Universidade de Aveiro
2017

Departamento de Eletrónica, Telecomunicações e Informática

Gustavo Alexandre da Fonseca Madeira Lopes Bica

Can you feel the spiders: haptic feedback on virtual reality

Consegue sentir as aranhas: feedback háptico em realidade virtual

Universidade de Aveiro
2017

Departamento de Eletrónica, Telecomunicações e Informática

Gustavo Alexandre da Fonseca Madeira Lopes Bica

Can you feel the spiders: haptic feedback on virtual reality
Consegue sentir as aranhas: feedback háptico em realidade virtual

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia de Computadores e Telemática, realizada sob a orientação científica do Professor Doutor José Maria Amaral Fernandes, Professor auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro e da Doutora Susana Manuela Martinho dos Santos Baía Brás, Investigadora de Pós Doutoramento do IEETA, Departamento de Eletrónica Telecomunicações e Informática da Universidade de Aveiro

Dedico este trabalho à minha namorada e pais pelo incansável apoio.

o júri

presidente / president	Prof. Doutor Carlos Costa Professor Auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro
vogais / examiners committee	Prof. Doutor Miguel Tavares Coimbra Professor Auxiliar da Faculdade de Ciências da Universidade do Porto
	Prof. Doutor José Maria Amaral Fernandes Professor Auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro

agradecimentos

Agradeço à minha mãe e ao meu pai pelo suporte incansável dado, desde sempre, contribuindo para o meu crescimento e permitindo-me seguir os meus sonhos desde tenra idade. Quero agradecer à minha namorada pela companhia, conselhos e apoio dado, colocando-se a si mesma em segundo plano de forma a apoiar-me sem pensar duas vezes.

Agradeço ainda ao Professor Doutor José Fernandes e à Doutora Susana Brás pelo apoio, paciência, orientação e pelas horas que gastaram a ajudar-me com os seus conhecimentos e experiência, muitas vezes em detrimento das suas vidas pessoais.

Quero ainda deixar um especial agradecimento ao Departamento de Educação e Psicologia, em especial à Professora Doutora Sandra Soares pela sua colaboração.

palavras-chave

Sistema de Monitorização Portável; Realidade Virtual; Fobia de Aranhas; ECG; Unity; Leap Motion; Frequência cardíaca; Biofeedback; Sensor háptico; Bitalino

resumo

Os distúrbios de ansiedade são uma das doenças mentais mais comuns no mundo, afetando o quotidiano de um elevado número de pessoas. Embora exista um número significativo de pessoas que têm algum tipo de distúrbio de ansiedade, apenas uma pequena percentagem procura tratamento, preferindo simplesmente evitar a fonte da sua fobia, tendo como consequência a privação de momentos/atividades diárias. Com o rápido desenvolvimento e aparecimento de novas tecnologias, o número de soluções tecnológicas focadas em saúde tem vindo a crescer, juntamente com um número de estudos que demonstram que a realidade virtual permite resultados tão bons quanto o *in vivo exposure*, além de provocarem menores graus de stresse. Estes resultados podem contribuir para a redução do elevado número de pessoas que nunca chega a procurar tratamento. Um trabalho anterior do nosso grupo de investigação, o *Veracity*, utilizou realidade virtual no contexto da aracnofobia, um exemplo de fobia específica, de forma a proporcionar a exposição à fonte de fobia sem qualquer tipo de interação sensorial física. Com o *Veracity*, a interação foi realizada ao utilizar um dispositivo de reconhecimento gestual que permitia uma interação com o ambiente e aranhas, sem qualquer tipo de toque real.

Nesta dissertação, quisemos acrescentar ao sistema uma resposta virtual háptica como feedback ao toque em aranhas. Apesar de o uso de respostas hápticas já ter sido usado ou estar a ser implementado com sucesso, noutras áreas, para nosso conhecimento, trata-se de uma inovação no que refere a trabalhos realizados na área do tratamento de fobias. O feedback háptico tem impacto no nível do realismo/interação das aranhas virtuais, ao adicionar o toque ao estimulo visual. Através do feedback háptico enquanto se aumentava o realismo tivemos como objetivo manter a experiência virtual segura do ponto de vista do utilizador fóbico, quando comparado com o in vivo exposure.

Neste trabalho integrámos o feedback háptico dentro do *loop* do trabalho *Veracity* e avaliámos o impacto na resposta dos utilizadores, ao adicionar estas novas funcionalidades. Tal como no sistema original, continuámos a recolher as repostas fisiológicas, ECG, Frequência Cardíaca, Vídeo e *Tracking* 3D dos objetos virtuais, de forma a comparar as respostas dos utilizadores com, e sem respostas hápticas.

Uma avaliação preliminar do sistema sugere que este método é de interesse para futuros trabalhos, apesar de necessitar de uma avaliação mais detalhada, por forma a garantir a sua utilidade e impacto do feedback háptico, entre os utilizadores fóbicos.

keywords

Portable Monitoring systems; Virtual Reality; Arachnophobia; ECG; Unity; Leap Motion; Heart Rate; Biofeedback; Haptic Feedback; Bitalino

abstract

Anxiety disorders are the most common mental health problem in the world and it affects, on daily basis, a vast number of people all around the world. Even though there are a high number of people suffering from phobia, only a small percentage ever seeks treatment, usually sufferers avoid the source of the problem, even if it is meaning of constrains in daily and social activities. Due to the development and creation of new technologies with the focus on healthcare growing rapidly and a number of studies proving that virtual reality can be just as effective as in vivo exposure, while providing a less stressful experience, these findings can contribute to reduce the high number of people that never seeks treatment.

In previous works of our group, the Veracity, virtual reality was already applied in the context of arachnophobia, an example of specific phobias as a mean to provide an exposure without any physical sensorial interaction.

In this dissertation, we want to extend the system with a virtual haptic response when touching spiders. Although the use of haptic response has been used and it is being used successfully in other areas, to our knowledge this is a novelty in the relation to other works in the phobia treatment. The haptic feedback has impact in virtual spider's level of realism/interaction, by adding the touch to the visual sensation. Through haptic feedback, while improving the realism, we aimed at maintaining the virtual experience "safe" in the phobic user perspective in comparison to in vivo exposure.

In this work, we integrated the haptic feedback within the Veracity loop and evaluate the impact in the response of users to this new add-on. As in the original system we still collect physiological response of the users such as ECG, HR, Video and 3D tracking of Virtual objects that were used to compare the responses with and without haptic feedback.

The preliminary evaluation of the system suggest that this approach is interesting to pursue but still need a more comprehensive evaluation to assert its usefulness and impact within the phobic users of the haptic feedback.

Table of Contents

Tables

Figures

List of Acronyms

AR- Augmented reality

ECG- Electrocardiogram

ET- Exposure Therapy

HR- Heart Rate

OS- Operating System

PC- Personal Computer

TV- Television

VE- Virtual environment

VR- Virtual Reality

1 Introduction

1.1 Motivation and Context

Anxiety disorders are the most common mental health problem in the world [1][2]. Phobia is a subtype of anxiety disorder, which is defined by an extreme, irrational and intense fear towards an object, animal, or situation [3][4]. This fear is irrational, however, the sufferer is not always able to deal with it, causing severe alterations in his daily life routine [4]. One of the most common anxiety disorders is the *specific phobia*, with a prevalence of 12.5% [4]. Phobia is a medical term used to describe an irrational and persistent fear to an object, animal or activity [4], and we can see this irrationality taking place in everyday activities, such as, merely watching a TV show, or entering a room, or even enjoying a picnic. Arachnophobia, the fear of arachnids, such as spiders is a good example of a *specific phobia.* For a large percentage of population, watching a TV show where a spider pops up out of nowhere might not be the most enjoyable experience, but we will keep watching the show, while at same time, entering a room where there is spider, just means we have to pick up the vacuum cleaner and a spider crawling over our food in a picnic, just makes us clean it. But for someone suffering from arachnophobia, just seeing the spider on the screen is a really stressful moment [5], stressful enough to just make them stop seeing the show all together. The spider in the room can seem a pretty good reason to avoid entering that room, and finally, the fact that having a spider near you is a reasonable event to happen in a picnic, the best solution is to not make a picnic. This behavior is called avoidance behavior [6], the sufferer always find strategies to avoid any circumstance where the phobic element is present, conducing only to the intensification of the problem [7]. Therefore, one of the most common treatments is the "Exposure Therapy (ET)", which is considered the most effective treatment in phobias where the patient has to face his fear [2][4]. The fear exposition therapy works by exposing the subject to anxiety-producing stimuli, while allowing the anxiety to gradually attenuate [8]. These stimuli are generated through a variety of modalities, by visual content display, in vivo-exposure (subject is exposed to real-life situations), imaginal (via imagination), etc. [7]. However, all of them are typically delivered in a laboratory, under highly controlled settings and on an environment completely unrelated to the phobic individual every day experience [9], this solution, although with good results, has some clear downfalls. The most effective ET method, is the in-vivo exposure[2], [4], however, it is called "The cruelest cure"[10], which is explained by the high levels of stress that the phobic is exposed, which in many situations leads to give up starting/continuing therapy[2][5], mostly because for some patients this treatment is unacceptable, due to their low tolerate to this adrenaline-based approach [10],contributing to both high percentages of suffers that never seek treatment (60%-80%)[11], [12] and refuse treatment (25%)[12] . Fortunately, through technology there is room to improve already stablish and effective methods such as ET.

Two good examples of emerging technologies, with the potential to improve established treatments [13] are Virtual Reality (VR) and Augmented Reality (AR). VR aims to generate an experience of being in a computer-generated environment that feels realistic [14] while being interactive in real time [15], which allows us to create realistic and familiar scenarios specifically made for the phobia in hands, allowing the sufferer to not face the fear in direct contact, which in some cases can increase the phobia instead of curing it [8] or to provide a safe first approach, just enough to give the confidence to seek treatment. Considering the quick grow in the VR field, such solution could mean that the patients could apply the "cure" to themselves in the comfort of their houses, while enjoying an effective and cheaper solution.

Augmented Reality, unlike VR, limits itself to producing certain virtual elements to then merge them into the view of the physical world [13]. Experiencing an AR environment is fundamentally different from experiencing VR, in AR the user is kept in his world, while in VR the user enters a "new world" [13]. Due this difference, in AR there is not a problem with the level of immersion [13].

Both solutions, AR and VR, have multiple studies showing their effectiveness [16], [2], [4], [5], [7], [13], [17]–[21]. Although both technologies have potential, they also face problems, may it be the lack of a physical feedback [22] and/or immersion [23]. Some candidates to fill those gaps are the haptic feedback and biofeedback. Haptic feedback allows users to experience tactile stimuli, making systems more immersive and close to the real world [24] while the biofeedback has been shown to improve task performance and motivations to practice [25]. In the case of the haptic feedback, our main point of focus in this dissertation, although it has been used in dental training[24] and minimal invasive surgery[22], there are not studies making use of it in the treatment of phobias, the only studies that come close to it, are studies that use tactile augmentation while using virtual reality [18], [26], [27]. In these studies, the approach taken was to use Virtual reality goggles to increase the immersion of the VE and to use a toy of a spider to mimic the touch of a spider. Even though these studies show positive results, they lack portability and are more expensive due to the extra hardware and software required not only to accomplish the VR experience but also to track both the movement of the head and hands of the user.

Combining all these approaches, in a single solution could potentially create a low stress, dynamic, customized, comfortable, cost efficient and portable treatment with the potential to become the modern approach to treat anxiety disorders in general.

1.2 Goals

In previous works of our group, the Veracity [19], we have already applied virtual reality in the context of arachnophobia, an example of specific phobias as a mean to provide an exposure without any physical sensorial interaction. In Veracity, this was done by relying on touchless interaction with the environment and spiders using gesture recognition device, the leap motion.

The main objective of the current system is to integrate in the existing Veracity with real-time haptic feedback, to increase the realism and credibility of the solution (in some cases patient feels that without confronting the real fear he/she won't be able to overcome it [2]). To our knowledge this is a novelty in relation to other works in the area. The closest that we could find was the use of tactile augmentation [18], [26], [27] where the patients would touch a toy of a spider while immerse in the VR world. Our assumption due to the multiple studies reporting the importance of haptic feedback[24] and the efficacy of tactile augmentation[18], [26], [27], is that the haptic feedback, modulated by users own response, will increase the impact of virtual spiders by increasing their level of realism/interaction. However, our concern was also to keep the experience virtual safe from the phobic users' perspective.

Our system builds on Veracity approach; therefore, some overall guidelines still apply:

- Using a game with gradual process to present the stimulus to the individuals, while providing interaction with the virtual reality environment using hand gestures; the haptic feedback is introduced only in later stages – preceded with similar levels without haptic feedback for reference;
- Monitor the physiology of the individual's response and behaviour – we extended the tracking of virtual spiders and users hands in order to relate user interaction vs the stimuli; we also integrated Bitalino as a physiological monitoring device;
- Concern on providing a bio responsive system, that reacts to the patient in real-time;
- Test the system in real case scenarios to assert its efficiency in making the user reach the desired levels of anxiety.

