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The Impact of Virtual Reality on the Experience of Exercise Pain

A Thesis Submitted to the University of Kent for
the Degree of Ph.D. in Digital Arts

By

Maria Matsangidou

July 2018

This thesis is dedicated to my family, a great source of encouragement and support

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Abstract (300 Words)

Exercise is essential for maintaining a healthy lifestyle, but intense or prolonged exercise can cause a degree of discomfort and pain. These negative exercise-based sensations have been considered as a limiter of exercise capacity and a potential barrier to physical activity. In recent years, computer technology has brought to light new opportunities for promoting physical activity. Virtual Reality (VR) is a representative example of this type of technology, since it allows users to experience a computer-simulated reality with visual, auditory, tactile and olfactory interactions, and distract them from perceiving nociceptive signals and pain.

The present thesis aims to identify whether and how VR with or without psychological intervention strategies may affect the perception of Exercise Pain (EP). These questions are answered through a series of studies conducted on a large group of participants. As a first step, the effect VR might have on EP during a weight-lifting exercise in comparison to a non-VR weight-lifting exercise is investigated. Then, the effect that personal awareness and internal sensations might have on VR technology during weight-lifting EP is examined. Lastly, the effect of VR and different psychological intervention strategies on weight-lifting EP is considered through three studies.

The findings of the present thesis extend our understanding of the physiological and psychological effects of VR, providing useful insights into the relationship of VR with the Heart Rate, the perception of task difficulty and the levels of pain and discomfort caused by an exhaustive muscle contraction. The main conclusion reached is that the use of VR during exercise can reduce physiological and psychological responses associated with negative sensations. This conclusion can be used as an informative input for the design of VR so that it can increase the level of physical activity and, by extension, promote a healthier lifestyle.

Keywords: Virtual Reality, Pain Intensity, Perceived Exertion, Physical Activity, Body Representation, Weight-lifting.

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List of Acronyms

ADHD: Attention Deficit Hyperactivity Disorder

AVF: Alter Visual Feedback

BED: Binge Eating Disorder

CRPS: Complex Regional Pain Syndrome

CT: Cognitive Therapy

ECG: Electrocardiography

EMG: Electromyography

EP: Exercise Pain

ET: Exposure Therapy

fHR: final rate of Heart Rate

fPIR: final rate of Pain Intensity

fRPE: final Rating of Perceived Exertion

GLM: Generalized Linear Model

HMD: Head Mounted Display

HR: Heart Rate

HR1: minute 1 (ISO time) for Heart Rate

HR2: minute 2 (ISO time) for Heart Rate

HR3: minute 3 (ISO time) for Heart Rate

HR4: minute 4 (ISO time) for Heart Rate

IASP: International Association for the Study of Pain

ISO: time-based data points consistently across all participants

mHR: mean Heart Rate

MT: Mirror Therapy

MVF: Mirror Visual Feedback therapy

PBC: Private Body Consciousness

PIR: Pain Intensity Rate

PIR1: minute 1 (ISO time) for Pain Intensity

PIR2: minute 2 (ISO time) for Pain Intensity

PIR3: minute 3 (ISO time) for Pain Intensity

PIR4: minute 4 (ISO time) for Pain Intensity

PLP: Phantom Limb Pain

PTSD: Post-Traumatic Stress Disorder

RM: Repetition Maximum

RPE: Rating of Perceived Exertion

RPE1: minute 1 (ISO time) for Rating of Perceived Exertion

RPE2: minute 2 (ISO time) for Rating of Perceived Exertion

RPE3: minute 3 (ISO time) for Rating of Perceived Exertion

RPE4: minute 4 (ISO time) for Rating of Perceived Exertion

SCIs: Spinal Cord Injuries

TTE: Time to Exhaustion

UE: Upper Extremity

VE: Virtual Environment

VR: Virtual Reality

VRCT: Virtual Reality Cognitive Therapy

VRET: Virtual Reality Exposure Therapy

Chapter 1: Introduction

1.1 Background

Exercise is essential for maintaining a healthy lifestyle, but intense or prolonged exercise can cause a degree of discomfort and pain. The International Association for the Study of Pain (IASP) (Merskey & Bogduk, 1994) defines pain as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage”, which suggests that pain has both a nociceptive[1] and subjective element to its perception. Therefore, whilst the sensory signal of pain for a given exercise intensity/duration is unavoidable, the intensity of pain that someone consciously experiences may not always be the same.

Pain has an important role in protecting the body from damaging stimuli by encouraging avoidance behaviour. More specifically, pain during exercise often influences decision making, leading either to a reduction of exercise intensity (so that pain is reduced) or a withdrawal from the exercise altogether (Mauger, 2014). In either scenario, this can have negative consequences for the individual’s physical activity level and/or training stimulus. On the contrary, if pain perception could be offset during exercise, this could result in an increased willingness to either intensify exercise or continue the exercise for a longer period of time. This would potentially result in an increased level of physical activity and thus a healthier lifestyle.

In recent years, computer technology and interactive video games such as Dance–Dance Revolution (DDR), Wii Sports, and Wii Fit[2] offer new opportunities for promoting physical activity. Some research has shown that computer technology and interactive video games have increased energy expenditure and physical activity which produces positive health benefits (Epstein & Roemmich, 2001; Graves,

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[1] A physiologic type of pain that afferents by actual or potential tissue damage.

[2] https://www.playstation.com/en-us/games/dance-dance-revolution-ps3

https://www.nintendo.co.uk/Games/Wii/Wii-Sports-283971.html

http://wiifit.com

Ridgers, & Stratton, 2008; Graves, Stratton, Ridgers, & Cable, 2007; Jacobs et al., 2011; Maloney, Threlkeld, & Cook, 2012; Smith, Sherrington, Studenski, Schoene, & Lord, 2011; Warburton et al., 2007). Consequently, technology which can reduce this sort of pain could be very beneficial for the individual, as these exercise-based sensations have been considered as a limiter of exercise capacity and a potential barrier to physical activity (Mauger, 2014).

In the past few years, Virtual Reality (VR) has moved beyond research labs into a mainstream consumer electronic device, allowing users to experience a computer-simulated reality based on visual cues and enhanced with auditory, tactile and olfactory interactions. VR provides the user with a complete illusion of different senses and creates an immersive experience (Li, Montaño, Chen, & Gold, 2011).

Low-cost consumer-facing immersive VR systems have now become widely available (e.g., Google Cardboard, Gear VR, and Oculus Rift[3]), providing a wide range of opportunities for healthcare applications.

