital distribution service platforms in the world and also provides a virtual reality service called SteamVR to support the HTC VIVE virtual reality headset. Data collection and data management use SQLite (SQLite.org) as the database engine and BioGraph Infinite software to

record bio-data. The VRET database management system (DBMS)'s entity-relation diagram is shown in Figure 5.

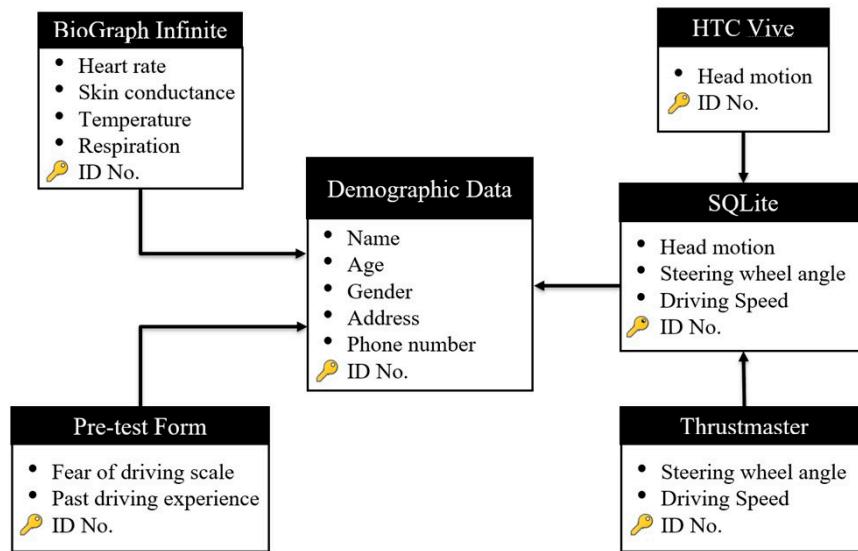


Figure 5. The entity-relation (ER) diagram for the VRET database.

4.3. Database

SQLite is a relational database management system (DBMS) contained in the C library. The reason for choosing SQLite over MySQL is because SQLite is a popular choice as an DBMS for client storage. SQLite is used to collect head motion, steering wheel rotation angle, and driving speed data in real time. These data are accessed from the database using the Python programming script. The database storage model is shown in Figure 6. BioGraph Infinite is a software platform that is specifically used for ProComp Infiniti data access, allowing high end users to create their own screens, scripts and channel sets. The purpose of BioGraph Infinite is to collect heart rate, skin conductance, body temperature, and respiration rate data during ET experiments. The biological and system data are integrated for analysis.

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Figure 6. Example of VRET's system database storage.

5. Pre-Test and Pre-Test Data Analysis

In order to examine the effectiveness of the VRET system and to improve the VRET system to facilitate future clinical trials, this study recruited 31 subjects for pre-testing. Before the pre-test experiment, subjects were asked to fill out the “Self-rating fear of driving scale,” for the purpose of measuring their degree of fear of driving. The rating scale was designed according to emerging measures offered by American Psychiatric Association [24]. During the pre-test experiment, the system data, bio-data, and subjects’ suggestions for refinement of the VRET system were recorded. This study was approved by the Chang Gung Medical Foundation Institution Review Board (IRB), the institution’s ethical commission, approval number 201901262B0.

5.1. Pre-Test Subjects’ Demographic Data

This study recruited 14 males and 17 females at the university participated in the pre-test of the VRET prototype. Pre-testing subjects’ demographic data including gender, height, weight, age, and the years of driving experience are presented in Table 1. 14 males with a mean height of 172.5 cm ($SD = 5.21$ cm) and a mean weight of 64.29 kg ($SD = 7.61$ kg), 17 males with a mean height of 160.43 cm ($SD = 4.75$ cm) and a mean weight of 52.71 kg ($SD = 5.44$ kg). All the subjects with a mean age of 22.39 years ($SD = 0.95$ year) and the mean duration of driving experience is 2.10 years ($SD = 1.13$ years).

Table 1. Pre-test subjects’ demographic data.