In this dissertation, we propose put together multiple pieces (haptic feedback, biofeedback and the Veracity system) in a single solution. Thanks to the haptic feedback, the system is now more realistic and immersive without sacrificing performance (too much objects or detail in each object for a common PC to handle) and without increasing significantly the cost of the solution while at same time allowing the virtual spiders to have higher impact in the physiological signals of the user. This system is easy and quick to set up without the need to be used in a laboratory, allowing more natural reactions, taking advantage of the efficiency of ET, while being less aggressive and more interesting for the patient [2]. Providing real time feedback allows the patient/therapist to understand better the impact that the treatment has. Although our aim is not to replace the laboratory environment, we would be able to provide a solid first contact solution that would increase the number of people willing to seek ET [2],[16] or an alternative tool for therapist that would allow them to provide a better solution where an in vivo therapy isn't possible or would require high costs[24], for instance fear of flying where to be able to face the fear itself would require to be constantly flying causing not only a logistic difficulty, but also putting in question the patient privacy [5].

Contributions:

- Integrate haptic feedback in a VR experience applied to spider phobia scenario;
- Catch the spider V2 – evolution of previous game [19] to incorporate haptic stimuli as a response to user interaction / behaviour. This implied the refactoring of original "Catch the spiders" game to improve its responsiveness and to integrate new off-the-shelf units for physiology and haptic feedback (BitaLino);
- Improved tracking of interaction between user and VR entities for better behaviour vs physiological analysis (Video, logical VR entities tracking);
- Integration of biofeedback in a VR experience applied to spider phobia scenario, to allow the VR experience to become more adjustable to the different levels of anxiety and immersion that every user experiences.

2 State of art

2.1 Typical Treatments

Despite the low proportion of phobia sufferers who seek treatment [2], [5], [28], specific phobia is among the most treatable of disorders [4]. Some of the biggest reasons for the low number of people that seek treatment might be the high levels of anxiety that traditional therapies carries[10], conducing to a natural avoidance behaviour of the phobic. Nevertheless, patients that actually finished the traditional treatment, such as in vivo exposure, ended up reporting the treatment as highly useful [10]

2.1.1 Exposure Therapy

In anxiety disorders problems, the ET is usually the elected therapy, since it is considered the most effective treatment for a variety of anxiety disorders, being the in vivo exposure the most effective treatment of them all [2], [4], [5], [7], [8], [24].

Although there are multiple ways to perform ET, the principle behind them is the same, to expose the patient to his/her source of fear, by exposing the subject to anxiety-producing stimuli, while allowing the anxiety to gradually attenuate, the phobia ends up cured or decrease [7], [8].

2.1.2 In-vivo exposure

In vivo exposure considered the most effective type of treatment for anxiety disorders [2], [4], [5], [7], [8], [24]. In vivo exposure, as the name suggests, is the direct exposure of the patient to the source of fear, for instance, in vivo therapy for spider phobia, patients gradually and systematically approach closer to a live spider over a period of several one-hour sessions [5]. There are obviously certain limitations for the therapist in this kind of treatment. It demands in vivo exposure to objects or situations frequently unavailable in clinical settings [7][29]. To stay in the presence of the feared object, even in a controlled environment, may be retraumatizing for certain people, which can result in undesirable attrition/refusal/dropout rates [16], [2], [21], [29], [30],[8] contributing to the negative perceptions of exposure therapy that seems to pervade public sentiment [10]. Since in vivo exposure relies heavily upon successful modelling, it also requires that the therapist must be skilled at handling the source of fear, may it be snakes, spiders, roaches, etc. [29]. In vivo exposure also brings other issues, due to the impossibility of recreating certain scenarios in a laboratory, it may be required to jeopardize the privacy of the patient by “forcing” him to seek treatment in public places[16], [5], [13], [18], [24].

2.1.3 Systematic desensitization

Until the mid-1970s, systematic desensitization was the most widely used behavioural treatment for anxiety disorders [31], but subsequent research has since shown, that in vivo exposure to the feared stimulus is more effective [32]. Systematic desensitization, requires the patient to imagine the origin of fear/anxiety with the help of a therapist. The idea behind this treatment is that by associating the present lack of anxiety/fear to the imagination of the source of trauma, the patient will learn to control his/her fear [29]. Obviously, this treatment although simple and cheap has a major setback, the therapist cannot force/guaranty that the patient is actually imagining the desired scenario [7], allowing avoidance behaviour [6], [24], [33].

2.1.4 Multimedia presentation

This sort of treatment consists in forcing the exposure of the patient to the source of fear/anxiety through media presentation (e.g.: images [34], sounds [35] or videos [36]). These treatments are widely accepted as valid and effective treatments, but has been shown that all of them have clearly room to improve, may it be in terms of costs, a better public acceptance, lower avoidance behaviour or less induced anxiety.

2.2 Digital realities

With the ever increasing of technologies in our daily lives and the reduction in size/price, it comes with no surprise, to also see them bringing positive impact in fields such as healthcare, with the potential to improve or fixing problems with standard approaches to multiple healthcare problems, being anxiety disorders just one example. With the quick development of technologies in general, in the last years, we have seen also a rapidly development of AR and VR which contributed to the increase number of studies using such technologies.

2.2.1 Virtual Reality

The potential of virtual reality is clear, with the opportunity to create highly customized environment [5], [37], where the patient can explore/react with it, while avoiding real danger [8],[5],[37] and without the need to handle/acquire live animals [5][37], is possible to give an answer to multiple problems found in classical treatments.

One of the biggest advantages of the VR is the possibility to create the environment, all the objects in the VE and all the actors in it. VR gives the patient and therapist the ability to control and to create the feared object accordingly to their desire. For example, unlike a real spider, virtual spiders can obey commands [5], can behave as desired. VR allows the therapist to control how frightening the spider appears and it allows patients to confront fears that otherwise would not be as easily accessible as in a virtual environment. VR provides a controlled and protected environment that allows patients who were reluctant to start an exposure program more willing to get involved in treatment [2], contributing to reduce the number of patients that dropout from classical forms of treatment and has already been demonstrated to be an effective treatment [16], [5], [24], [38], and even, in some cases, a more appealing treatment[16].

Two particular areas where VR stands out is in flying phobia and small animals phobia, where arachnophobia is included. In the flying phobia, the possibility to treat the patient in the therapist office is a huge advantage, not only the therapist is able to provide an effective treatment, he/she is also able to reduce costs and avoiding dealing with the logistics problems of flying.

For the small animal phobias, not dealing with real animals can have mixed results, although it reduces refusal rates and dropout rates [2], as shown before, some patient consider to be necessary to face the real fear to really overcome the phobia, feeling that computer-generated spiders are not enough to make them believe they are confronting real spiders[2].

An important factor to consider in VR is the level of immersion[39], even though by increasing the exposure to a VR environment can increase the level of presence (immersion) that is felt by participants [18], the level of immersion still is a relevant question that any VR treatment has to take in consideration. The concept of immersion corresponds to the quality and the quantity of the stimuli employed to simulate the environment [13]. There are three levels of immersion[13], [24]:

- Non-immersive - Employs conventional workstation, used by most of us, with a monitor, a keyboard and a mouse;
- Semi-immersive - uses a relatively high-performance graphics computing system coupled with a large surface to display the visual scene;
- Immersive VR systems - projects the visual scene into some kind of head mounted device or large projection surfaces with the goal of completely filling the user's field of view.

Another approach to improve the degree of immersion and to improve the efficiency of interactions, is to take advantage of the combination of the three main sensorial channels: vision, audition and haptic [24].

2.2.2 Augmented Reality

Unlike VR where a new world is created, in AR limits itself to produce certain virtual elements and then merge them into the view of the physical world [11]. Augmented reality and Virtual Reality share some goals, being one of them the immersion, but here, the augmented reality has a clear advantage, because in AR the real world is present, to achieve a higher level of immersion is much easier. AR also aims at simplifying the user's life by bringing virtual information not only to his immediate surroundings but also to any indirect view of the real-world [14]. Just like VR, AR is also being used in multiple studies to treat with success phobias, in particularly small animals phobias [11], [35], [38]–[40].

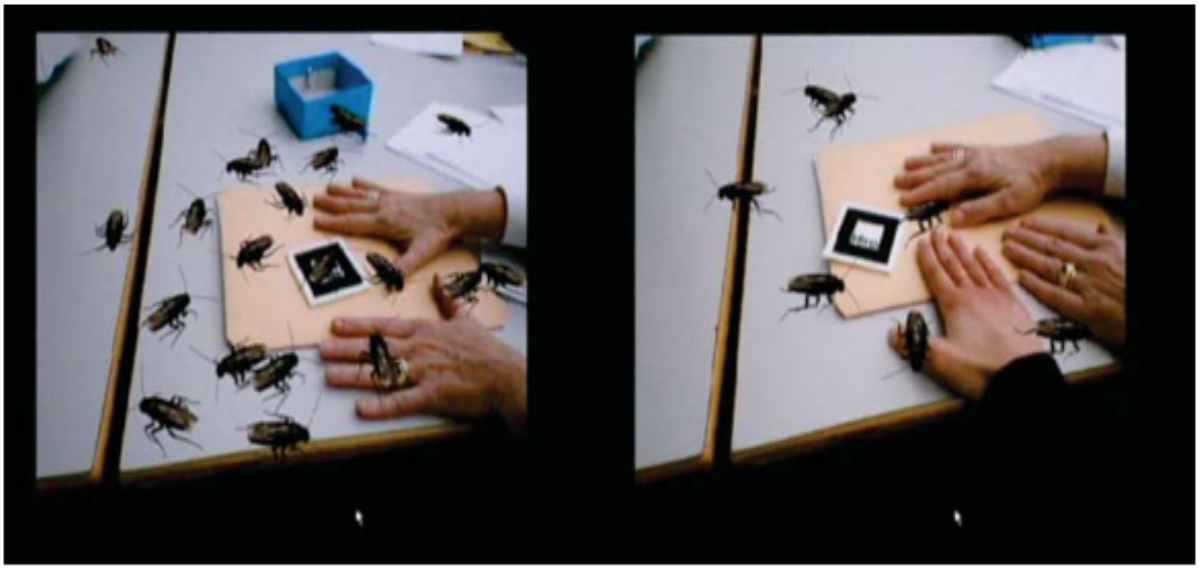


Figure 1– Example of an AR treatment, where the patient sees virtual cockroaches on a real table[36]

2.2.3 Haptic feedback

A tactile stimulus may have an important role in the immersion within a specific context namely the impact on level of involvement, attention focus on coupled or related events. So the sensation of feeling/touching helps subjects to focus more on the virtual reality experience as they become immersed in virtual reality surroundings which leads to an increased sense of presence[14].

For that reason multiple studies used/suggested the use of haptic/tactile feedback as a means to provide tactile stimuli within VR context [5], [26].

Haptic feedback is a simple, safe, inexpensive interaction technique for adding physical texture, force feedback or cues to virtual objects[27] that not only increases the realism and immersion, but also has the ability to help transferred virtual skills to the real world daily life[24]. It has multiple applications, namely in providing feedback whenever the user clicks on the screen or in more complex scenarios in training (e.g. medical training). One good example is dental training, where haptic feedback is already part of the dental curriculum of colleges of dentistry across the USA and the EU, it allows dentist apprentices and dental hygienists to acquire the psychomotor skills that are required to achieve complex clinical procedures[40].

Haptic feedback shares a close resemblance with tactile feedback, the term haptic feedback is typically used in a more broad sense which includes multiple characteristics of the touch, the tactile and force information

[41]. However, the use of the term haptic feedback is also commonly used as a simplify way to describe force feedback applied to the user through rumble of a motor, controller, etc [14], [24], [42], [43] or by providing opposite force to the user motion [22], [44]. On the other hand, tactile feedback is usually associated with texture and not necessary associated with the use of a motor to provide the feedback[14]. Both methods, tactile and haptic, have the goal of providing a sense of touch to the user, the major difference is the way the touch is simulated, while in tactile this sense is accomplish normally by using props[27], when using haptic feedback is common to use motors.

In the context of treatment of phobias, the use of haptic feedback, to best of our knowledge this is a novelty. However, tactile feedback has been used multiples time namely as tactile augmentation using a toy spider while the user was immerse in the VE using VR goggles[5], [26], [27]. In these studies, the goal was to provide a more effective treatment than VR by merging together a real object with the virtual spider, by doing so the level of immersion would be increase and the spider would feel more realistic and interactive. These studies shown that tactile augmentation led to a bigger improvement in users in comparison those that were only submitted to the VR. From these results is natural to consider that using haptic feedback to treat specific phobias, such as, arachnophobia, may have similar positive impact as the tactile augmentation presented.

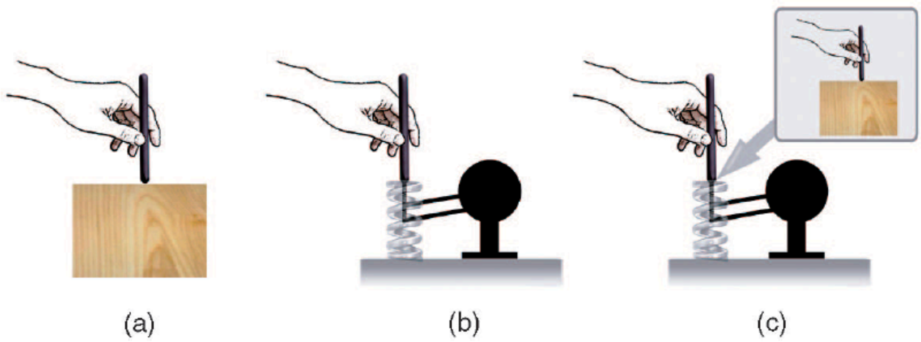


Figure 2 – Example of haptic feedback: a) contact with a real object; b) position-based virtual wood; c) event-based virtual wood

2.2.4 Biofeedback

Biofeedback lacks a clear definition as can be easily testified by the multitude of definitions and interpretation within the published studies[7], [45]–[47]. However, overall, most studies tend to support that it has a positive contribution regardless of the application. In a clinical setting, biofeedback, has been used to manage disease symptoms as well as to improve overall health and wellness. Research has shown that biofeedback interventions provide an efficient treatment in a variety of medical conditions [48].