Therefore, if VR could be appropriately designed to moderate the expected difficulty of an exercise task, such technology could potentially be used to reduce the subsequent pain perception caused by training. Through this, VR has the potential to reduce Exercise Pain, and by extension to increase physical activity. One can imagine how beneficial it would be for individuals who are reluctant to engage in physical activity, as well as clinical populations where their recovery can be enhanced through physical physiotherapy, or specific populations such as athletes where an increased level of physical activity is of vast importance.

1.2 Problem statements

Despite the potential benefits of VR technology, there is a striking gap in literature with regard to the positive outcomes of immersive VR technology on exercise pain.

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[3] https://store.google.com/product/google_carboard

www.samsung.com/global/galaxt/wearables/gear-vr

www.oculus.com

This is even more surprising given the growing interest in VR and pain management. Apparently, there is a need for further research on the attributes and characteristics of VR technology, if it is to be used as an effective solution for pain management during strenuous exercise.

If VR is proved to be effective in altering pain perception and extending the duration of exercise, it can open up new ways for promoting physical activity and a healthier lifestyle. Previous research has shown that VR technology may provide an alternative solution to pain management for clinical and experimental applications based on several psychological intervention strategies, without the use of pharmacological analgesics (Mahrer & Gold, 2009; Malloy & Milling, 2010; Morris, Louw, & Grimmer-Somers, 2009).

In particular, Distraction is the commonest and most successful psychological intervention strategy for the treatment of pain via VR technology, especially in relation to pain from burn injury and thermal stimuli-induced pain (Czub & Piskorz, 2012; Hoffman et al., 2014; Maani et al., 2011; Markus et al., 2009; Wender, Hoffman, Hunner, Seibel, Patterson, & Sharar, 2009) (for details, see sections 2.3.3, 2.3.3.1, 2.4.3, and 2.4.3.1). On the other hand, according to recent studies, Alter Visual Feedback strategy (AVF) presents an alternative approach to pain management and may be more appropriate for pain caused by physical movement (Bolte, de Lussanet, & Lappe, 2014; Chen, Ponto, Sesto, & Radwin, 2014; Harvie et al., 2015) (for details, see sections 2.4.3 and 2.4.3.2). However, the effect of psychological intervention strategies on the experience of exercise pain should be further investigated. A comprehensive comparison of the above intervention strategies would be a good starting point.

Although positive results were found in using VR and psychological intervention strategies to manage chronic[4] or experimental[5] pain, little or nothing is known about the use of VR for reducing the naturally occurring pain experienced during strenuous

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[4] Chronic pain could be any type of pain lasting more than 12 weeks and persisting for months or years.

[5] Experimental pain is arising from standardized stimuli of thermal, electrical, or chemical modalities, which are applied to the skin and muscles to induce and assess pain.

exercise when no psychological intervention strategy is in place. Such investigation will improve our knowledge about the impact of VR technology on the experience of pain and, more specifically, on pain arising from muscle constriction during an exhaustive exercise.

Finally, with few exemptions (Maani et al., 2011) the majority of previous studies used high-cost immersive VR solutions. Therefore, further research needs to be conducted in order to examine the feasibility of low-cost affordable VR technologies. As will be argued, moving to low-cost, accessible solutions will provide a personalised solution which will reduce the cost and time of equipment maintenance and allow a more frequent home-based use. The above will result in an increased and more frequent level of physical activity which will improve and promote a healthier lifestyle for the users.

Therefore, the present thesis will provide knowledge for designers, which can turn out to be invaluable in creating Virtual Environments (VE) for reducing exercise pain.

1.3 Aim and research questions

The aim of the present research is to fill the aforementioned gap in literature by investigating how VR and/or psychological intervention strategies may affect the perception of Exercise Pain (EP). The focus is placed on the way in which a low-cost VR technology can impact on the perception of task difficulty and exercise performance, as well as the influence VR may exercise on the level of pain and discomfort caused by an exhaustive muscle contraction. Discussion pivots around the following research questions:

1. *How does Virtual Reality influence Exercise Pain?*

The first research question attempts to examine if and how VR technology influences the perception of task difficulty, endurance performance and pain experienced during an exhaustive exercise of muscle contraction. Understanding the effect VR might have on exercise pain is the first step in designing appropriate VE for a less painful exercise experience. This question is mainly addressed in chapter 4, where the impact of VR technology on EP is investigated in comparison to conventional non-VR exercise.

2. *How does the awareness of personal internal body sensations influence the effect of Virtual Reality on the perception of task difficulty, endurance performance and pain experienced during exercise?*

The second research question examines whether and how personal characteristics such as Private Body Consciousness (PBC) (for details see chapter 5 and section 2.1), which is a measure of the awareness of internal body sensations, might influence the effect of VR technology on the perception of task difficulty, endurance performance and pain experienced during exercise. Given that those with a higher PBC are believed to be better attuned to their internal physiology and are more affected by disruptions to this (Fenigstein, Scheier, & Buss, 1975), it may be expected that VR can induce changes to perceptions of pain and effort during exercise, but this may be more pronounced in those with high PBC. Currently, there are no studies examining whether PBC can moderate the positive effect of VR on exercise capacity. Therefore, understanding the effect personal characteristics might have on VR technology during exercise pain is the first step in designing personalised VR systems for a less painful exercise experience. This question is mainly addressed in chapter 5, where an experimental study seeks to investigate whether the awareness of internal body sensations can lessen the effectiveness of VR on pain and effort during exercise.

3. *How do different psychological intervention strategies in Virtual Reality influence the perception of task difficulty, endurance performance and pain experienced during exercise?*

The third research question relates to the way different VR-based psychological intervention strategies influence the perception of task difficulty, endurance performance and pain experienced during EP. Researchers have widely implemented Distraction and Alter Visual Feedback strategies in order to improve the experience of pain for patients and healthy population. Understanding the effect VR and the aforementioned psychological intervention strategies might have on EP is the first step to identify the most appropriate and effective psychological intervention strategy for a less painful exercise experience. This is mainly addressed in chapter 6, where two different studies examine how each intervention strategy via VR technology influences EP providing us with different levels of pain and effort.

Furthermore, a novel psychological intervention strategy is suggested, which draws upon the positive characteristics of each strategy (Distraction and Alter Visual Feedback) and seeks to offer a new solution for a more effective treatment of exercise pain. This is mainly addressed in chapter 7, where the combination of the positive aspects of each intervention strategy in VR technology as well as the impact of this combination on exercise pain are investigated.

Lastly, chapter 8 contains a meta-analysis, which compares all the three intervention strategies with an attempt to identify the most effective and appropriate strategy for managing exercise pain.