Subject No.	Gender	Height (cm)	Weight (kg)	Age	Driving Experience (Years)
1	Female	164	52	23	4
2	Female	164	62	21	2
3	Male	173	57	24	3
4	Male	178	74	24	2
5	Male	160	48	22	1
6	Female	156	48	22	1
7	Male	174	75	22	2
8	Female	153	52	23	1
9	Female	152	47	22	1
10	Female	162	52	23	3
11	Male	167	69	22	3
12	Male	172	58	22	2
13	Female	164	49	22	1
14	Female	161	55	23	4
15	Female	167	49	22	2
16	Female	166	62	22	2
17	Female	158	50	22	1
18	Male	175	65	22	1
19	Male	170	65	22	2
20	Female	165	50	22	1
21	Male	171	60	22	3
22	Male	170	65	22	1
23	Female	162	53	22	3
24	Female	160	65	21	2
25	Female	164	52	22	1
26	Male	174	71	24	1
27	Male	177	71	24	2
28	Female	162	46	22	2
29	Male	172	65	22	3
30	Male	182	57	25	6
31	Female	162	52	21	2

5.2. Pre-Test Procedures

1. Explain the purpose and precautions of the experiment and ask subjects to sign the consent form.

2. Subjects filled out the “Self-rating fear of driving scale.”
3. Subjects were equipped with bio-sensors for the purpose of detecting the real-time bio-data. Bio-sensors including heart rate, temperature, respiration, and skin conductance.
4. Conducting the pre-test VRET experiment and collect subjects’ real-time bio- and system data.
5. After the pre-test experiment, subjects were asked to fill out the feedback form and provide some suggestions to the refinement of VRET system.

5.3. Pre-Test Data Analysis

The real-time VRET system data, shown in Figures 7 and 8, and the pre-test subject’s bio-data, are shown in Figures 9 and 10. For the current prototype of VRET for driving phobia, the bio-data of each subject are monitored and analyzed for trends and correlations between bio-data and system data. The data spike abnormalities are monitored during the pre-testing experiment sessions. The goal is to improve the effectiveness of the therapy design of the VRET immersive system based on data analytic outcomes to avoid levels of driving conditions showing insignificant bio-effects or causing overly dramatic effects (i.e., lacking the feature of gradual systematic desensitization). The following discussion describes the statistical analysis results of the system’s pre-test experiments with 31 subjects.

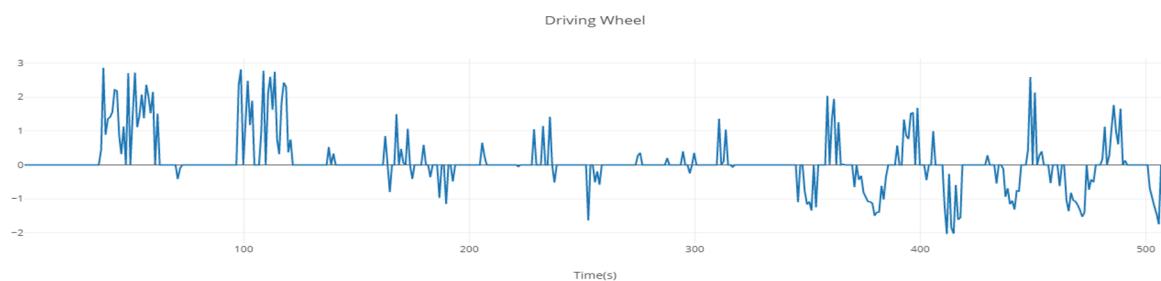


Figure 7. System data—Steering wheel rotation data tracking.

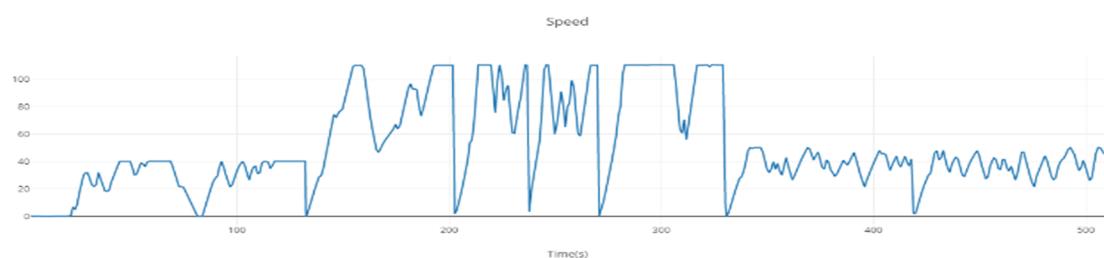


Figure 8. System data—Tracking driving speeds over time.