In this work, biofeedback will have narrower scope and will refer to the computer based system that allows individuals to receive some form of return in a given context that is modulated by their physiological status quantified using biomedical sensors[45]. This type of systems has been shown to have positive impact on task performance and on increasing motivation to execute prescribed experiments [49], on valid treatment for headaches disorders [47], on improving balance and reaction time[15]. Biofeedback can also be used in relaxation training, by providing real-time clues to the subject on his physiological helping him to understand (consciously or not) and to learn to develop strategies to reached / maintain a given anxiety level [46][50], [51].

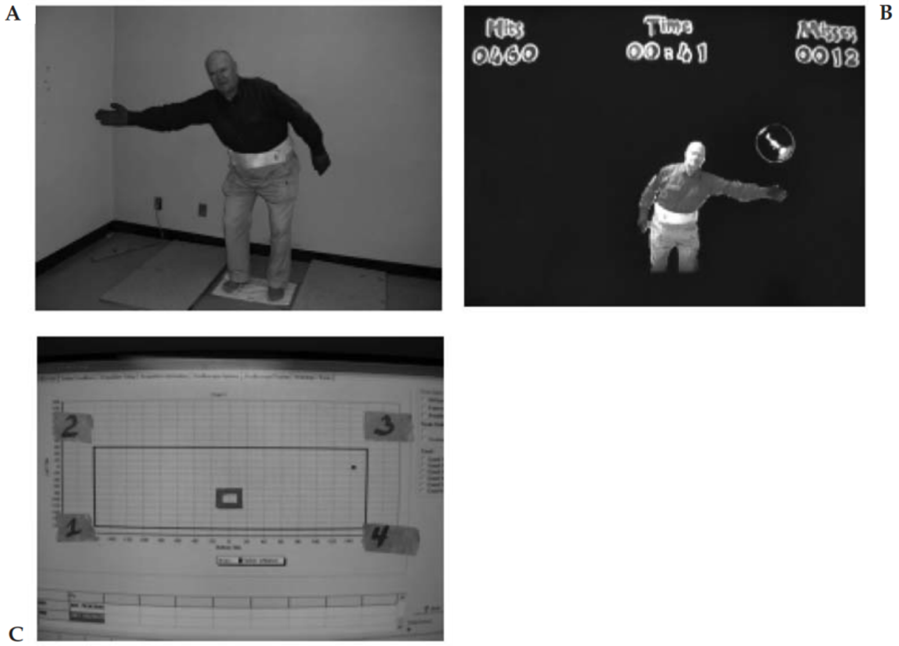


Figure 3 – Example of a biofeedback training session [13] - (A) The participant stands in front of the camera and television monitor while working on one of the activities involving reaching. (B) What the patient is seeing during the session on the television monitor. (C) The patient view of the center of pressure displacement on the screen during biofeedback training.

2.3 Phobia: when virtual can help the reality

As seen before, typical treatments although effective, have major problems. The biggest one is clearly the fact that around 60–85% of sufferers never seek treatment[11], and in the small percentage that does seek treatment approximately 25% either refuse exposure therapy upon learning what it entails or drop out of therapy[11]. Another problem is the difficulty to reach desired anxiety levels, media exposure or imaginary exposure, only work if the patient reaches a minimum level of anxiety required to "activate" the phobia[13], which is difficult to do, considering that the therapist cannot force the patient to pay attention or to actually imagine the source of fear. And considering the normal tendency of avoidance behavior is easy to see why this type of treatments might not always be effective.

Using game logic and haptic feedback the therapist can maintain the patient focus on the treatment, and provide a treatment with a much higher acceptance between the sufferers, only 3% refuse treatment using VR and when given a choice, 67% chose the VR over in vivo exposure[2].

By introducing the haptic feedback the patient not only is expected to stay more focus on the task, but also to be more involved and connected to the VE. Moreover, as seen before, the haptic feedback also provides an essential component from the in vivo exposure, which is the real-life exposure. This "real" exposure is a key part of the treatment of phobia, by confronting the real fear, preferably, in a real-life scenario, the patient is capable of diminish his/her fear. Although in VR the patient is not interacting with real life objects, it is possible to create closer to real life scenarios, that by using the haptic feedback provides a solid solution to transfer these "virtual skills" to the real world and helping to decrease the gap between the VR and real life. By using a combination of intuitive input system, such as, the leap motion where the user uses his/her own arms/hands and the haptic feedback, the way the patient behaves and interacts with the VE is more similar to real life than the "basic" VR.

VR also allows to reduce the occurrence of unpredicted events during exposure such as weather, turbulence, broken elevator, unpredictable animals, etc. While at same time allowing the therapist to repeat scenarios as many times as required, in the order that he/she wants with the actors in the VR environment behaving in the manner that is most useful for the treatment.

Another important benefit is the ability to have a stricter controlled environment (as we just saw), but much more portable and easy to setup. VR systems can allow the therapist to perform a large variety of treatments in the patient home (allowing to confront the fear, in a closer scenario to what would happen in the patient daily life) or in therapist office, without the need for logistics nightmare or recurring high costs for the patient.

In essence, by combining these digital realities, we can produce an effective, easy, portable, cheap, highly customized and controlled environment that takes advantage of well-established methods of treatment such as ET.

2.4 Humans monitoring in virtual environments

Due to the success of virtual treatment [2], [18], [20], especially in phobias, monitoring humans in VR is somewhat common[23], [24][24], [44].

There is a set of physiological measures that are typically used to quantify the human physiologic response namely:

- Heart rate[19], [24], [48];
- Skin resistance[7];
- Skin temperature[45];
- ECG[19], [23], [24];
- Respiration rate[7].

Applying these measures in VR environment could help better understand the patient response and better characterize the effectiveness of the treatment itself.

A good example is the study Fear of Flying: A Case Report Using Virtual Reality Therapy with Physiological Monitoring [7] where the patients with phobia shown a clearly diverge from the non-phobic results, although the non-phobia patients shown variations on their results (a decrease in the skin resistance), not only that decrease was lower, it came back to the normal values much quicker.

All these physiological measures are based on the variation of their values and how quickly they return to their value[7], [23], [24].

3 Catch the spiders

3.1 Catch the spiders - Original version

This work is on top of previous work, *Veracity* - Low cost physiology assessment tool using Virtual Reality [19]. Veracity work comprise two main parts – one based on AR experiments, the other on the "Catch the spider" game which is more relevant for our work. Both system focus on the scenario of spider phobia and presented ways to expose users to virtual spiders while being monitored.

Figure 4 – Veracity augmented Reality: A) Mobile Device running the main game, the device camera recognizes the marker and deploys the VR in top of it, in the respective device screen; B) Developed Virtual environment [16]

3.1.1 Augmented Reality Experiment

The *Veracity* augmented reality version consisted in using markers, in this case a 5€ or a 10€ bill, the application, using phone's camera, would detect the bills and start the game.

The game basically consisted in two different mini games. The first one, required the user to move a box, using buttons on the virtual environment or by moving the finger to the desired direction, in order to catch as many spiders and donuts as possible. The second one, consisted in trying to catch the object displayed in a white text at the bottom of the board.

Most of the downsides rely on inherent properties of the AR itself, one of them was the fact that to be able to implement AR is required the use of markers, because for us, markers are not something normal, it could easily steal the attention from the users, reducing the level of immersion and removing the focus from what is important, the spider. Another problem was the fatigue that resulted from holding the mobile device, by trying to keep it pointed to the respective marker/markers, but also trying to maintain the mobile device stable the users would become tired.

Finally, this solution would turn the tracking of the hands extremely difficult. Forcing to leave out an important information from the collected data.

3.1.2 Catch the spiders – the game

The Catch the spiders was the VR supported solution for *Veracity*. It consists on a game, divided in 6 different levels with increasing exposure to virtual spiders where the system feedback is modulated by the user hand position, which is tracked by the leap motion device.

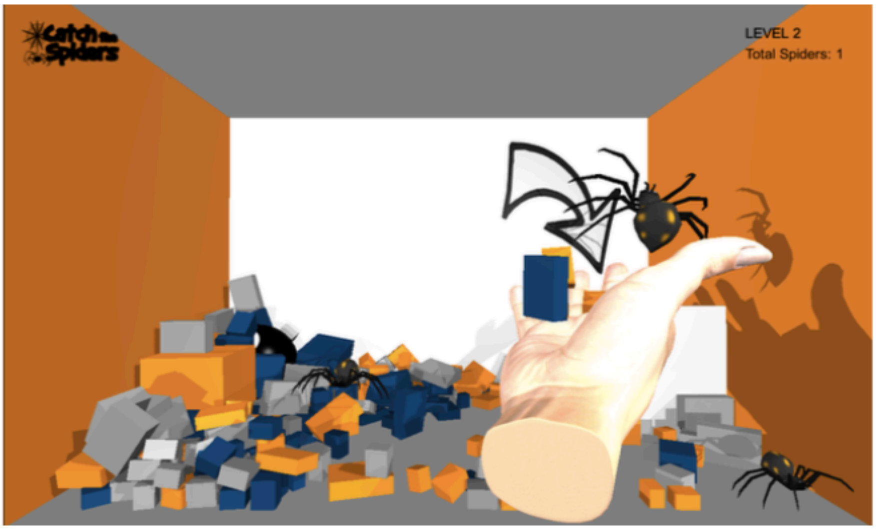


Figure 5 – Catching the Spiders on the Level 2 [16]

The first two levels consisted in adaptation levels, where the user is invited to explore the virtual world and to adapt to the leap motion. From those first two levels on, the goal of the user was to capture as many spiders as possible by putting them inside the box. To increase the difficulty, there were also added random objects, and every time a spider was caught, a new one would respawn. Finally, in the last level, the goals would reverse, this time, the spider would be the one trying to catch the hand.

3.2 Catch the spiders V2

The main contribution of the current work is the Catch the spider V2. This work follows on the approach of the Catch the spiders in part based on its positive feedback – for that reason the original game environment was maintained in this project to allow a tested and controlled environment capable of reproducing similar results of other studies. However, although the original architecture already provided a solution combining both VR experience and user's physiological response monitoring, the introduction of new sensors and addressing existing issues implied refactoring the original implementation.

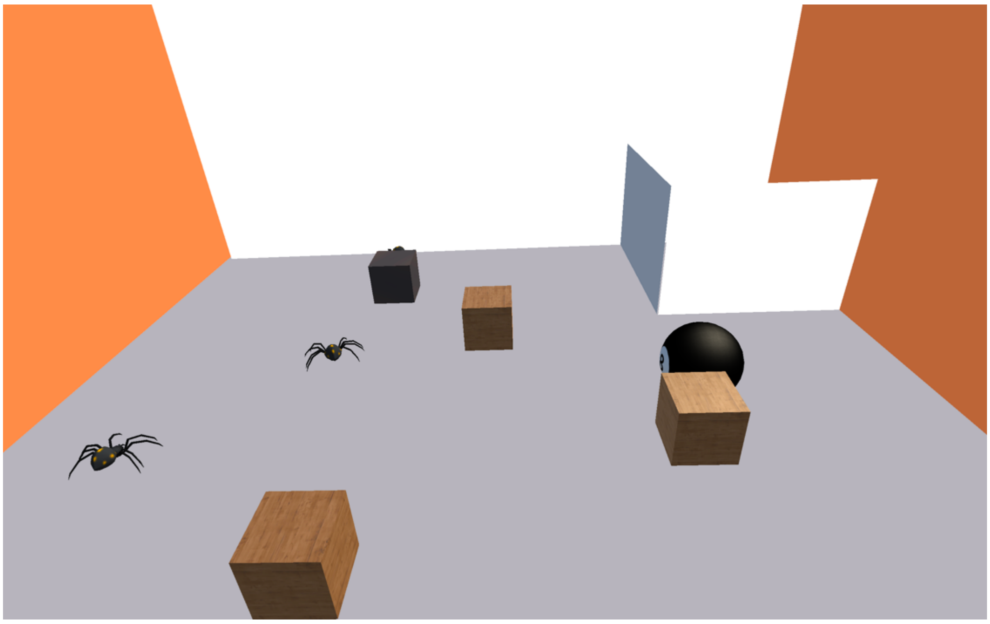


Figure 6 – VR environment in the 2nd level

3.3 The Game

Most of the higher structure of the original Catch the spider was maintained, may it be the game logic of levels and on each level increasing the level of difficulty or introducing a new concept, or the game objects, such as the spiders, cubes and storing box.

A) B)

Figure 7 – Game levels from A) Original Catch the spider and B) Catch the spider v2

3.3.1 Game levels

All levels have a common goal that is to pick all the objects (with exception of the 8-ball, unless intended) and place them in the box. The change of levels is always controlled by the system operator, not the user, although every time the user places all the objects in the box or stores the 8-ball he/she is greeted with a notice on the screen. This option was made to reduce inadvertent change of levels (e.g forgot that the 8-ball is just to end the game).