4. *How can effective Virtual Reality frameworks for pain management be designed?*

This is an overarching research question, as the answer draws upon the analysis included in chapters 4 to 8. The findings and conclusions of the present thesis result in suggestions on how Virtual Reality frameworks can be designed in order to have beneficial effects on pain management. This question is mainly addressed in chapter 9.

1.4 Contribution

The key contribution of this Ph.D. is the insights it offers into the way VR may affect the perception of EP among people during exercise. Although research interest in VR and healthcare applications is thriving nowadays, little attention has been paid to this particular topic by psychologists, sports scientists or the HCI community. The key contributions of this thesis can be summarised as follows:

1. An understanding of the effect that VR might have on exercise pain (Chapter 4).

2. An understanding of the effects personal characteristics regarding body awareness might have on VR technology during exercise pain (Chapter 5).

3. An understanding of the effects that VR - psychological intervention strategies might have on exercise pain (Chapters 6 and 7).

4. An understanding of the most effective intervention strategy for designing better VE which can alter pain perception and extend the duration of exercise promoting physical activity and a healthier lifestyle (Chapter 8).

5. Practical suggestions as to the creation of virtual environments which improve pain management, reduce perceived pain and exertion, and increase time to exhaustion (Chapter 9).

Some of the findings derived from the present Ph.D. thesis have already been published in a number of journals and conferences. These are summarised in Table 1.1 (see Appendix B for articles arising from this Ph.D. and some of which are currently under review).

Table 1.1: A list of publications arising directly from this Ph.D. thesis.

Chapter	Journal/Conference	Title	Citation
2	British Journal of Neuroscience Nursing	Clinical Utility of Virtual Reality in Pain Management: A Comprehensive Research Review from 2009 to 2016.	Matsangidou, M., Ang, C. S., & Sakel, M. (2017).
5	Psychology of Sport and Exercise	Is your virtual self as sensational as your real? Virtual Reality: The effect of body consciousness on the experience of exercise sensations.	Matsangidou, M., Ang, C. S., Mauger, A. R., Intarasirisawat, J., Otkhmezuri, B., & Avraamides, M. N. (2018).
6.2	INTERACT: Conference on Human-Computer Interaction	How Real is Unreal? Virtual Reality and the Impact of Visual Imagery on the Experience of Exercise-Induced Pain.	Matsangidou, M., Ang, C. S., Mauger, A. R., Otkhmezuri, B., & Tabbaa, L. (2017, September).

1.5 Scope

The definitions and scope of many of the key concepts, on which the thesis is based, are still widely debated. One example is the concept of VR for clinical purposes. In general literature, VR for clinical applications has been divided into three types depending on its immersiveness: the non-immersive VR system, the semi-immersive system, and the fully immersive, head-mounted system (see section 2.2). This thesis focuses only on the fully-immersive VR, as it is believed that the level of immersion may affect the participants' experience (see section 2.2).

The present thesis is also concerned with the concept of pain, as opposed to burn care[6], chronic[7] and experimental[8] pain. Even though universally pain is one of the commonest medical complaints, researchers admit that its treatment is difficult due to its complexity and subjectivity. The focus of the analysis is on a type of acute single limb pain experienced during weight-lifting exercise. The aim is to expand our understanding of the effectiveness of VR for pain management, since this specific type of pain lacks other effects that might trigger the pain and complicate the understanding of VR's effectiveness. Therefore, a weight-lifting exercise is considered to be suitable to induce pain which will arises during prolonged muscle contraction due to a build-up of noxious biochemicals in and around the muscle.

Last but not least, the concept of psychological intervention strategies that have been used for eliminating perceived pain is also investigated. In general bibliography, it was found that two types of psychological intervention strategies have been used in order to enhance the effectiveness of pain management via VR – Distraction and Alter Visual Feedback. Even though both strategies yielded promising results (see sections 2.4.3, 2.4.3.1, and 2.4.3.2), their effectiveness is still debated, since research in this field is still in its infancy. It should be noted that the aim of this thesis is to identify the most appropriate and effective psychological intervention strategy for a less painful exercise experience, and to provide suggestions on how Virtual Environments can be designed in order to be beneficial for pain management during exercise.

In the past five years, low-cost consumer-facing fully immersive VR systems have been developed and released. These affordable, fully immersive VR technologies can provide a feasible solution that can be implemented in real-world settings to improve

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[6] A pain that arises from burn wounds.

[7] Any type of pain lasting more than twelve weeks and persisting for months or in many cases for years.

[8] Any type of induced pain that assess the therapeutic efficacy of the analgesic.

pain management and rehabilitation therapies (see section 2.3) for all kind of users (patients and healthy population). However, nurses and technicians need to spend a significant amount of time cleaning the equipment and providing technical support (Markus et al., 2009). Thus, the present thesis investigates the effectiveness of this affordable, fully immersive VR technologies for pain management, and addresses the need for low-cost and easy-to-maintain consumer equipment. As will be argued, moving to low-cost, accessible solutions will reduce the need for technical support and cleaning by staff. Furthermore, if low-cost VR technology proves to be effective, patients will be able to have their own head-mounted display (HMD), which could offer a personalised solution and reduce the cost and time of equipment maintenance, allowing a more frequent home-based use. This could improve healthcare and pain management, since patients would be able to manage pain and improve their physical rehabilitation on a daily basis. VR pain management not only will increase patients' ability of more frequent physical therapy but it will also reduce clinical costs, as patients will be able to carry out therapeutic sessions on their own. This may improve patients' health and provide clinicians with extra time, since they would not have to participate in each therapeutic session (see sections 2.4 and 2.4.1).

It therefore emerges that, as well as increasing users' ability of more frequent physical exercise, the use of low cost and affordable VR technology can also improve hygiene issues, since each user has its own personal VR-HMD. All the above promise a reduced intensity of negative perceptions of pain and effort associated with exercise, resulting in a more frequent exercise.

1.6 Structure

The analysis is organised in chapters 2 to 8 as follows:

- Chapter 2 contains a review of existing literature on topics that are relevant to the present analysis. Theories around the two main components of this thesis, namely "Pain" and "VR technology", are discussed, whereas another point of focus is the use of "VR technology" and "VR interventions" in the general Healthcare sector which includes psychopathy, physical/motor rehabilitation, and pain management practices. Then, a Systematic Literature Review is presented, mainly in relation to elements which are central to this thesis, namely "Virtual Reality and Head Mounted Technologies for pain management", "Virtual Reality and Interactive Modality for pain management", and "Virtual Reality and Intervention Strategies for pain management". At the end of the chapter, a summary of the key elements of this review is presented.