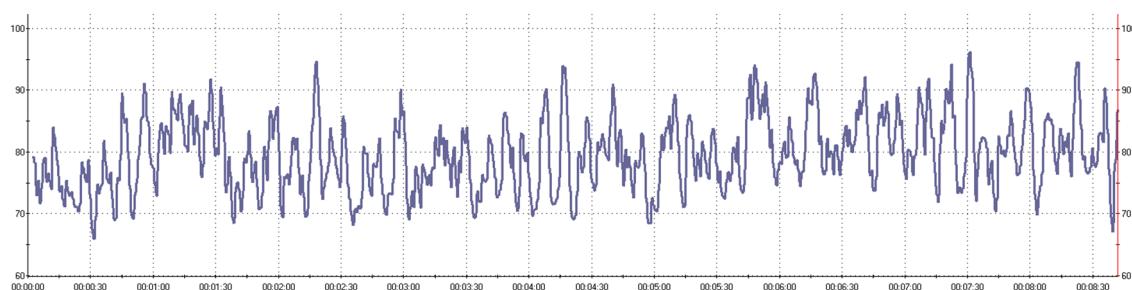


Figure 9. Bio-data—Tracking subject’s heart rate during experiment session.



Figure 10. Bio-data—Subject’s skin conductance during the experiment session.

The Pearson correlation coefficient has been applied to measure the strength of linear association between the VRET system data and the subject’s bio-data. The result indicates that the correlations are relatively small with most coefficients falling between -0.3 and 0.3 . Nonparametric test for gender differences compared the 14 males and 17 female subjects that participated in the pre-test experiment. The Mann–Whitney U test was used to test if there was a statistically significant difference between the overall satisfaction medians of the male and female groups. The null hypothesis is $\eta_{male} = \eta_{female}$, using a significance level of $\alpha = 0.05$, the p -values related to four kinds of bio-data are all higher than alpha value (0.05), so there is insufficient evidence to conclude a statistically significant difference between the overall satisfaction medians of the male and female groups.

The Mann–Whitney U test was also used to test if there is a statistically significant difference between the overall satisfaction medians of the high anxiety and low anxiety groups. Subjects were divided into two groups, high anxiety groups and low anxiety groups, according to the rating of “Self-rating fear of driving scale” filled out before the pre-test experiment. Eleven subjects were in the high anxiety group and 20 subjects were in the low anxiety group. The null hypothesis is $\eta_{high} = \eta_{low}$, using a significance level of $\alpha = 0.05$, three out of the four p -values related to bio-data (heart rate, respiration, and skin conductance) are lower than alpha value (0.05), so there is statistical evidence that there is a difference between the overall satisfaction medians of the two anxiety types. The VRET system does affect the subject’s bio-data according to their degree of fear of driving.

One-way ANOVA tests comparing means of bio-data in seven scenarios are used to estimate the 95% confidence interval and determine whether the associated population means in different scenarios are significantly different. The results are presented in Figure 11a,c,e,g. Fisher’s least significant difference method for multiple comparisons was applied to examine which means at different levels are different, as presented in Figure 11b,d,f,h.

The bio-feedback data of the one-way ANOVA interval plots, presented in Figure 11, indicate that pre-test subjects become increasingly anxious as the fear level of the scenarios increases (shown by heart rate, temperature, and skin conductivity trends). For detailed information from the ANOVA results, multiple comparisons analysis between different levels was also conducted, as higher fear levels tend to be assigned to the same groups and lower fear levels tend to be assigned to the same groups, a significant difference in the sample means between higher levels and lower levels was demonstrated. This trend supports the hypothesis that increases in the severity of pre-existing phobias increase the subject’s bio-feedback responses.

An interesting observation is that the bio-feedback data in level 1 seems to be significantly higher than level 2 data as shown in heart rate and temperature plots and the Fisher’s LSD method supports the same result. A possible cause of this phenomenon may be related to the experimental design where subjects never exposed to a VR environment may become more anxious during the initial ET session. As the experiment progresses, the subjects become acclimated to the VR environment so there is less tension and greater ease of use of the system. In order to prevent this problem from happening, a ten-minute static VR experience can be added to the experiment flow between pre-test questionnaire and VRET interface to stabilize the subject’s bio-response before the experiment begins.