The game is divided in 4 levels and a configuration stage (just to check Pulse sensor and ECG are being collected correctly). In the configuration screen a line is modulated by the inputs – if the line is red and/or the line is flat some problem occurred namely, no incoming information from the Pulse/ECG sensor , in other situations, the colour is orange, in case we have real data coming in.

A) B)

Figure 8 – Levels of new version: A) Level 1 – Adaption level, the user just needs to store the cubes B) Level 2 –First level with spiders, but not haptic feedback

The first level is just a level to collect baseline data and to allow the user to get used to the environment and mechanics of the game. The first level consists only on trying to pick up the cubes and/or the 8-ball and storing them in the box.

The second level, introduces the spiders and the biofeedback. The haptic feedback was not introduced in this stage, the idea is to study if haptic feedback is capable of inducing significant alterations on anxiety levels when dealing with the spiders.

3.3.2 Game objects

Most game objects are very similar if not the same of the original version, because they were well received and in order to reach new conclusions it was important to reduce the number of variables that could impact the final result, for instance, if the spiders were changed to a different model, would that be the real reason for the variations on the HR and ECG, do the users consider it to be more realistic? To avoid these uncertainties to infer the real impact of the haptic feedback and biofeedback, the objects are the same or at least similar to the original version. The major change was the decrease in the number of objects and the spiders do not respawn. This change was made has a trade-off between computational resources needed to both ensure a fluid experience of the VE and, at the same time, needed to be able to acquire all information i.e. the position of the hand, position of all game objects, interactions between objects, events, Pulse and ECG are being recorded every frame, the more objects we have, higher are the chances for the PC to become overloaded with these information. This decision also allows to focus more on the spider - the main focus on the game.

Figure 9 – Zoom view of the spider from the front

Figure 10 – 3D model of the spider view from the top. From https://www.assetstore.unity3d.com/en/#!/content/22986

Besides the spider, the new version kept the following objects as part of the scenarios:

- Cube
- 8-ball
- Hand

3.3.2.1 Cube

The cube is present in the VR environment to allow the user to have an initial training without contacting with any spider, so the use of leap motion or the adjustment to the VR environment are not a relevant issue to take in consideration. Another interesting approach to use to the cube, is to see the reaction from the users, do they try to catch the cubes before the spiders? Or do they simply grab whatever comes first? Does it change according to the level of phobia? All these questions can be answer by analysing the events log, from which is possible to create a chronological timetable where is easy to see what the user interacted and in what order.

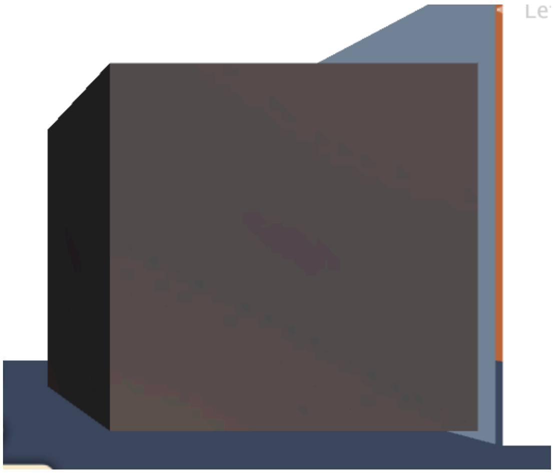


Figure 11 – 3D model of the cube

3.3.2.2 8-ball

We decided to maintain the 8-ball (a free model in the Unity asset store (https://www.assetstore.unity3d.com/en/#!/content/24730)). The concept behind it was to have a marker that would be specific for a set of conditions, end the game if the individual is tired and wants to end the game or if the content is comprehended as being too aggressive/ distressing by the phobic individual. When the ball is placed inside the box, it acts as an end switch and an event is register in the log

3.3.2.3 Hand Model

Finally, the last component that was maintain from the previous work was the hand model. The hand model picked was a close to real model, given that the interaction between user and spider is the most important interaction in the VE, it was a key aspect to make the user felt he was using "his hands", increasing in this way the level of immersion. The model used is the "SaltMediumRoundedHand" that comes with the leap motion SDK.

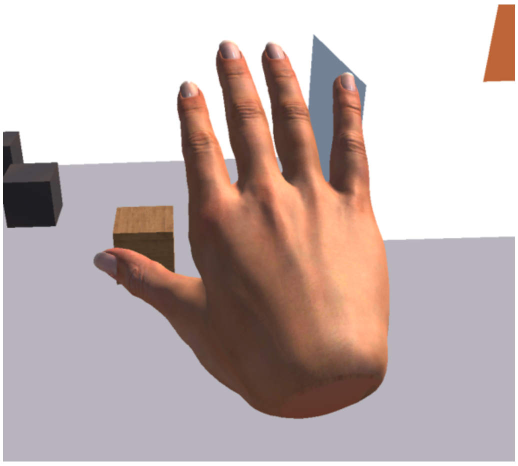


Figure 12 – The hand model used in the VE

3.3.3 The architecture

The architecture used in this evolution follows a similar path when comparing with the original while adding new blocks. The overall architecture of the system is presented in figure 11. The main components are:

- Virtual reality engine
- Media recorder
- Data manager
- Data analyser
- Biofeedback module

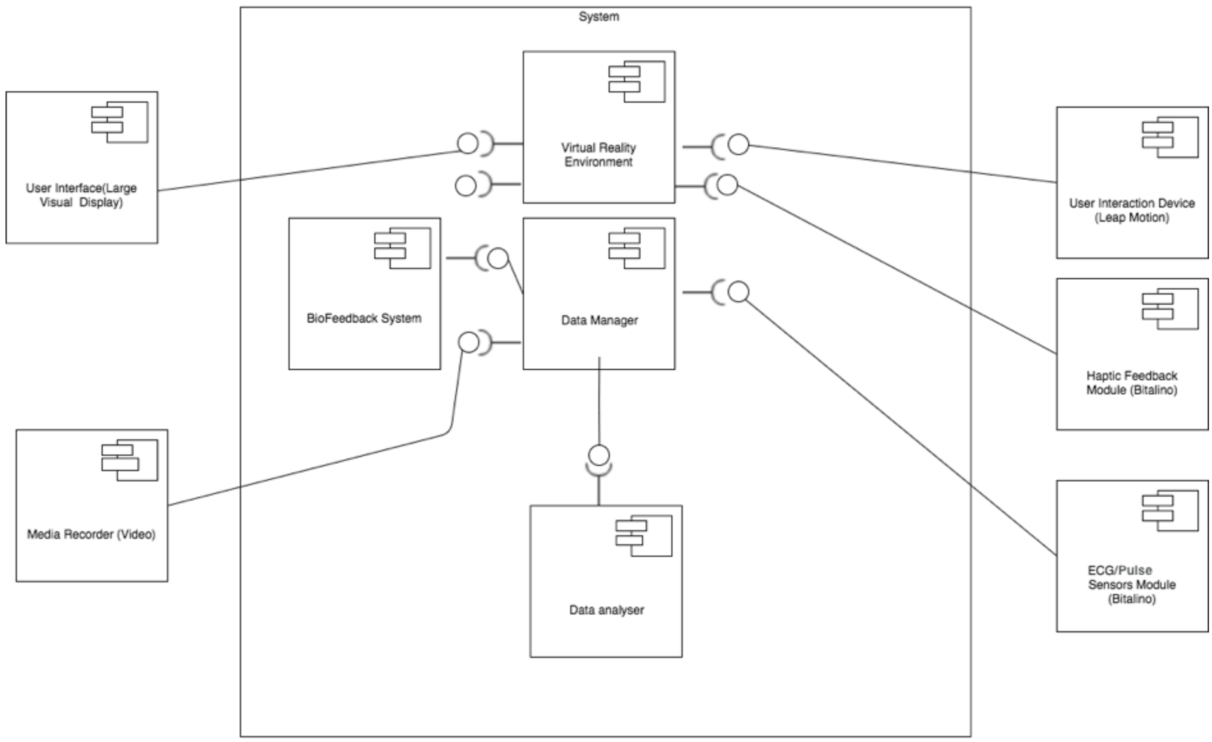


Figure 13 - System internal architecture

3.3.3.1 Virtual Reality Engine

The VR environment engine (VE) is a relevant part of the system - as in the original version, it still relies on Unity engine. The VE is the glue that puts everything in place, by presenting not only scenario objects but also keeping a visual representation of user hand's position on the VR. The VE is also responsible for tracking of all the game of objects in the game. Although the system was built from scratch, due to the new features and also because the PC communicates directly via Bluetooth with Bitalino, it made sense to take advantage of the most that was possible, for instance, the spider movement algorithm which was adapted from the original as well as the models and animations used in the system. Considering that the intention was to build a UI similar to the original, it would be harder to accomplish that goal by using a different framework and/or different models. Another positive aspect of using the same framework, Unity, is that unity has a large developer's community, the integration between Unity and peripherals is most of the time simplify by existing SDK that allows to quickly integrate solutions such as Leap motion or Bitalino, instead of building the integration software from scratch. Another advantage of Unity is the agnostic OS approach that it provides, Unity allows the application, without any change in the C# code, to work in all platforms (MacOs, Linux, Windows, iOS and Android) which is exactly want we would like to have considering that one of the goals is to have a portable and easy to setup solution.

3.3.3.2 Media Recorder

The “Media Recorder” is responsible for recording the video information incoming from an action camera. The video information is stored to later use namely to contextualize key events during the game, namely comparing user face with other context related information (e.g. HR, hand position, spiders, etc).

3.3.3.3 Data Manager

The "Data Manager" module, allows all the acquired data to be stored locally into specific folders, accordingly to the user using the system, time used, levels and the specific vitals and events using xml format, so it can later be analysed by the Data Analyser. Although the integration with the data analyser would be simplified by using json format, the xml format allowed a quicker initial development due to it being easier to read. The chosen structure follows a module approach, each level can be seen as distinct module without the need to follow any particular order or going through any particular set of levels. As a consequence, the data needed to be splitted to reflect the change of levels. By structuring the vitals in such way, the therapist/observer can analyse each level individually. Another advantage is in the scenario of something unpredictable happening (a sensor stops working, lost contact and stops collecting, bug in the system), only the data of the current level/event/object might be unreliable, something that would not happen with a single file, where all the collected information could potentially be lost. Another advantage in this approach is to simplify the process of analysing the data. By having multiple files organized by levels and type, we can go directly to the type or level required instead of filtering or searching within a large file where we have everything.

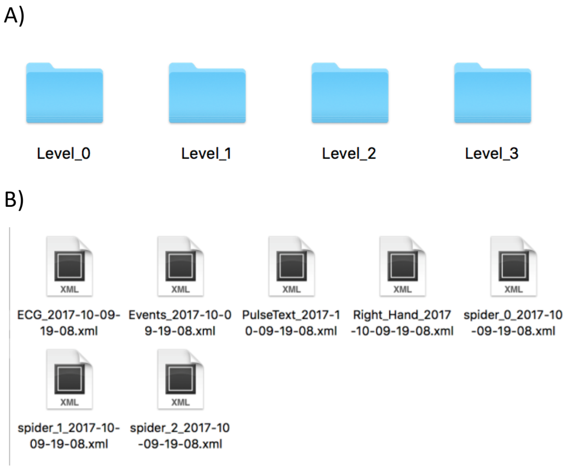


Figure 14 – Example of the structure of the data after a session: each session data is placed in a folder splitted in sub folder, one for each level. Inside in level folder the data acquired is placed in XML files according to the sources or object. For instance file with prefix ECG_ contains ECG data, file with prefix spider_1 contains the tracking of the position of spider 1 while Events_ contains all the timestamps from each interaction between hands and game objects, etc.


```xml
<Normal_Value><TimeHuman>19:08:59.6404</TimeHuman><Time>1507572539640</Time><value>0.5358571</value></Normal_Value>
<Normal_Value><TimeHuman>19:08:59.6772</TimeHuman><Time>1507572539677</Time><value>0.5520952</value></Normal_Value>
<Normal_Value><TimeHuman>19:08:59.7082</TimeHuman><Time>1507572539708</Time><value>0.5683333</value></Normal_Value>
<Normal_Value><TimeHuman>19:08:59.7402</TimeHuman><Time>1507572539740</Time><value>0.4871429</value></Normal_Value>
<Normal_Value><TimeHuman>19:08:59.7737</TimeHuman><Time>1507572539773</Time><value>0.4709048</value></Normal_Value>
<Normal_Value><TimeHuman>19:08:59.8067</TimeHuman><Time>1507572539806</Time><value>0.4709048</value></Normal_Value>
<Normal_Value><TimeHuman>19:08:59.8705</TimeHuman><Time>1507572539870</Time><value>0.503381</value></Normal_Value>
<Normal_Value><TimeHuman>19:08:59.9052</TimeHuman><Time>1507572539905</Time><value>0.519619</value></Normal_Value>
<Normal_Value><TimeHuman>19:08:59.9387</TimeHuman><Time>1507572539938</Time><value>0.503381</value></Normal_Value>
<Normal_Value><TimeHuman>19:08:59.9731</TimeHuman><Time>1507572539973</Time><value>0.503381</value></Normal_Value>
<Normal_Value><TimeHuman>19:09:00.0059</TimeHuman><Time>1507572540005</Time><value>0.519619</value></Normal_Value>
<Normal_Value><TimeHuman>19:09:00.0396</TimeHuman><Time>1507572540039</Time><value>0.519619</value></Normal_Value>
<Normal_Value><TimeHuman>19:09:00.0732</TimeHuman><Time>1507572540073</Time><value>0.519619</value></Normal_Value>
<Normal_Value><TimeHuman>19:09:00.1061</TimeHuman><Time>1507572540106</Time><value>0.503381</value></Normal_Value>
<Normal_Value><TimeHuman>19:09:00.1407</TimeHuman><Time>1507572540140</Time><value>0.519619</value></Normal_Value>
<Normal_Value><TimeHuman>19:09:00.1746</TimeHuman><Time>1507572540174</Time><value>0.519619</value></Normal_Value>
<Normal_Value><TimeHuman>19:09:00.2070</TimeHuman><Time>1507572540207</Time><value>0.5358571</value></Normal_Value>
<Normal_Value><TimeHuman>19:09:00.2406</TimeHuman><Time>1507572540240</Time><value>0.519619</value></Normal_Value>
<Normal_Value><TimeHuman>19:09:00.2738</TimeHuman><Time>1507572540273</Time><value>0.519619</value></Normal_Value>
```


Figure 15 – Example of ECG xml

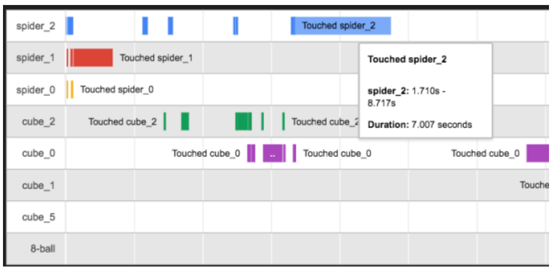
3.3.3.4 Data Analyser

After the development of the system, with the new features; the validation and analysis of the physiological data became the major concern in the project. In order to make easier the understanding and initial evaluation of the data, including validation of collected data, an analysis platform to analyse the data was developed.