- In chapter 3, there is a description of the VR Equipment, the InteractivE Device and the Virtual Environments used in all studies conducted and presented in chapters 4, 5, 6, and 7, as well as a presentation of the procedures followed for the calculation of Baseline Mass. The Instruments used for the data collection, that is the VR questionnaire, the device for heart rate, and the scales for the exhaustion data such as ratings of perceived pain and exertion, are also presented.

- Chapter 4 contains the results Study 1 which aims to investigate the effectiveness of VR in pain management. The results indicate the superiority of VR in comparison to conventional non-VR exercise.

- Chapter 5 outlines the results of Study 2 which examines the relationship between the effectiveness of VR and body awareness. The results indicate that VR is an effective medium for managing pain, which is not affected by personal characteristics such as Private Body Consciousness.

- Chapter 6 is concerned with Studies 3 and 4, which examine the effectiveness of VR on Exercise Pain when it is enhanced by well-established psychological intervention strategies (such as Distraction and Alter Visual Feedback). These results are also suggestive of the positive characteristics of each strategy for a less painful exercise experience.

- Chapter 7 contains the results of study 5, which shows how a new psychological intervention strategy can positively influence the effectiveness of VR on Exercise Pain.

- In Chapter 8, a meta-analysis of the results presented in chapters 6 and 7 is performed. This meta-analysis aims to inform the research community on how psychological intervention strategies influence the effectiveness of VR, and which intervention strategy is the most effective for pain management on Exercise Pain. The results indicate that the effectiveness of a virtual environment depends on the requirements of the population.

- In Chapter 9, the overall findings and implications arising from the five studies are summarised, explained and discussed. Based on these results, suggestions are presented on how virtual environments can be designed to better aid pain management during weight-lifting exercise. Finally, some guidance for future research in the field is presented.

Chapter 2: Literature Review

The present chapter contains a review of the existing literature on a range of topics which are directly related to the research questions of this thesis. More specifically, the definitions given to key terms and concepts, such as “Pain”, “VR technology”, “VR-Head Mounted Display (HMD) technology”, “Pain Management”, and “Interactive Devices”, are discussed. Also, the use of “VR technology” and “VR interventions” in the general Healthcare sector, which includes psychopathy, physical/motor rehabilitation, and pain management practices, is examined. How previous researchers and practitioners have used VR applications enhanced with interventions/strategies is another point of focus of the present literature review; representative examples are also mentioned to illustrate each environment. Finally, a summary of the key points is presented.

2.1 Pain

Pain is a multidimensional, complex phenomenon that involves negative sensations. It can be defined as a reaction to threatening information that causes a sense of self-danger to the brain (Merskey & Bogduk, 1994; Price, 1999; Moseley, 2003; Arntz & Claassens, 2004). Pain can be caused by injury, illness or any invasive medical procedure. Furthermore, pain is a sensory and emotional experience that causes discomfort to the individual following apparent or believed tissue injury (Merskey & Bogduk, 1994). As such, it is both nociceptive and subjective, with the same sensory signal of pain giving rise to different levels of pain intensity among individuals and situations.

Recent research shows that the level of pain one experiences depends on Private Body Consciousness (PBC), that is, how well one is aware of one’s internal bodily sensations (Bekker, Croon, van Balkom, & Vermee, 2008; Haugstad et al., 2006; Miller, Murphy, & Buss, 1981). Indeed, studies on both clinical patients and healthy participants have shown that individuals with high levels of PBC tend to report greater frequency and intensity of pain symptoms compared to those with low levels of PBC (Ahles, Pecora, & Riley, 1987; Ferguson & Ahles, 1998; Martin, Ahles, & Jeffery, 1991; Mehling et al., 2009; Pincus, Burton, Vogel, & Field, 2002).

The significance of pain as a human experience can be inferred from the high percentages of people who are in pain. One in four US adults experiences continuous pain that lasts for a year or even longer (Hyattsville & National Centre for Health Statistics, 2007).

In general, pain in clinical settings can be classified in four basic categories: i) chronic, ii) neuropathic (Mancini, Longo, Kammers, & Haggard, 2011), iii) inflammatory, and iv) nociceptive / acute (Dannecker & Koltyn, 2014; Ellingson, Koltyn, Kim, & Cook, 2014). Chronic pain could be any type of pain lasting more than twelve weeks and persisting for months or in many cases for years (Manchikanti, Singh, Datta, Cohen, & Hirsch, 2008). On the other hand, neuropathic pain is more specific and occurs as a primary lesion or dysfunction in the nervous system (Merskey & Bogduk, 1994). Inflammatory pain can be internal or external and usually accompanies the sense of warmth, due to tissue injury, which sets off a cascade of biochemical reactions that prime the nervous system for pain sensing. Finally, nociceptive or acute pain is a physiologic type of pain that increase by actual or potential tissue damaging stimuli (Treede et al., 2008).

A number of studies have used brain imaging approaches to test whether pain expectations are associated with concomitant changes in nociceptive circuitry. Some studies revealed the relationship between expectations and pain experience. Interestingly, it has been found that expectations about painful stimulus can profoundly influence brain and pain perception (Atlas & Wager, 2012). This suggests that pain expectations can influence neurobiological responses to noxious stimuli. Therefore, mental representations of an impending painful sensory event can shape neural processes that result in an actual painful sensory experience (Atlas et al., 2010; Atlas & Wager, 2012; Koyama, McHaffie, Laurienti, & Coghill, 2005).

Specific visual cues can influence and reduce pain (Longo et al., 2009). It has been shown that individuals initially apply force to lift an object. This force is based on the visual material properties, such as the size (Adelson, 2001; Johansson & Westling, 1988). Consequently, the object size is important to shape material expectations, which are used to produce target force. The perception of object weight is usually based on memory-driven expectations (Gordon, Westling, Cole, & Johansson, 1993), which are termed “material-weight illusions” (MWI) (Seashore, 1899) and are responsible for pain perception. Therefore, moderating expectation (by deception of object size) can affect pain perception.

2.1.1 Exercise Pain

Pain has long been associated with successful exercise and it is well-known that intense and repetitive muscular contraction, which is consistent with endurance performance, induces Exercise Pain (EP) (Mauger, Jones, & Williams, 2010; Dannecker & Koltyn, 2014). Exercise Pain is usually acute or nociceptive (Cook et al., 1997). Like acute pain, EP arises during exercise due to a build-up of noxious biochemicals (Katz, Lindner, & Landt, 1935; Kjaer et al., 1989; Lewis, Pickering, & Rothschild, 1931; Perlow, Markle, & Katz, 1934) in and around the muscle, such as serotonin, bradykinin, histamine, adenosine, potassium, and substance P combined with increased intramuscular pressure (Cook, O'Connor, Eubanks, Smith, & Lee, 1997; O’Connor & Cook, 1999).