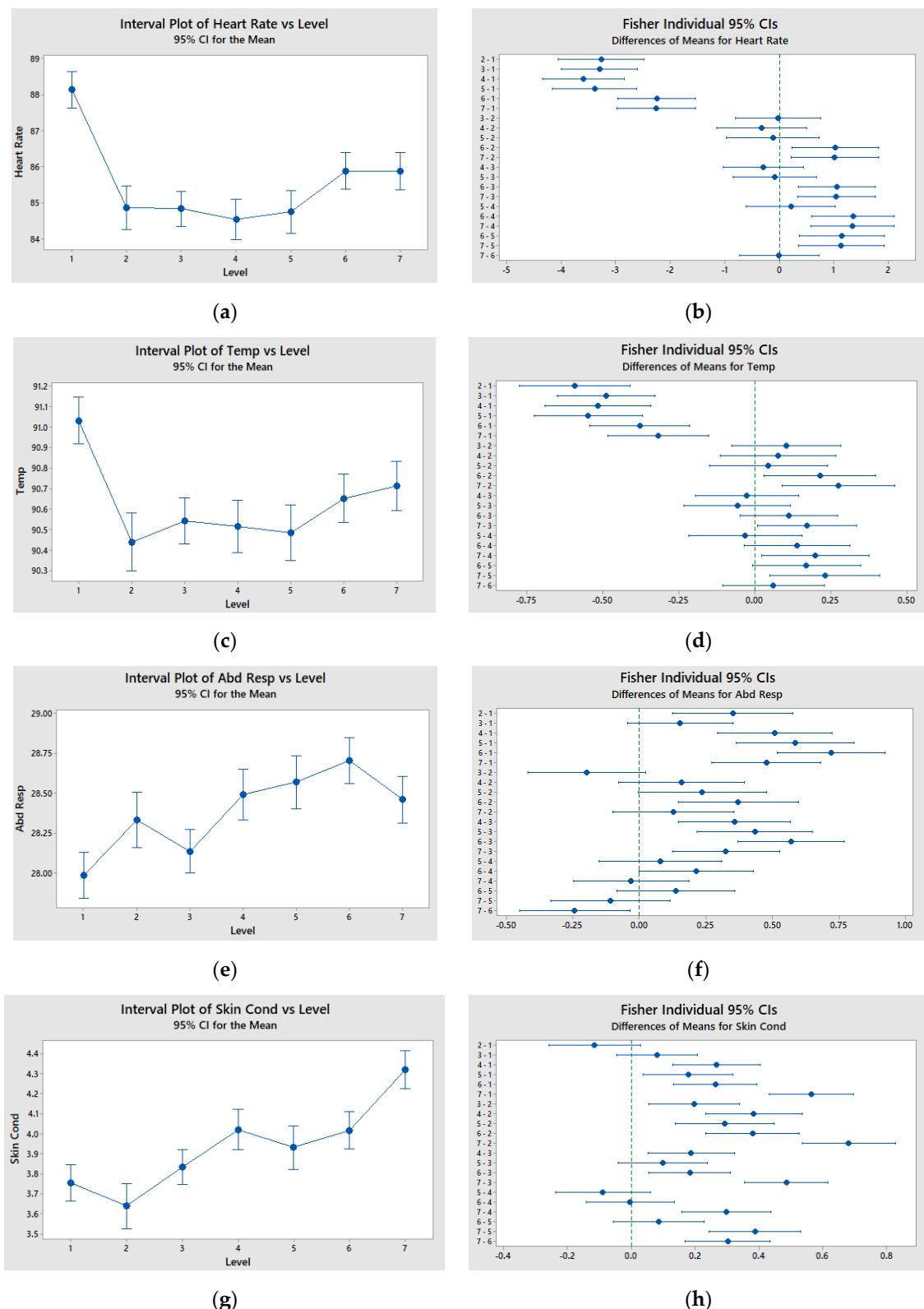


Figure 11. (a) One-way ANOVA interval plot of heart rate vs. level; (b) Fisher's least significant difference (LSD) method for multiple comparisons of heart rate vs. level; (c) One-way ANOVA interval plot of temperature vs. level; (d) Fisher's LSD method for multiple comparisons of temperature vs. level; (e) One-way ANOVA interval plot of respiration vs. level; (f) Fisher's LSD method for multiple comparisons of respiration vs. level; (g) One-way ANOVA interval plot of skin conductance vs. level; (h) Fisher's LSD method for multiple comparisons of skin conductance vs. level.