As shown in the Figure 16 A), we can see the timeline of the events for a given level. Each row corresponds to a different game object, and within each row we can see when the user touched the object and for how long. In the example provided we can see, for example, that the user touched the spider number two multiple times, being the longest interaction the one ranging from the second 1.7 to the second 8.7, having this particular interaction lasted seven seconds.

In the Figure 16 B), we can see the ECG signal. In this module of the platform we can zoom and crop the graph in order to see in more detail a particular set of time in the level that is being analysed. Although the example shows a ECG signal, the pulse signal is shown in the same manner.

A)



B)

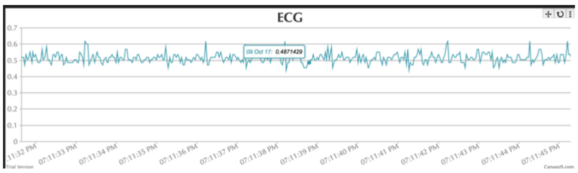


Figure 16 – The platform interface allows to review the experiment timeline (A) where is possible to identify interaction with objects and spiders and review each of the acquired signals . In (B) the ECG is presented – similar display for Pulse data.

The data analyser allows us to quickly see the result from each session and levels. Using this platform, we can compare if there was any significant variation in the pulse HR or ECG and compare it to the events map, where we can see if there was any relevant event during that period. The platform calculates the bpm and peaks average for both pulse HR and ECG HR, by picking the desired level, these values are automatically displayed together with the graphs. So, if we want for instance to compare the results for the first level and the second level, all that is required is to choose the first level, see the results and then change to the second level and compare values.

To compare key moments of the game with the matching the vital signals, the platform has two different tools, one of them is the zoom in on the selected section, it is possible to choose the area that we want to zoom on the graph, so that we can see the signal in more detail. The other tool is the option to see the duration and starting/ending time of an interaction. By hovering on the desired interaction on the event map, those values are display in a popup. By using these two tools, we can detect correlations between the different signals and files.

3.3.3.5 Biofeedback Module

The biofeedback module integrates all information from external sensors (e,g, data from the bitalino sensors) and analyses it. In the case of the average value of the pulse is low, the module activates in the VE the higher speed mode for the spiders, making them look more aggressive/agitated. Lower values make the spiders more aggressive while higher values make them more relaxed. This module only starts working in the level 2, so that the level 1 is a regular VR experience without any new updates from the traditional setup, which allows us to compare the impact of the haptic feedback and biofeedback.

3.3.4 Interface with Exterior

The system interacts with exterior through the following modules:

- User interaction device
- ECG/Pulse sensors
- Haptic feedback

3.3.4.1 User Interaction Device

The interaction device, which is the leap motion, is the device that captures the user movement and translate them to a language that unity is capable of understanding, so we can track the hands of the user and create the respective hand models.

3.3.4.2 ECG/Pulse Sensors

The "ECG/Pulse Sensors" module guarantees that we can acquire the physiological signals produced by the user during the session. The vitals collected are the ECG and Pulse using the Bitalino board that communicates via Bluetooth with the system and captures the ECG, Pulse. Currently the vitals are collected at 1000 Hz.

3.3.4.3 Haptic Feedback Module

The haptic feedback motor is connected to the system via the bitalino and consists in a vibrating motor that is activated by touching the spider from the 2^{nd} level forward. By vibrating it replicates the feeling of having something moving in your arm, it's as subtle vibration but strong enough to be impossible to not feel it.

3.3.5 System flow

The system flow can be divided in three different stages: connection, configuration/adaption, game period.

During the connection, period the observer of the session needs to establish a connection between the Bitalino and the PC via Bluetooth v3.0. Obviously, this is an important step, because without the Bluetooth connection, the system will not be able to acquire the physiological signals of the user.

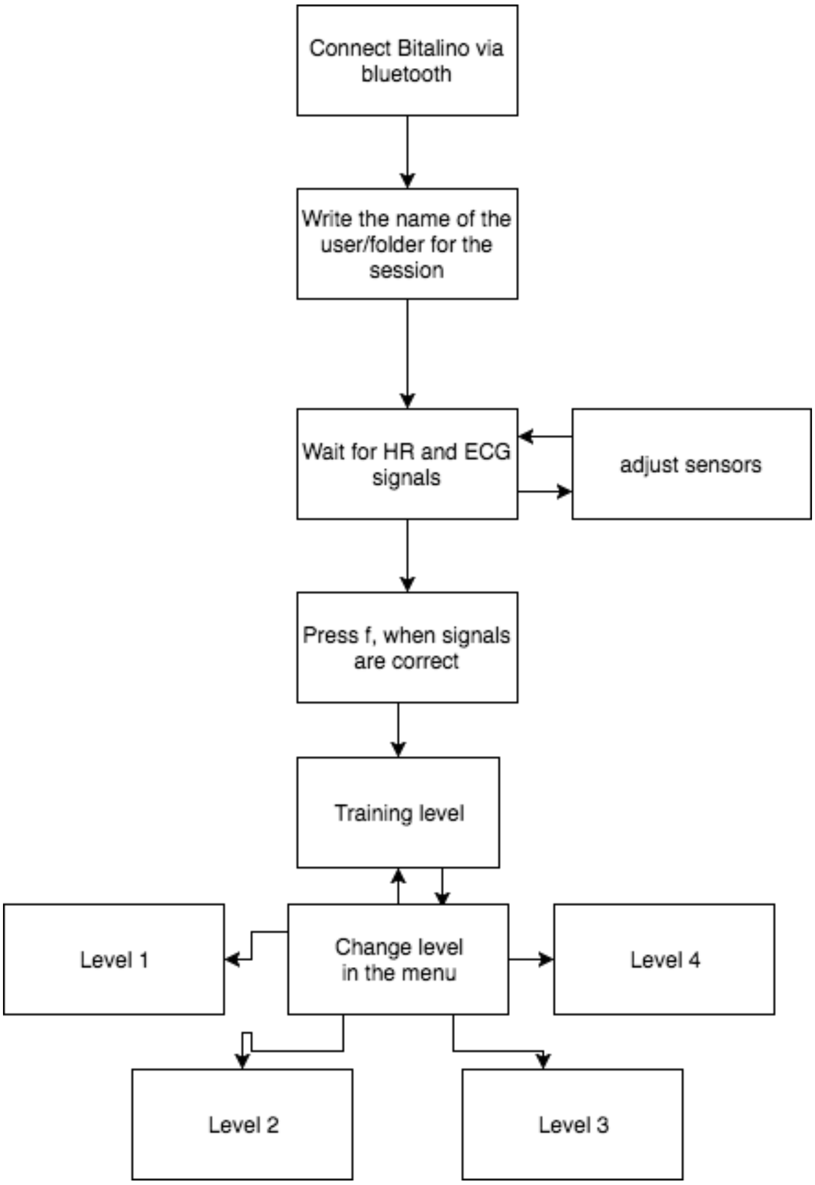


Figure 17 – System flow diagram

The connection period is followed by the configuration/adaption, by this time the user is already hook to the ECG, Pulse sensor and haptic motor. To ensure that all the data is collected properly, the observer needs to guaranty that all the signals are properly displayed in the configuration view, if not, this is the time to test different positions for the sensors until the desire result is achieved. After the signals are properly displayed, the user can now start to explore the VE and adjust to the use of the leap motion. Because this still is an adaption level, the observer can without compromising the collected data, change the position of the leap motion and/or Bitalino.

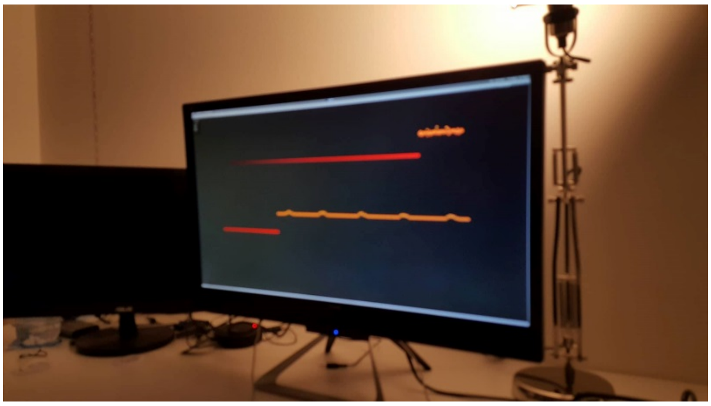


Figure 18 – Configuration Screen, in the bottom we have the pulse and in the top the ECG

Finally, during the game period, the leap motion, Bitalino and sensors should be in place and stay put without interference, during the following levels the acquired data is the data that is going to be analysed in detail. Although typically the change of levels follows a bottom to top approach, the system allows to move freely between levels. If the observer chooses to go directly from adaption to the level 4, he/she is free to do so. Every time the level is changed, the system resets all the game objects and creates a new file entry for each collected data giving each file a timestamp, so the user can easily distinguish the files.

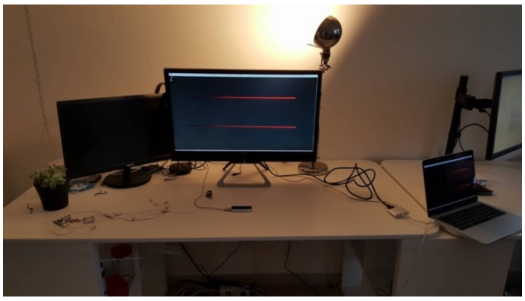
3.3.6 The setup

The setup is intentionally minimalist, so that the system can be easily reproduced and moved to different spaces.

All that is needed to have the completed loop is:

- A computer running linux, windows or MacOs. In this case, the case studies where all done in a Mac computer running MacOs High Sierra with a 2 GHz Intel Core i5 processor and Intel Iris Graphics 540 1536 MB graphic card.
- A display, although the system can run using only the own computer display, in order to increase the immersion, the use of a large display is advice, and in this particular case, the display was a 4k 32 inches monitor, while the own computer display was used to allow the observer to control/motorize the experience from a certain distance, so that the user could fully focus on the VE as if the observer was not there.
- Leap motion – this device translates the arms/hand gesture to the virtual world, without it, the user has no way of interacting with the system
- Bitalino and sensors, the bitalino works as a bridge between the input/output sensors and the computer by maintaining the connection between sensors and computer. The version of the Bitalino used is the Board Kit v3 Bluetooth version.

A)



B)

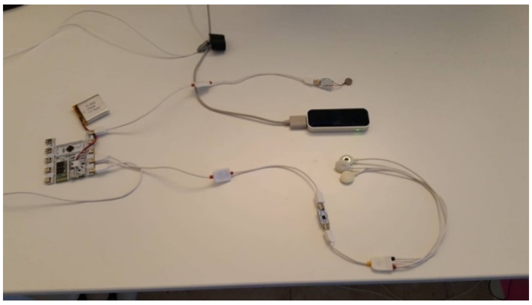


Figure 19 – The setup: A) The large display with the application running in full screen, in this case, showing the configuration view. B) Bitalino with the ECG, Pulse and haptic feedback module

3.4 Considerations

Considering the scientific question that we want to answer with this work, some decisions had to be made, that affect all the system:

- Real VR or close to real
- Fully immersive VR
- Gaming system or real case scenario
- Use of haptic feedback
- Use of bio feedback
- Combining Pulse with ECG
- Interaction with leap motion

3.4.1.1 Real VR or close to real

The first temptation is to create an environment the closest as possible to the reality, but with this are certain problems that arise. One of them is the system ability to run such smooth and real environment. Most low-cost setups cannot run extremely complex environments. Even users/therapist with a better setup would risk breaking the immersion in case the Computer cannot run the VE smoothly all the time, so the user cannot detect whenever the system is under heavy work. This problem was detected in the original project, where the over sampling provoked the creation of artefacts (e.g displaying multiple hands instead of two)

Another problem is to build a realistic environment requires a lot more work. A realistic environment could be counterproductive, it has been detected that too much realism can produce counterproductive results in terms of treatment, it can traumatize the user. Due to all these reasons and since in the previous results, the user indicated that the environment was realistic enough to allow an immersive VR experience [19], we decided to keep it similar and to explore other aspects of the project.