Apart from the natural bodily physiological responses, as explained above (see section: 1.1), the IASP defines pain as an unpleasant sensory and emotional experience associated with actual or potential tissue damage (Merskey & Bogduk, 1994). This implies that pain is subjective and involves emotional elements, whereas its perception is not always directly related to tissue damage (O’Connor & Cook, 1999). Research has shown that psychological factors, such as expectations, play a vital role in pain experience (Bayer, Coverdale, Chiang, & Bangs, 1998; Ohrbach, Crow, & Kamer, 1998; Zatzick & Dimsdale, 1990). Therefore, not all pain signals a danger to the body, but experience of it may lead to undesirable behaviour change. For example, the naturally occurring pain caused by vigorous exercise (EP) does not cause physical harm, but may moderate exercise behaviour (Mauger, 2014). Therefore, the subjective perception of the athlete is a crucial component to the experience of pain. This conclusion is a useful starting point towards the identification of effective psychological intervention strategies for subsequent exercise improvement.

A variety of pharmacological analgesics and psychological intervention strategies are used to treat pain and have yielded a series of positive results (see sections 2.3.3.1, 2.3.3.2, 2.4.3, 2.4.3.1, and 2.4.3.2). Consequently, interventions which reduce this sort of pain could be very beneficial, as these exercise-based sensations have been suggested to be a limiter of exercise capacity and a potential barrier to physical activity (Mauger, 2013 and 2014).

2.2 Virtual Reality

Virtual reality is a technology that allows users to experience a computer-simulated reality with visual, auditory, tactile and olfactory aspects via a computer-generated world. The users interact in real-time with the Virtual World or the Virtual Environment, based on an overall illusion of different senses which creates an immersive experience (Li, Montaño, Chen, & Gold, 2011).

There are three types of VR systems (Ma & Zheng, 2011). A non-immersive VR system is a desktop computer-based 3D graphical system that allows users to navigate through the VE by means of a keyboard, mouse and a computer screen. A semi-immersive system is a graphical display projected on a large screen, and there may be some form of gesture recognition for natural interaction. The third type of VR is a fully immersive, head-mounted system, where users’ vision is completely enveloped, generating a sense of total immersion.

The first interactive VR system was developed by Scott Fisher and his colleagues at NASA Ames Research Center in the mid-1980s, in order to convey three-dimensional acoustic information. The results suggested that this was the first successful attempt at synthesizing localised sound (Begault, 2000; Wenzel, Wightman & Foster, 1988). A few years later, NASA presented the Virtual Interface Environment Workstation (VIEW) (Figure 2.1). VIEW was a HMD system in which the user was able to navigate an artificial computer-generated environment or a real environment relayed from remote video cameras. Data Gloves were developed as an interactivity device which was able to detect the user’s finger movements. The user’s movements were conveyed into a computer generated image, which caused the virtual hand to imitate the move of the real hand (Rosson, 2014; Burdea & Coiffet, 2003).

Figure 2.1: A NASA Ames Scientist Demonstrates Virtual Reality Headset and Data Gloves.

In recent decades, VR was used in several areas mostly for research purposes. One of the most common is VR for Education and Training purposes. Many have considered VR to be one of the emerging and highly promising technologies for learning (Barbour & Reeves, 2009; Dalgarno & Lee, 2010; Loup, Serna, Iksal, George, 2016; Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014; Parmaxi, Zaphiris, Papadima-Sophocleous, & Ioannou, 2013). VR has also been used for Military training purposes. An illustrative example is the use of VR to train infantry in urban combat tactics. Specifically, the soldiers navigate a virtual city filled with computer-generated enemies and friendly troops (National Research Council, 1995).

VR is also used in several other areas such as Video Games and Cinema for entertainment purposes. It is also used in Architecture and Urban Design for the creation of architectural “walk-through” homes and buildings (Burdea & Coiffet, 2003), as well as in Social Sciences, Psychology, and Healthcare/Clinical settings. The latter use is discussed below in more detail (see sections 2.3, 2.3.1, 2.3.2, 2.3.3).

Even though VR systems have been successfully incorporated into several areas within industry, education, and clinical settings, research has demonstrated that their use may also cause some negative symptoms and side effects (Cobb, Nichols, Ramsey, & Wilson, 1999; Sharples, Cobb, Moody, & Wilson, 2008). Some potential side effects associated with the use of VR are nausea and disorientation (Cherniack, 2011). A more in-depth analysis has shown that fully-immersive VR HMD systems might increase nausea symptoms in comparison with non-immersive VR-desktop computer (Sharples et al., 2008). It was also found that the use of fully-immersive VR HMD compared to semi-immersive VR produces significantly increased nausea, oculomotor and disorientation symptoms (Sharples et al., 2008). The level of interactivity seems to be an important factor, for higher levels of interactivity with the VR system appears to reduce the aforementioned symptoms (Sharples et al., 2008).

2.3 Virtual Reality in Healthcare

During the last two decades, there has been an increasing interest in the use of VR technology in healthcare, with the majority of research highlighting the benefits arising from the use of VR during the rehabilitation process. As will be described below, exploratory proof-of-principle and/or small scale of clinical experimental studies explore the effectiveness of VR interventions for clinical purposes, revealing positive effects on psychotherapy, physical/motor rehabilitation, and more recently pain management (Li et al., 2011; Mahrer & Gold, 2009; Riva, 2005; Sveistrup, 2004).

2.3.1 Virtual Reality and Psychotherapy

VR in psychotherapy can be described as an advance imaginal system that can induce emotional responses in order to manage mental traumas successfully (Riva, 2005; Vincelli, 1999; Vincelli, Molinari & Riva, 2000). Over the past decades, VR technology has been widely used in academia to study the treatment of mental health disorders with positive outcomes (Riva, 2005). Specifically, clinical research has shown that VR has been used successfully in Exposure Therapy (ET) for Depression, Anxiety, social and general Phobias, low Self-esteem and Post-Traumatic Stress Disorder (PTSD) (Difede & Hoffman, 2002; McLay et al., 2011; Parsons & Rizzo, 2008; Price, Mehta, Tone, & Anderson, 2011; Riva, 2005; Rothbaum & Hodges, 1999; Rothbaum, Hodges, & Kooper, 1997; Rothbaum et al., 1996; Wiederhold & Wiederhold, 2005).