According to Dawson's research, if the amplitude of skin conductance is larger than $0.1 \mu\text{s}$, then the skin conductance indicates a larger emotional response [25]. In this research, skin conductance data are converted into the form of amplitude data. A Shewhart control chart of amplitude data is presented in Figure 12. If four out of five data points exceed $0.1 \mu\text{s}$, it is marked in red, which means the subject has a larger emotional response at this point of time. Sixteen of the thirty-one subjects meet the above conditions and have data points marked in red. These data points frequently appeared for the 6th, 21st, 25th, and 32nd subjects.

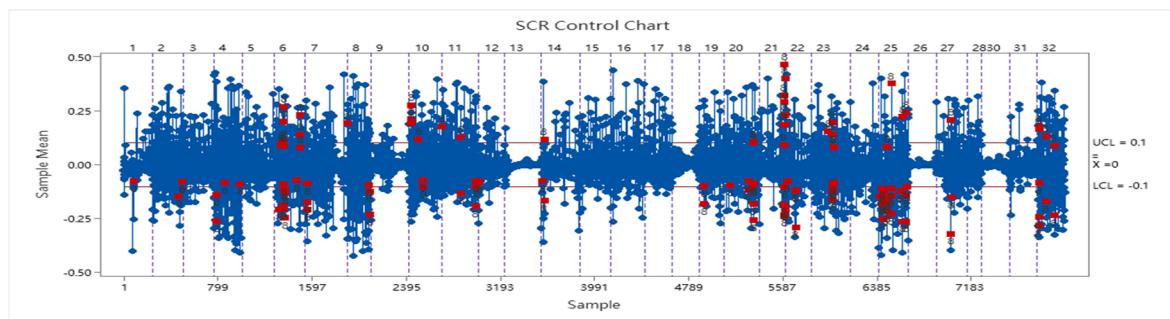


Figure 12. Shewhart control chart of skin conductance amplitude data.

The heart rate data are standardized according to individual data distribution and a Shewhart control chart of the standardized data is presented in Figure 13. If four out of five points exceed two standard deviations, the data points are marked in red indicating the subject has experienced a larger emotional response at this point of time. Twenty-one of the thirty-one subjects met the above condition with their heart rate data points marked in red.

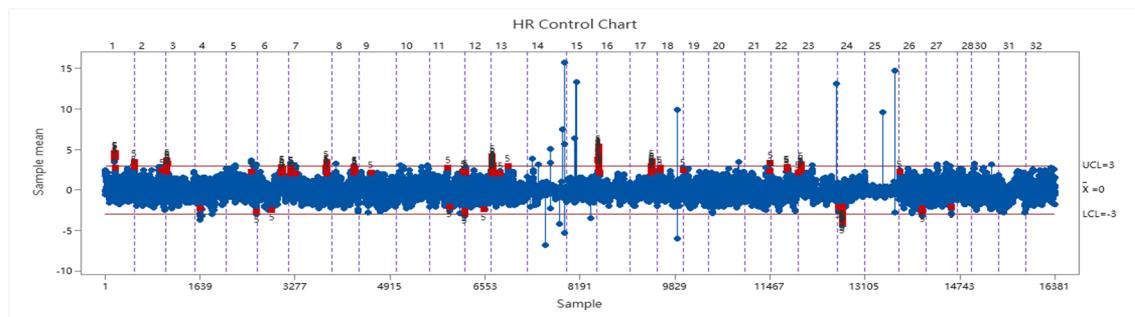


Figure 13. Shewhart control chart of standardized heart rate data.