3.4.1.2 Fully immersive VR

While it could be interesting to create a fully immersive VR environment, there are a couple of motives why we did not do it. First of all, it would have required to use a VR Goggles, which would not allow to see and register the face of the user bringing a similar problem that AR brought by not allowing to collect the position of the hands, which is important information, because it can help to make stronger assertions about the collected data, for instance, let's imagine that when the user touches the spider his/her heart beat increased, is it simply a coincidence or did the user react to the touch (haptic feedback)? By looking to the face of the user in that moment it may be obvious that it was due to fear or due to surprise. The recording allows to give context to the data collected while the position of the hands allow to, in an easier manner, correlate higher values in the ECG/HR to the interaction with the spider.

3.4.1.3 Gaming system or real case scenario

In the same way, that there might be a temptation to build a solution that is closest possible to reality in terms of graphics/detail, the same happen with the approach of creating a game or a real case scenario. The real case scenario has his own advantages, like dealing with the specific situation that the patient deals with every day, but due to the current system being an evolution of the veracity system, our system was from the start planned to be a gaming system. Which has also its advantages, the reward system, so inherent to the gaming world, helps the user by providing an extra motivation to stay focus on the matter in hands and to keep doing the task required in order to accomplish the desired goal. By putting out front that is “just a game”, it creates the opportunity to achieve two of the desired goals, reduce the refusal treatment and provide a first contact solution. The group of sufferers who never seek treatment are probably the ones that would benefit the most from solutions/treatments as this one. The sufferers that seek treatment, are typically willing(75%) to undergo treatments as ET [2]. By creating a solution that is immersive enough to trigger the anxiety [19] while reducing the stress and fear associated to the treatment can be an important step to decrease the high number of people who never seek treatment, leaving the real case scenarios for patients that require a higher level of immersion to reach the needed level of anxiety.

3.4.1.4 Use of haptic feedback

Haptic feedback is a really interesting approach to add more realism to the virtual environment. By using haptic feedback the VR becomes more attractive by blurring the distinction between real and virtual world, and maybe due to that, it has also been shown to improve the results of VR treatments in phobias[27]. Talking all these facts in consideration, adding haptic feedback to spiders that were considered realistic[19] should bring better results while having a neglectable impact, both in the cost and portability of the solution. The haptic feedback was accomplished by connecting a vibrating motor to the bitalino. Whenever the user touches the spider, the game activates the motor through the bitalino, making the motor vibrating. The motor only stops when the user is no longer in contact with the spider. The motor is placed in the wrist of the user before starting the session and without telling the user what is his purpose. Although using this tactic does not allow to feel textures, like in tactile augmentation, this approach has other advantages. One of these advantages is that the user does not need to use goggles, the use of a toy spider only makes sense if the user cannot see the toy, otherwise the immersion would be easily broke, which makes the use of the goggles an important aspect of the session. By not requiring the use of goggles, the chose implementation allows to reduce costs and times of setup, while at the same time also allowing to record the user facial expressions. Another advantage is the higher interaction with the system, and consequently bigger immersion. By using the motor to provide feedback, the user feels more connected with the system, instead of requiring the therapist to detect when is the right time to provide the toy to the patient, the user is in a constant and in real time interaction with the system, by being able to feel instantly the feedback provided by the interaction with the spider and as a consequence of his/her actions, just like it would happen in the real world.

3.4.1.5 Use of biofeedback

The used of feedback is potentially another low cost – high results type scenario, considering that the system is already collecting both ECG and Pulse in real-time and that the biofeedback is an emerging technology being used in medical technique for several medical issues [45]. With no need to add any extra hardware, the only thing required is to add more functionality to the software. Every patient is unique, each one has his own level of immersion for the same VR environment, each one has different levels of phobia, etc. Using the biofeedback, is possible to reduce the chances for the patient not reaching the required levels of anxiety[27], if the patient is not reacting as supposed (is too calm) the spiders can automatically become more aggressive or we can have the opposite, if the patient is becoming too stressful, we can make the spiders calm down allowing the patient to return to a lower level of anxiety.

3.4.1.6 Combining Pulse with ECG

Both HR[52] and ECG[24] have been used as a valid way to control the level of anxiety of the patient, and will be also used in this dissertation. The use of both is a method to not only be sure that the expected variations, in both the ECG HR and pulse HR are detected, in case, one of them is not capable of detecting, but also a solution to provide relevant information that otherwise would be missed, for instance the amplitude in the R wave in the ECG signal which is not picked by the pulse sensor. With this approach, we have a multivariable analyse of the results, which increases our changes of detecting any relevant variation and also increases the reliability of our readings, which taking in consideration that the user will be moving his/her arms around while trying to catch the spider will increase the level of noise in the collected data. By combining both, although not in systematic way, we tried to empirically understand how similar are the values of the pulse HR and ECG HR and possible trade-off of selection one or both for this and future studies namely in which cases relying only on Pulse HR would represent loss of relevant information on physiological characterization. Although while capturing the same events (heart function), it is expected to find differences given their different natures (electrical vs imaging), number of sampling locations (Pulse 1, ECG 3 electrodes), placement and susceptibility to motion among others. The ECG due to its higher complexity (multiple phases of the signal) is also more prone to noise.

3.4.1.7 Interaction with leap motion

Leap motion allows an excellent integration with Unity, which makes easier to create VR environments and to interact with them. The use of an input system like Leap motion is essential to a system like catch the spider V2, it increases the level of immersion and makes the interaction with the virtual objects more enjoyable. These aspects are even more important if we take in consideration the haptic feedback, by combining the leap motion and the haptic system we have two real important components of a real touch, the motion of our arms, hands and fingers and the touch stimuli.

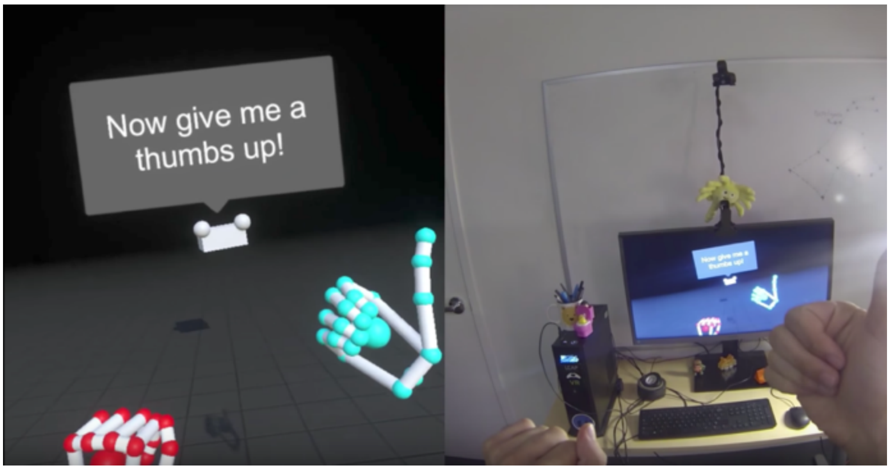


Figure 20 – Unity with Leap motion as the main input

4 Catch the spiders evaluation

Although the previous catch the spiders and the new evolution share goals and overall approach the introduction of the haptic feedback (novelty) led to a new evaluation procedure to provide insight on the do's and don'ts when using haptic feedback in similar contexts. The purpose of this evaluation was to:

- Test the overall flow of the game including the monitoring
- Verify the ability to monitor and provide haptic feedback
- Test the ability to spark anxiety, even if small, in non-phobic users (users that normally would not be affected by this type of VR)
- Test the ability to cause higher levels of anxiety than the original version, when using haptic feedback in phobic users
- Detect if there is a clear correlation between ECG HR and Pulse HR when measuring anxiety levels

At the present moment, there were conducted two different sessions.

4.1 Subjects

Two subjects (Table 1) were considered in the evaluation, one male (26 years) and another female (27 years). The male has a heart condition. When looking to the collected data, in order to understand if everything was fine, it was noticeable that the Pulse was not "normal" (example seen in Figure 21), so the user was asked if he suffers from any heart condition, to which he responded that multiple doctors told him that he had Heart arrhythmia (as shown in Figure 22).

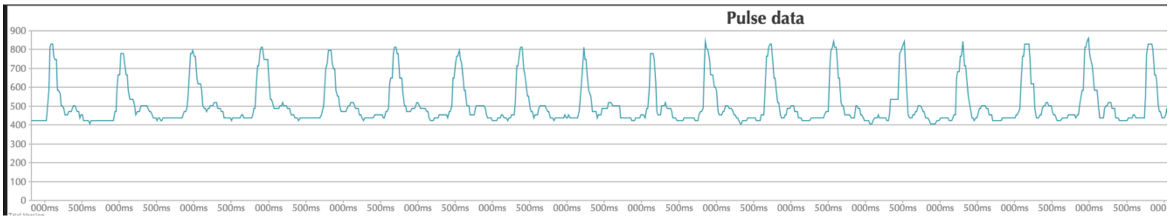


Figure 21 An example of a regular Pulse collected by the system. As shown, in this example we have a stable a Pulse that follows a pattern in peak and in frequency. Approximately every second apart, we can see the peak matching the heart beat

The female user also has a heart condition, in her case the heart condition is called Mitral valve prolapse, and in the case of this project it reflects in lower values both in the ECG and Pulse HR.

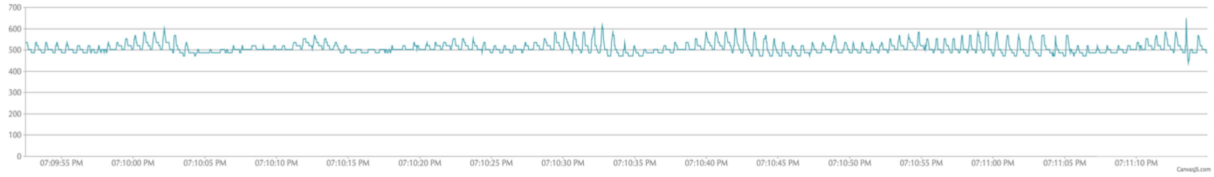


Figure 22 – The Pulse of the male user with Heart arrhythmia. As we can see, instead of a pulse following a somehow similar pattern in frequency and peak, the user displays an irregular pulse

4.2 Session 1 – protocol

The first session had multiple goals, the main one was to validate the impact of haptic feedback as previously stated; the second one, which is specific for this first trial was to validate the system, in order to understand if there was any major error/improvement that should be corrected/made to provide valid or better results. For this session, there were recruited two individuals, with no phobia and with previous experience in a VE.

To evaluate the degree of phobia, both users answered to the fear of spiders questionnaire available at https://goo.gl/forms/5JowmVWJLGvjnl762, with 31 questions, every time a user provides an answer that can be interpreted to displaying phobia, is "award" with one point. Due to the low number of participants in this first trial, instead of using a system of percentile, the users where distinguish by their total points as we can see in the

Table 1 – List of participants.

	Occupation	Age	Phobia (result in the test)	First Time using VR
Participant 1	Engineer	26	None (9 points)	No
Participant 2	Gerontologist	27	None (3 points)	No

Table 1 – List of participants

The session starts by telling the user, that he/she is going to experience a VR game where the goals is to grab multiple objects, including spiders, using his/her hands and to put them in the box. There is no time limitation and the user is free to stop session/skip level whenever he/she feels like it, by putting the 8-ball in box. After this, the user sits and is connected to the sensors.

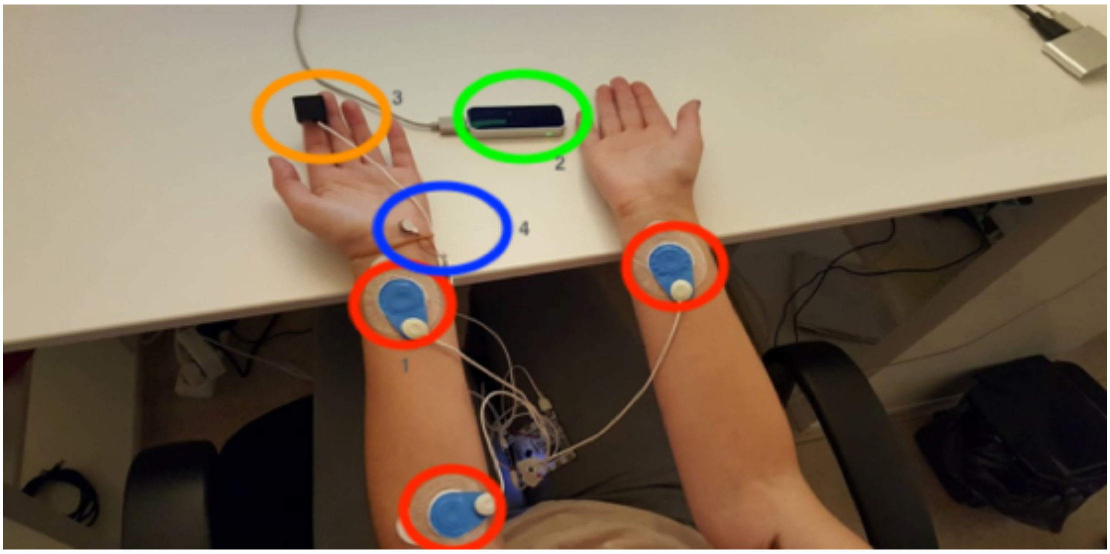


Figure 23 – The user with all sensors in place.