Several studies have been concerned with the effective use of VR as part of Exposure Therapy (VR + ET = VRET) training, in which VRET may be an alternative solution to exposure in vivo or in imagination practices. To illustrate this, the VE can possibly evoke anxiety and represent phobic situations, and can therefore be an alternative solution to induce exposure (Krijn, Emmelkamp, Olafsson, & Biemond, 2004; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008; Pull, 2005). A particularly good example of VRET was given by Rothbaum and Hodges (1999), who explored the use of VRET for reducing acrophobia, the fear of heights. In particular, the participant was exposed to a VE which simulated a lift made of glass (Figure 2.2). The results revealed a positive effect on acrophobia and a decrease of user's anxiety, avoidance behaviour, and distress. In addition to that, during the VR session, most of the users reported being able to expose themselves to a higher level of heights than the instructed one.

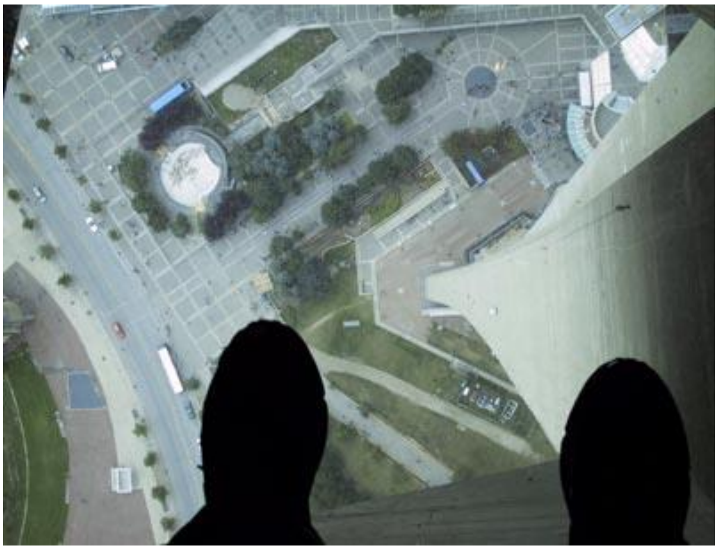

Figure 2.2: Illustration of Virtual Lift Made of Glass.

Studies have also demonstrated that a key advantage of VR is the high level of immersion and presence offered to users. Immersion illustrates a state of consciousness in which the user's responsiveness to its own physical self-diminishes due to the user's involvement in the VE. As explained above (see section 2.2), the sense of immersion can be achieved through the generation of a realistic visual, auditory, tactile and olfactory interaction. In addition to that, the sense of being physically immersed can result in a sense of presence. Presence could be characterised as perceiving the VE as being real (Eichenberg & Wolters, 2012).

Therefore, VR has a critical advantage in terms of the sense of presence and immersion. Compared to traditional psychological ET, VRET has proved to be more beneficial to the patient (Botella et al., 1998), since it exceeds imaginative exposure by adding the sense of presence (Eichenberg & Wolters, 2012). As opposed to imagery exposure, VRET helps the patient to overcome difficulties towards imagining fear and anxious scenes (Botella et al., 2004).

Presence and immersion are significant, but not the only components of VRET's success. In addition to these factors, VR enhances ET by providing both patient and therapist with control over the therapeutic session (Botella et al., 2004; Eichenberg & Wolters, 2012; Gregg & Tarrier, 2007; Glanz, Rizzo, & Graap, 2003; Tarrier, Liversidge, & Gregg, 2006). This means that the patient is able to experience the therapeutic session "as if" s/he is in the real environment (totally threatening), but at the same time "as if" s/he is in a consulting room (totally protected). This makes the patient feel safe in the VE condition and, supported by the therapist, the patient is in a position to explore, experience and react to the situation on her/his own pace in order to deal with the traumatic experience (Botella et al., 2004). In addition to that, VRET can also benefit the therapist, since the therapist is able to monitor and control the VE and therefore intervene in specific phobic scenes (Gregg & Tarrier, 2007).

As with VRET, VR in psychotherapy has been widely used in research in order to enhance Cognitive Therapy (CT), such as in attention enhancement training for Attention Deficit Hyperactivity Disorder (ADHD) (Cho et al., 2002) and as part of Experiential Cognitive Therapy for obesity and Binge Eating Disorder (BED) (Riva et al., 1998, 2000, 2001 and 2003). In this case, VR is used in order to modify body image perception and treat individuals with eating disorders (Figure 2.3). This is because research has shown that body image dissatisfaction could be a type of cognitive bias (Williamson, 1996; Thompson, Heinberg, Altabe, & Tantleff-Dunn, 1999), which is mostly associated with the way the visual information is being unconsciously proceeded by the subject. This self-oriented body distortion usually results in an oversized body image and is severely associated with attentional and memory driven biases for body-related information (Williamson, 1996). Through Virtual Reality Cognitive Therapy (VRCT), the subject can be induced into a Controlled sensory VE where the therapist is able to modify the body schema. This process helps the individual to process the visual information in the most realistic way, since VR allows the user to project the self-image as part of an extension of its own body (James, Humphrey, & Goodale, 2001).

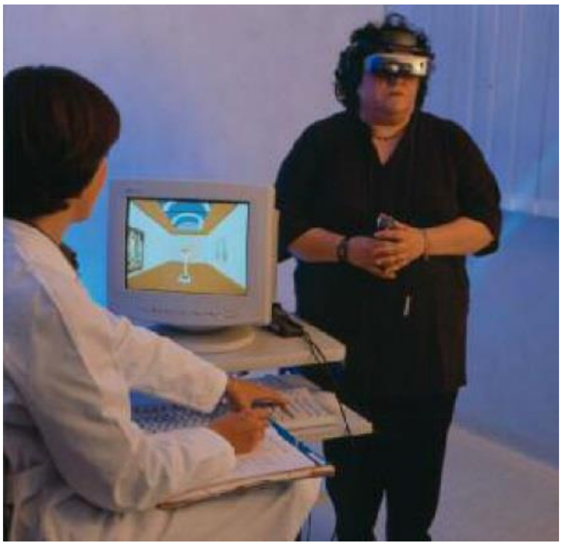

Figure 2.3: Illustration of Virtual Reality Modification of Body Schema for Binge Eating Disorder.