5.4. Discussion of Pre-Test

The proposed VRET system has integrated system and bio-data collection for real-time data analytics compared to previous VRET research. In the Kaussner et al. VRET pilot study, anxiety and habituation during the VRET sessions were assessed using ratings on subjective units of a distress scale as well as the heart rate [20]. Costa et al. used subjective discomfort scores and heart rate to measure subjects' physiological response and sense of presence [21]. Additionally, in Claudio et al.'s fear of driving in tunnels research, questionnaires measured the outcome of the experiment and no real-time data was collected [22]. Most previous VRET literature uses heart rate for real-time data tracking. Temperature, respiration, and skin conductance are for real-time data tracking in our VRET system. These preliminary design and development efforts are for the construction of a self-adaptive VRET system that will automatically adjust the levels of exposure according to real-time data tracking. The proposed future system will be tested for improvements to the immersive experience and to better ensure subjects' safety.

Compared to previous VRET research which only demonstrates the development of VRET without verification, this research has uniquely combined VRET design and development with the verification of its efficacy through pre-test. According to the results of Mann–Whitney U test, there is a significant difference between the overall satisfaction medians of high anxiety groups and low anxiety groups. Moreover, the results of ANOVA analysis show that bio-data and level are positively correlated except for Level 1. Therefore, through pre-test data analysis, VR is demonstrated to provide the subject with a sense of authenticity and can indeed cause anxiety similar to actual driving.

The problem of high level 1 bio-data is also emerging within pre-test data analysis. For this problem, follow-up studies may consider adding a ten minutes of VR experience before the experiment starts to assist the subjects to adapt to the VR environment and to improve the VRET system for official clinical trials.

6. Conclusions

The immersive technologies, most typically referred to as virtual reality (VR) and lately also to include augmented reality (AR) enabling technologies, are popularly researched and developed to improve healthcare and treatments for physical, psychological and social wellbeing with respect to different populations and their health issues (e.g., elderly, autism spectrum disorder, PTSD, phobia, etc.) [26,27]. For example, Lee et al. [24] have comprehensively reviewed VR and AR technologies developed for physical, psychological and social wellbeing of an elderly population. The review article discovers that plenty of R&D has been deployed for improving physical healthcare and treatments. Nonetheless, considering the rising psychological (mental and social) health issues, there are great needs to pursue immersive technologies and design immersive solutions for psychological therapies and treatments. The research presents the systematic design and development of virtual reality exposure therapy applied to fear of driving. Therapeutic treatments for this phobia remain as a major clinical challenge for psychiatrists, psychotherapists, and their patients. A VR headset, a high specification steering wheel, bio-sensors, and software are integrated to develop a realistic driving experience in an immersive environment for effective exposure therapy. The subjects are exposed to varying levels of fear inducing driving levels for treatment. Thirty subjects provided pre-test data for the system. The bio-feedback data and suggestions for improvement were derived from the experiments. Through pre-test data analysis, VR convincingly causes anxiety like actual driving. Furthermore, some systemic problems are discovered, so the follow-up research can improve the VRET system and improve the system design. Carefully crafted experimental design is required for collecting valid and reliable data for the VRET analytical models and system modification. The clinical psychiatrists' feedback is critical to improve the design before the VRET can be used for clinical trials.

In summary, this research has presented the VRET technical components, the system framework, key modules for implementation, and the experiment database design and development for the research. Specifically, the bio- and system-data analysis demonstrates the efficacy of the VRET for use in initial hospital-based clinical trials with continued improvement as the trials are analyzed. In the future, the research team hopes to extend the VRET treatments to other phobias, such as acrophobia, arachnophobia, and claustrophobia. The future research direction also includes the intelligent development of self-adaptive VRET systems incorporating progressive brain neurology and brain computer interface (BCI) technologies. When the degree of a subject's fears are detected through advanced BCI sensors, the self-adaptive VRET system will have sufficient knowledge and intelligence to automatically adjust the levels of exposure to ensure safe and effective gradual systematic desensitization.

Author Contributions: A.T.: Constructed the research framework and incorporated VR and IoT technologies for the system; C.V.T.: CBT and ET literature overview for anxiety disorders and panic disorders, interpretation of meta-analysis studies; C.-M.C.: PTSD, OCD, and PD theories and clinical ET design; R.R.T.K.: VRET system development and implementation, data analysis; A.P.C.L.: VR and VRET literature search, VRET prototype testing, data validation; C.H.N.: CBT and ET literature review and data validation. All authors have read and agreed on the published version of the manuscript.

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