Red/1 - ECG Sensor; Green/2 - Leap motion; Orange/3 - Heart rate sensor; Blue/4 – Haptic feedback motor

Before starting the actual session, we run the configuration view, to be sure that all the sensors are properly working, the only one that is not tested is the haptic feedback, so the user is not aware of what is going to happen. In no moment, the user is told that he/she is going to feel anything in the arm.

After all the sensors are in place and the signal is validated, we move to the training level, in this level the user just needs to adapt to the system, there are no spiders in the VE and the user receives feedback from the observer to help him/her to properly grab and move around in the VE, for instance: "- Do not move your arm too much into the screen", or "- Avoid putting one arm on the top of the other", etc. Basically, explaining basic concepts so the user, so he/she adapts to the VE quicker, considering that most people never used the leap motion it helps to accelerate the process and to help the user to have a more fluid experience. The only request for this level and all the next ones, for that matter, is that the user should avoid moving the left arm. In the left arm, we have part of the ECG, the haptic sensor and the pulse sensor. The reason for this is that considering that the user will be moving the arms around, it is easy to have a lot of noise in the data, by allowing the user to efficiently play using only one arm, the level of noise should be lower, which allow us to collect the data with minimal noise.

Now that the user is used to the system and we have all the sensors working, it is time to move to the first level, in this level the user needs to grab both cubes and spiders. Now during this level and the consequent levels, the user is left alone to accomplish the challenges, unless the user is feeling some sort of difficulty. While the user is playing the observer is by his/her side just to make sure that everything goes well.

Figure 24 – the user playing while the observer is controlling the experience

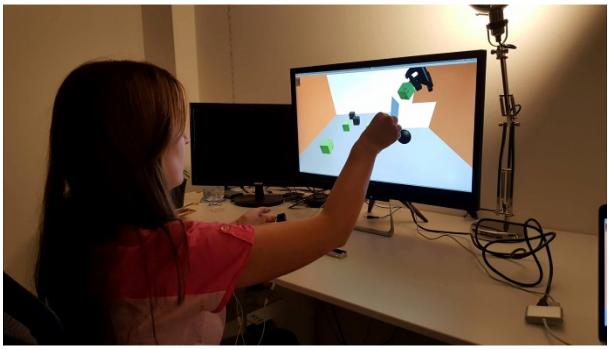


Figure 25 – The user storing the cube in the box

4.3 Results

Unfortunately, for both users there was clearly a lot of noise in the collected data, which considering that both already have a heart condition makes it harder to understand if the VR affected them in any way. The most probable cause for the noise is the small cable that connects the Bitalino to the sensors. Due to the fact that the cable is not big enough, the user ends up moving the left arm in order to successfully grab the objects. This makes not only the sensors more susceptible to pick up noise, but it forces the Bitalino to move around. In future sessions, to prevent this from happening, it will be used a longer cable, that should be long enough to allow the user to just move the right arm. The system should also, be tested in users that do not have any heart problem.

The results were divided by levels and the collected values are presented using the average value of the entire level and the average value of HR for both ECG and pulse, but taking only in consideration when the user is in contact with spider. Both HR are calculated automatically by the web platform that analyses the sessions results. For the HR extracted from the ECG the platform uses an algorithm that processes the given data twice. The first time it detects the P wave of the ECG for every QRS signal followed by calculating the average value of the P wave for all the session. The algorithm calculates the peak by storing the highest value in a sequence of increasing values. When the next value is lower than the current stored value, it means that the stored value is the peak. To avoid picking noise as false peaks, the algorithm only considers a new peak after 0.5 secs have passed, in this way, not only the level of noise in the result is reduce it also stops the algorithm from picking the P,R an T wave as 3 distinct peaks instead of belonging to the same signal. On the second round, using the average value of the collected P wave, the algorithm ignores every value inferior to the average while only still accepting values after 0.5 secs have passed from the previous one. Given that the R wave is the higher signal from the 3, by filtering values by the P average and minimum interval we can collect only the R wave value. With the R wave we calculate the average peak value and bpm for the entire session. For the pulse, the process is simpler, because we only have a peak for every beat, we just need to apply the same time filter to reduce false peaks.

Figure 26 – Visual representation of the filter applied by the algorithm on the values to reduce noise and to pick only the R wave, In this case, only values above 0.54 mV can enter the consideration for peak value. On the top we can see the entire session, while on the bottom we can see a zoom in section of the same session and level.

4.3.1.1 Level 0 (Adaptation Level/baseline)

Both users showed low levels of anxiety, by the pulse HR and ECG HR evaluation/ variation, which presented normal-slightly high values and constant for most of the levels. This result was already expected, considering that both users have not any particular phobia or fear towards spiders and are used to use VE. The difference between pulse HR and ECG HR is also expected, once again, the pulse sensor is located in the left arm while the ECG is in both, due to the higher activity of the right arm, the ECG has the tendency to pick more noise, resulting in different values. Another factor to take in consideration is that both sensors are not high precision sensors, although it is expected to be able to collect reliable data from both, we are not using high-end sensors that could be more precise, resulting in more precise values and consequently matching or close to matching values from the HR ECG and HR pulse.

	ECG HR BPM	**ECG HR Average Peak**	**Pulse HR BPM**
Participant 1	80.94	0.599mV	86.03
Participant 2	72.53	0.578mV	71.84

Table 2 – Baseline results (no spiders)

4.3.1.2 Level 1 (First contact with spiders)

Although the users did not express any phobia for spiders, there was a difference between them, one reported to be close to almost have no fear at all (3 points out of 31) while the other reported to have only stress if he feels like the spider might touch him or jump to him (9 out of 31). But in everyday activities he rarely fills affected. These differences were detected in the collected data as we can see in the Table 3, the user with lower fear, goes after the spiders sooner and shows lower values and increments in the HR, the bigger increment is in the ECG HR when in contact with the spiders 20.93% (ECG) increment and 6,16% (ECG) for the entire session, for the same period, the pulse HR stays practically the same for the entire session, while actually reducing 3.3% (Pulse) when in contact with the spider. The second user avoids the spiders and collects first the cubes going only then to the spiders, and shows the bigger increment with 14.04% (ECG) and 13.33% (Pulse) when in contact with the spiders and 1.24% (ECG) and 1.21% (Pulse) for the entire session.

	ECG HR BPM	**ECG HR BPM Average Peak/average with spider only**	**ECG HR BPM Average with spider**	**Pulse HR BPM average/ average with spider only**
Participant 1	81.95	0.592mV/0.601	92.31	87.07/97.50
Participant 2	77.00	0.572mV/0.570	87.71	71.85 / 69.47

Table 3 – Results from level 1

4.3.1.3 Level 2 (First contact with haptic feedback)

The introduction of the haptic feedback brought mixed results as shown in theTable 4. While the users, when in contact with the spider shown clear increments from the baseline, but not as high as we would expect, the major increment came from the user 1 with a 11.19%(ECG) increment. When comparing for the entire session the values actually stayed the same or even decrease, 3.36% (Pulse for the user with higher fear). The only metric where the introduction of the haptic feedback was clearly "superior" was for the user 1 for the ECG peak average, where not only the value increase from the baseline (15.19%) it also was also higher than the level 1 (13% increment), showing that in fact the user was surprised by the haptic feedback.

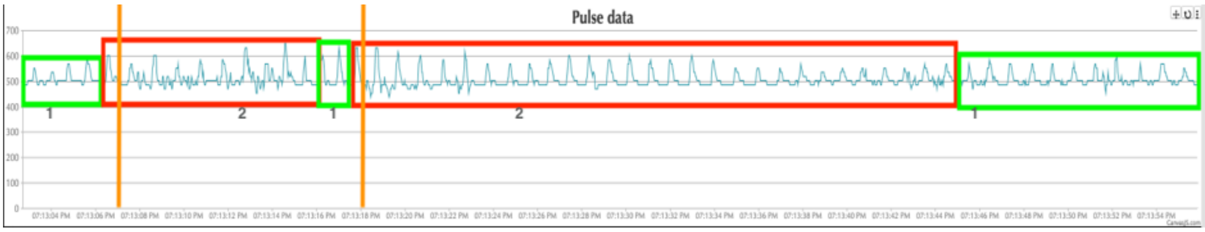


Figure 27 – Pulse sensor: values without spider contact (green/1) followed by an increase in the Pulse HR (red/2) after contact with spider (vertical orange line). Zoom in on section with 50s of duration.

	ECG HR BPM	**ECG HR BPM Average Peak/average with spider only**	**ECG HR BPM Average with spider**	**Pulse HR BPM average/ average with spider only**
Participant 1	81.62	0.585mV/0.690mV	90.00	83.72/88.88
Participant 2	72.41	0.572mV/0.546mV	80	82.06 / 80

Table 4 – Results from level 2

4.3.1.4 Level 3 (Aggressive spiders with haptic feedback)

In the last level, the higher levels displayed in the Table 5, were also expected, in this level the spiders followed the hand of the user making it hard to not touch them. Because of this, the normal tendency is to “run” from the spiders, or in this case, to avoid touching them. Both users Pulse and ECG came back to normal values in the late seconds of the levels. For instance, for the user with higher fear of spider, in the first level, average 87 bpm (Pulse) for the entire level 1 while in the last level the same user averages a 88 bpm(Pulse) or a 90 bpm(Pulse) when touching the spiders. Even more, during the first 24 seconds of the level (where the spiders immediately go after the hand and touch it), the bpm averages 112 (Pulse).

	ECG HR BPM	ECG HR BPM Average Peak/average with spider only	ECG HR BPM Average with spider	Pulse HR BPM average/ average with spider only
Participant 1	81.68	0.593mV/0.594mV	87.03	88.19/90
Participant 2	69.15	0.580mV/0.743mV	73.33	77.28 /72

Table 5 - Results from Level 3

Figure 28 – Pulse sensor: On the top the HR for the level 3 (88 bpm for 2min30s) and on the bottom the HR for the first level (87bpm for 1min22s)

For both users is noticeable a correlation between ECG and Pulse HR in the key moments in the VE, although it can be hard due to the noise in the data to detect them. Although in future sessions the level of noise needs to be reduced, in order to facilitate the reading and to be able to make stronger assertions, the system seems to behave as expected. Another change in future sessions will be to find a user with fear of spiders, so we can evaluate if there is any relevant difference when using our system.

4.3.1.5 Conclusion Session 1

The haptic feedback displayed a clear impact in the data collected, both users reacted to it showing clear differences when comparing with the baseline values, notably when comparing with the periods where the spider interacts with the users. When comparing with the level with no haptic feedback, it would be expected a bigger difference that the one detected, this slight difference between the level with haptic motor and without it might have happen due to the fact, that the user by the end of the level 1 is already used to the spiders, which would explain the values present and imply that in this scenario the used of haptic feedback was useful to maintain a certain level of stress. In a certain way, we could say that the haptic feedback broke the routine and forced the user to stay engaged with the game instead of increasing the level of anxiety. This conclusion would not be new, considering that as seen in other studies, the haptic feedback was detected to be an effective way to motivate the users to stay focus on the given task. This conclusion is even more reasonable when considering that none of the users do not present phobia for spiders. The same can be said for the last level, once again, when comparing the moments where there is interaction with the spider, the baseline values are smaller, but considering that the last level is the most aggressive, with the spiders following the user hands and providing haptic feedback, this level was expected to be the one that would provoke the higher values. Seeing all the levels as a progression it seems that the users where slight excited by the VE in the level 1 and progressively start adapting to the environment being only affected by the interaction with the spiders and introductions of new behaviours.

5 Conclusions and future work

The preliminary evaluation of the system suggest that this approach is interesting to pursue, the haptic feedback seems to have induced an increase in the level of anxiety in the users, which is in line of the expected and its overall purpose - increase realism. The introduction of the haptic feedback was expected to induce a higher level of stress in comparison to the level without haptic feedback, due to the higher realism/immersion. Taking in consideration that on average the contact with the virtual spiders induce an increment of 17.49% (ECG bpm) and 4.99% (pulse bpm), for the haptic level, we would expect for the increment to be higher than 17.49% for the ECG and higher than 4.99% for the Pulse. Although the effect on the users might not be as high as expected when comparing with the level where there is not haptic feedback, there is clearly a significant increase in the collect data when comparing with the baseline values. Due to the small sample size and lack of phobic users, a more comprehensive evaluation to assert its usefulness and impact within the phobic users should take place in future works.

Also on future works, an important aspect that should be improved is the setup. Even though the current setup is simple and capable of achieving the desired objectives, in a real scenario of therapist-patient, it can become confusing and impractical due to the multiple cables, placement of the Bitalino and proper connection between sensors and Bitalino. A good solution, in the case that there is enough data to support the reliability of the results, could be a smartband or a smartwatch to replace the Bitalino and respective sensors. Because these devices support haptic feedback, Heart Rate monitoring and wireless communication (via bluetooth) they are good candidates to provide an improvement over the current solution by merging multiples pieces in a single and practical device.