2.3.2 Virtual Reality and Motor Rehabilitation

As can be inferred from the above findings, VR has been successfully integrated into numerous aspects of psychotherapy. Additional research in the field of medicine has proved the potential of using of VR technology in rehabilitation practices in the general health care sector (Riva et al., 1997; Schultheis & Rizzo, 2001; Sveistrup, 2004).

Apart from the encouraging potentials described above (see section 2.3.1), several studies have demonstrated that VR can be a unique platform in which therapy can be enhanced within a pleasurable, functional, purposeful and motivational context (Sveistrup et al., 2003 and 2004; Weiss, Bialik, & Kizony, 2003).

A number of studies emphasise the positive effects that VR have on patients with Stroke and Spinal Cord Injuries (SCIs) that usually result in a type of locomotor disability. In particular, the use of VR technology in physiotherapy, exercise and rehabilitation for people with SCIs improves the patient’s confidence, optimism, and motivation (Riva, 1998). In addition, positive outcomes were observed for patients with a right hemispheric stroke and poor control on foot balancing and standing (Kizony & Katz, 2003), as well as for patients with upper limb motor impairments (Holden & Dyar, 2002; Turolla et al., 2013).

It is worth mentioning that research suggested that hemispheric stroke patients might be unable in general to concentrate. However, concentration is a crucial component of being able to perform standing activities. Via VR the patient practices and improves abilities that have to do with space concentration. Specifically, a VR system was developed in order to allow the patient to concentrate on the virtual space (Kizony & Katz, 2003). Since the VE contained virtual balls appearing from all directions, the patient was forced to pay attention to the entire virtual space.

A preliminary study on VR technology for chronic stroke patients with Upper Extremity (UE) motor control was also presented revealing positive results (Holden & Dyar, 2002). Via this VR application, the patients were instructed to imitate the systems movement in order to perform their physiotherapy sessions. The results demonstrated improvements in motor recovery and patients' strength (Holden & Dyar, 2002). This was not the only study that proved VR's efficiency with stroke patients. A more recent study involving a stroke patient suffering from upper limb motor impairments and motor-related functional disabilities corroborated the effectiveness of VR rehabilitation in comparison to conventional interventions (Turolla et al., 2013). In this study, the VE (Figure 2.4) incorporated a wide range of conventional exercises, including shoulder and elbow flexion-extension, abduction-adduction, internal-external rotation, circumduction, forearm pronation-supination, and hand-digit motion. The results indicated that the VR rehabilitation for restoring upper limb motor impairments and motor-related functional abilities could benefit stroke patients more than conventional rehabilitation practices (Turolla et al., 2013).

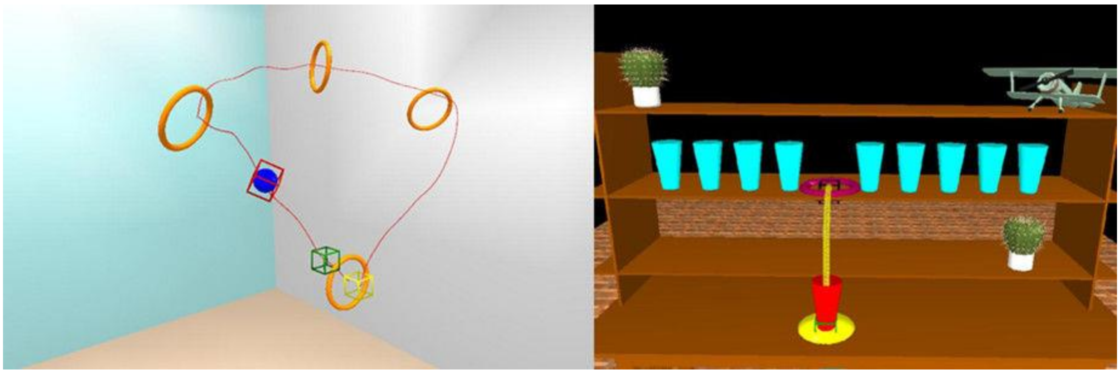

Figure 2.4: Illustration of Motor Exercises in the Virtual Environment.

Similar findings were also demonstrated by Merians and partners (2002). According to these researchers, physiotherapy can improve and modify the neural process and contribute to the recovery of motor skills for stroke patients. This study used VR technology to create an interactive and motivational VE in which the patient was able to perform and practice rehabilitation exercises more intensely. The results yielded positive outcomes. This study suggests that VR not only can play a significant role in patient’s recovery but also has the possibility of enhancing its efficiency via personal feedback and, as a consequence, individualized treatments can be achieved.

2.3.3 Virtual Reality and Pain Management

As explained above (see sections 2.3.1 and 2.3.2), over the past decades VR has been successfully used in several medical and psychiatric interventions. More recently, researchers have commenced to use VR in order to reduce pain perception during painful therapeutic processes, but the use of VR for pain management is still at its early stages with debatable findings regarding its effectiveness (Gold, Belmont, & Thomas, 2007; Mahrer & Gold, 2009).

Even though pain is one of the most universally common medical complaints (Malloy & Milling, 2010), researchers encounter difficulties in its treatment due to its complexity and subjectivity (Gold, Belmont, & Thomas, 2007; Mahrer & Gold, 2009) (see section 2.1). As explained before (see section 2.1), a variety of pharmacological analgesics and psychological intervention strategies are currently being used with positive results. Distraction and Mirror Box Therapy are the commonest psychological intervention strategies for the treatment of pain (see sections 2.3.3, 2.3.3.1 and 2.3.3.2). VR could present new opportunities for enhancing the effectiveness of these strategies (see sections 2.3.3.1, 2.3.3.2, 2.4.3, 2.4.3.1, and 2.4.3.2) by offering a unique platform for pain management.

2.3.3.1 Distraction Strategy

Over the past years, a variety of pharmacological analgesics and psychological methods, such as Distraction via imagery, meditation, relaxation, hypnosis, and positive thinking, have been used by clinicians and nursing staff to decrease the patient’s perception of pain (Blount et al., 1992; Cohen, Blount, & Panopoulos, 1997;

Jay, Elliott, Fitzgibbons, Woody, & Siegel, 1995; Patterson & Ptacek, 1997). Examples of Distraction techniques include deep breathing, video viewing, bubble blowing, reading stories, and listening to music or singing (Cassidy et al., 2002; De Jong, 2013; Miller, Hickman, & Lemasters, 1992; Seers & Carroll, 1998).