Finally, another improvement worth to mention would be the combination of the current motor haptic feedback and tactile augmentation, by doing so, it would be possible for the therapist to also provide texture to the virtual spiders, increasing even more the level of immersion and sensation of being actually touching a spider.

These digital solutions can and are already leaving an impact on the current society by helping people to enjoy life at its fullness, which is in my opinion one of the most noble things Engineering can accomplish. Solutions using technologies such as VR are not only becoming an excellent solution to improve the immersion in Games, but are also becoming the way to experience the most fascinating scenarios without putting our life's in jeopardy. It's a brave new and there is still a lot of room to improve on.

6 References

[1] W. J. Magee, “Agoraphobia, Simple Phobia, and Social Phobia in the National Comorbidity Survey,” *Arch. Gen. Psychiatry*, vol. 53, no. 2, p. 159, 1996.

[2] A. Garcia-Palacios, C. Botella, H. Hoffman, and S. Fabregat, “Comparing Acceptance and Refusal Rates of Virtual Reality Exposure vs. In Vivo Exposure by Patients with Specific Phobias,” *CyberPsychology Behav.*, vol. 10, no. 5, pp. 722–724, 2007.

[3] American Psychiatric Association, *American Psychiatric Association, 2013. Diagnostic and statistical manual of mental disorders (5th ed.)*. 2013.

[4] K. B. Wolitzky-Taylor, J. D. Horowitz, M. B. Powers, and M. J. Telch, “Psychological approaches in the treatment of specific phobias: A meta-analysis,” *Clin. Psychol. Rev.*, vol. 28, no. 6, pp. 1021–1037, 2008.

[5] A. Garcia-Palacios, H. Hoffman, A. Carlin, T. A. Furness, and C. Botella, “Virtual reality in the treatment of spider phobia: A controlled study,” *Behav. Res. Ther.*, vol. 40, no. 9, pp. 983–993, 2002.

[6] T. G. Wilson and G. C. Davison, “Processes of fear reduction in systematic desensitization,” *Psychol. Bull.*, vol. 76, no. 1, pp. 1–14, 1971.

[7] B. K. Wiederhold, D. P. Jang, R. G. Gevirtz, S. I. Kim, I. Y. Kim, and M. D. Wiederhold, “The treatment of fear of flying: A controlled study of imaginal and virtual reality graded exposure therapy,” *IEEE Trans. Inf. Technol. Biomed.*, vol. 6, no. 3 SPEC., pp. 218–223, 2002.

[8] B. A. Thyer, “Prolonged in vivo exposure therapy with a 70-year-old woman,” *J. Behav. Ther. Exp. Psychiatry*, vol. 12, no. 1, pp. 69–71, 1981.

[9] F. H. Wilhelm and P. Grossman, “Emotions beyond the laboratory: Theoretical fundaments, study design, and analytic strategies for advanced ambulatory assessment,” *Biol. Psychol.*, vol. 84, no. 3, pp. 552–569, 2010.

[10] B. O. Olatunji, B. J. Deacon, and J. S. Abramowitz, “The Cruelest Cure? Ethical Issues in the Implementation of Exposure-Based Treatments,” *Cogn. Behav. Pract.*, vol. 16, no. 2, pp. 172–180, 2009.

[11] S. Agras, D. Sylvester, and D. Oliveau, “The epidemiology of common fears and phobia.,” *Compr. Psychiatry*, vol. 10, no. 2, pp. 151–156, 1969.

[12] J. H. Boyd *et al.*, “Phobia: prevalence and risk factors,” *Soc. Psychiatry Psychiatr. Epidemiol.*, vol. 25, no. 6, pp. 314–323, 1990.

[13] O. Baus and S. Bouchard, “Moving from Virtual Reality Exposure-Based Therapy to Augmented Reality Exposure-Based Therapy: A Review,” *Front. Hum. Neurosci.*, vol. 8, no. March, pp. 1–15, 2014.

[14] E.-L. Sallnäs, K. Rassmus-Gröhn, and C. Sjöström, “Supporting Presence in Collaborative Environments by Haptic Force Feedback,” *ACM Trans. Comput. Interact.*, vol. 7, no. 4, pp. 461–476, 2000.

[15] E. Bisson, B. Contant, H. Sveistrup, and Y. Lajoie., “Functional Balance and Dual-Task Reaction Times in Older Adults Are Improved by Virtual Reality and Biofeedback Training,” *CyberPsychology Behav.*, vol. 10, no. 1, pp. 16–23, 2007.

[16] B. O. Rothbaum, P. Anderson, E. Zimand, L. Hodges, D. Lang, and J. Wilson, “Virtual Reality Exposure Therapy and Standard (in Vivo) Exposure Therapy in the Treatment of Fear of Flying,” *Behav. Ther.*, vol. 37, no. 1, pp. 80–90, 2006.

[17] J. Carmigniani, B. Furht, M. Anisetti, P. Ceravolo, E. Damiani, and M. Ivkovic, “Augmented reality technologies, systems and applications,” *Multimed. Tools Appl.*, vol. 51, no. 1, pp. 341–377, 2011.

[18] S. Bouchard, S. Côté, J. St-Jacques, G. E. Robillard, and P. Renaud, “Effectiveness of virtual reality exposure in the treatment of arachnophobia using 3D games,” *Technol. Heal. Care*, vol. 14, pp. 19–27, 2006.

[19] B. Marques, “Veracity - Low cost physiology assessment tool using Virtual Reality.,” 2016.

[20] Ottawa (ON): Canadian Agency for Drugs and Technologies in Health, “Virtual Reality Exposure Therapy for Adults with Post-Traumatic Stress Disorder: A Review of the Clinical Effectiveness,” *Virtual Real. Expo. Ther. Adults with Post-Traumatic Stress Disord. A Rev. Clin. Eff.*, no. August, 2014.

[21] D. Opriş, S. Pintea, A. García-Palacios, C. Botella, Ş. Szamosközi, and D. David, “Virtual reality exposure therapy in anxiety disorders: A quantitative meta-analysis,” *Depress. Anxiety*, vol. 29, no. 2, pp. 85–93, 2012.

[22] A. M. Okamura, “Haptic Feedback in Robot-Assisted Minimally Invasive Surgery,” *Curr Opin Urol*, vol. 19, no. 1, pp. 102–107, 2009.

[23] F. H. Wilhelm, M. C. Pfaltz, J. J. Gross, I. B. Mauss, S. I. Kim, and B. K. Wiederhold, “Mechanisms of virtual reality exposure therapy: The role of the behavioral activation and behavioral inhibition

systems," *Appl. Psychophysiol. Biofeedback*, vol. 30, no. 3, pp. 271–284, 2005.

[24] M. Ma, L. C. Jain, and P. Anderson, *Intelligent Systems Reference Library 68 Virtual , Augmented Reality and Serious Games for Healthcare 1*. 2014.

[25] D. Cunningham and M. Krishack, "Virtual reality: A wholistic approach to rehabilitation," in *Studies in Health Technology and Informatics*, 1999, vol. 62, pp. 90–93.

[26] A. S. Carlin, H. G. Hoffman, and S. Weghorst, "Virtual reality and tactile augmentation in the treatment of spider phobia: A case report," *Behav. Res. Ther.*, vol. 35, no. 2, pp. 153–158, 1997.

[27] H. G. Hoffman, A. Garcia-Palacios, A. Carlin, T. A. Furness III, and C. Botella-Arbona, "Interfaces That Heal: Coupling Real and Virtual Objects to Treat Spider Phobia," *Int. J. Hum. Comput. Interact.*, vol. 16, no. 2, pp. 283–300, 2003.

[28] D. A. Regier, W. E. Narrow, D. S. Rae, R. W. Manderscheid, B. Z. Locke, and F. K. Goodwin, "The de Facto US Mental and Addictive Disorders Service System Epidemiologic Catchment Area Prospective 1-Year Prevalence Rates of Disorders and Services," *Arch Gen Psychiatry*, vol. 50, no. 2, p. 1993, 1993.

[29] S. Wells, K. Polglase, H. B. Andrews, P. Carrington, and A. H. Baker, "Evaluation of a meridian-based intervention, emotional freedom techniques (EFT), for reducing specific phobias of small animals," *J. Clin. Psychol.*, vol. 59, no. 9, pp. 943–966, 2003.

[30] Z. Wlazlo, K. Schroeder-Hartwig, I. Hand, G. Kaiser, and N. Münchau, "Exposure in vivo vs social skills training for social phobia: long-term outcome and differential effects.," *Behav. Res. Ther.*, vol. 28, no. 3, pp. 181–193, 1990.

[31] S. Rachman, "Joseph Wolpe (1915-1997)," *Am. Psychol.*, vol. 55, no. 4, pp. 431–432, 2000.

[32] L. G. Öst, P. M. Salkovskis, and K. Hellström, "One-session therapist-directed exposure vs. self-exposure in the treatment of spider phobia," *Behav. Ther.*, vol. 22, no. 3, pp. 407–422, 1991.

[33] T. D. Borkovec, "Effects of expectancy on the outcome of systematic desensitization and implosive treatments for analogue anxiety," *Behav. Ther.*, vol. 3, no. 1, pp. 29–40, 1972.

[34] B. N. Lang, P.J., Bradley, M.M., & Cuthbert, "International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-8.," *Tech. Rep. A-8.*, p. Technical Report A-8., 2008.

[35] M. M. Bradley and P. J. Lang, "Affective reactions to acoustic stimuli," *Psychophysiology*, vol. 37, no. 2, pp. 204–15, 2000.

[36] J. Rottenberg, R. R. Ray, and J. J. Gross, "Emotion elicitation using film clips," *Handb. Emot. elicitation Assess.*, no. April 2013, pp. 9–28, 2007.

[37] C. Monserrat, "Reality to Treat," *Ieee Comput. Graph. Appl.*, pp. 31–37, 2005.

[38] G. Robillard, S. Bouchard, T. Fournier, and P. Renaud, "Anxiety and presence during VR immersion: a comparative study of the reactions of phobic and non-phobic participants in therapeutic virtual environments derived from computer games.," *Cyberpsychol. Behav.*, vol. 6, no. 5, pp. 467–476, 2003.

[39] P. Bun, F. Gorski, D. Grajewski, R. Wichniarek, and P. Zawadzki, "Low – Cost Devices Used in Virtual Reality Exposure Therapy," *Procedia Comput. Sci.*, vol. 104, no. December 2016, pp. 445–451, 2017.

[40] P. Xia, A. M. Lopes, and M. T. Restivo, "Virtual reality and haptics for dental surgery: A personal review," *Vis. Comput.*, vol. 29, no. 5, pp. 433–447, 2013.

[41] A. M. Okamura, "Methods for haptic feedback in teleoperated robot-assisted surgery," *Ind. Robot An Int. J.*, vol. 31, no. 6, pp. 499–508, 2004.

[42] J. Martin-Moreno, D. Ruiz-Fernandez, A. Soriano-Paya, and V. Jesus Berenguer-Miralles, "Monitoring 3D movements for the rehabilitation of joints in physiotherapy.," *Conf. Proc. IEEE Eng. Med. Biol. Soc.*, vol. 2008, pp. 4836–9, 2008.

[43] T. Morelli, J. Foley, and E. Folmer, "VI-Bowling : A Tactile Spatial Exergame for Individuals with Visual Impairments," *Tennis*, pp. 179–186, 2010.

[44] K. J. Kuchenbecker, J. Fiene, and G. Niemeyer, "Improving contact realism through event-based haptic feedback," *IEEE Trans. Vis. Comput. Graph.*, vol. 12, no. 2, pp. 219–229, 2006.

[45] M. F. Alhamid, M. Eid, and A. El Saddik, "A multi-modal intelligent system for biofeedback interactions," *MeMeA 2012 - 2012 IEEE Symp. Med. Meas. Appl. Proc.*, pp. 1–5, 2012.

[46] J. L. Reeves and W. L. Mealiea, "Biofeedback-assisted cue-controlled relaxation for the treatment of flight phobias," *J. Behav. Ther. Exp. Psychiatry*, vol. 6, no. 2, pp. 105–109, 1975.

[47] Y. Nestoriuc, A. Martin, W. Rief, and F. Andrasik, "Biofeedback treatment for headache disorders: A comprehensive efficacy review," *Appl. Psychophysiol. Biofeedback*, vol. 33, no. 3, pp. 125–140, 2008.

[48] D. L. Frank, L. Khorshid, J. F. Kiffer, C. S. Moravec, and M. G. McKee, "Biofeedback in medicine: Who, when, why and how?," *Ment. Health Fam. Med.*, vol. 7, no. 2, pp. 85–91, 2010.

[49] D. L. Nelson, "The effects of an occupationally embedded exercise on bilaterally assisted supination in persons with hemiplegia," *Am. J. Occup. Ther.*, vol. 50, no. 8, pp. 639–646, 1996.

[50] C. Botella *et al.*, "Treating cockroach phobia using a serious game on a mobile phone and augmented reality exposure: A single case study," *Comput. Human Behav.*, vol. 27, no. 1, pp. 217–227, 2011.

[51] C. Botella, J. Bretón-López, S. Quero, R. Baños, and A. García-Palacios, "Treating Cockroach Phobia

With Augmented Reality," *Behav. Ther.*, vol. 41, no. 3, pp. 401–413, 2010.

[52] J. F. Thayer, F. Åhs, M. Fredrikson, J. J. Sollers, and T. D. Wager, "A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health," *Neurosci. Biobehav. Rev.*, vol. 36, no. 2, pp. 747–756, 2012.