Research has concluded that Distraction might positively complement the treatment of pain (Linton, 1982). However, mixed findings were reported regarding its effectiveness (Seers & Carroll, 1998). The Agency for Health Care Policy and Research (US Department of Health and Human Services, 1993) and numerous researchers (Ceccio, 1984; Jessup & Gallegos, 1994; Johnstone & Vogele, 1993; Mandle et al., 1990; Miller, Hickman, & Lemasters, 1992; Miller & Perry, 1990; Ziemer, 1983) maintained that Distraction can be particularly effective in reducing pain perception. However, many other studies were unable to corroborate this view (Domar, Noe, & Benson, 1987; Good, 1995; Laframboise, 1989; Mogan, Wells, & Robertson, 1985).

In an attempt to explain how the Distraction strategy can turn out to be effective in treating pain, several theories have been developed. Gate Control Theory (Melzack & Wall, 1965) is perhaps the most popular one. This theory suggests that pain perception is affected by the level of attention the individual pays to the sensory signal of the pain along with past emotional experiences which are strongly associated with the experience of pain. In this case, the effectiveness of Distraction lies in its ability to divert attention from the painful sensory signal. Emphasis was also given to the number of different sensory resources which are accessible to the individual. Therefore, based on the Multiple Resources Theory (Wickens, 2008) a higher level of Distraction can be achieved by multiple sensory signals; audiovisual signals, for example, can distract the person more successfully than just audio signals.

VR and Distraction Strategy

In recent years, VR has proved to be an alternative solution to conventional Distraction, since it provides the user with multisensory signals. Specifically, the use of VR for pain management purposes has been introduced in the research community as VR-analgesia and it seems to be an advanced form of analgesia caused by conventional Distraction. Research on neurobiological mechanisms has shown that

VR is able to alter the perception of pain with the help of actions which are perceived by the subject in pain as withdrawing its attention from the painful sensory signal (Gold, Belmont, & Thomas, 2007). This is because the individual's attentional resources are limited; thus, the use of Distraction decreases the cognitive capacity the individual has to process painful incomes (McCaul & Malott, 1984). Virtual reality technology offers multi-sensory information that helps the person become fully immersed in the simulated world.

Likewise with VR in Psychotherapy, research has shown that a significant component of the effectiveness of VR Distraction for pain management is the high level of immersion and presence in which the users are involved. As a result, the user engages strongly with this sensory experience, and thus is prevented from perceiving nociceptive signals and pain.

VR systems and especially the HMD systems surround the users completely. These VR HMDs often include head-tracking machinery to track the motion of the user's head and present a 360° VE. Furthermore, some VR-HMD devices incorporate headphones to add sounds, music and reduce environmental noise. Finally, it has also been stated that user's engagement with the virtual experience is enhanced by the interactive devices that are incorporated into the VEs. These interactive devices include joysticks, touch controllers, and gesture recognition technologies which facilitate more natural movements and navigations to the VE. The above features result in an improved system that is able to produce a higher degree of presence and immersion based on a multisensory experience (Mahrer & Gold, 2009).

The first findings in regards with Distraction strategy via the use of VR for pain management was presented at the beginning of the twenty-first century by Hoffman and his colleagues (Hoffman et al., 2000). The study used VR SpiderWorld (Figure 2.5), which was a modified version of KitchenWorld[9], to distract two burn-injured patients during a painful wound care process. Via the VR SpiderWorld, the patient's persona/avatar was a spider and s/he was navigating into a kitchen environment where s/he was able to interact with spiders and objects. The VR SpiderWorld enabled the

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[9] Division Ltd., San Mateo, CA

patient to “pick up” objects, “eat” candy bars, and “touch” or “kill” other spiders. The results confirmed the hypothesis advanced by Hoffman and his colleagues (Hoffman et al., 2000), since it was found that VR is an effective medium for distracting patients from perceiving burn pain signals. This is because the conscious attention of the individual is limited (Kahneman, 1973) and the perception of pain necessitates conscious attention (Chapman & Nakamura, 1998). Therefore, the use of Distraction via VR immersed the patients in the visual experience and shifted the conscious attention of the patient away from the painful experience (see Schneider & Shiffrin, 1977). As a result, engagement with VR consumes the available cognitive resources that would otherwise allow the patient to perceive the nociceptive signals and pain (see McCaul & Malott, 1984).

Figure 2.5: Illustration of the SpiderWorld Equipment.

Since SpiderWorld was found to be an effective tool in reducing pain for burn-injured patients, it was also used in several other studies for the treatment of pain (Hoffman, Garcia-Palacios, Kapa, Beecher, & Sharar, 2003; Hoffman, Patterson, & Carrougher, 2000). Specifically, SpiderWorld was used during painful physical therapy and induced ischemic pain in order to examine the effectiveness of Distraction via VR. Particularly, in the first study, 12 burn patients performed a range of motion exercises using SpiderWorld during physical therapy. The results suggested that VR along with Distraction strategy can provide a non-pharmacological analgesia that reduces significantly pain perception for burn patients during physical therapy. More specifically, it was shown that the amount of time each patient spent on thinking about pain during physical therapy was significantly reduced during the VR Distraction intervention in comparison to conventional interventions (Hoffman, Patterson, & Carrougher, 2000). In the second study, SpiderWorld was found to be effective in eliminating induced ischemic pain for 22 participants of both sexes. The results once again suggested that VR along with Distraction strategy can generate a robust non-pharmacological analgesia that reduces significantly pain perception for any type of adult population in pain (Hoffman et al., 2003).

Although the majority of studies examined the effectiveness of VR among adult populations, there have also been some studies which investigated the issue in relation to younger patients. A study used VR Distraction to treat the child-distressing procedure of blood drawing (Gold et al., 2005). Fifty-seven children participated in the study. VR Distraction was used to reduce the perceived pain during phlebotomy[10] for venepuncture[11]. The results corroborated the effectiveness of VR and Distraction, since the reports of pain intensity from the needle were significantly lower during VR Distraction in comparison to other types of Distraction, such as cartoon video viewing and video-game Distraction with flat-screen equipment. VR pain Distraction for paediatric intravenous placement also proved to be an effective solution in a sample of 20 children which received an intravenous placement for a magnetic resonance imaging/computed tomography (Gold, Kim, Kant, Joseph, & Rizzo, 2006). The study used VR Street Luge[12], which was a racing game. The patient was instructed to race on a hill while lying on a skateboard.

Positive results were also recorded in the use of VR Distraction on paediatric patients with acute burn injuries. This study (Das, Grimmer, Sparnon, McRae, & Thomas, 2005) examined the effectiveness of VR Distraction on the procedural pain of burn dressing changes. The research involved seven children playing a video game, in which the patient was able to shoot monsters with the use of a pointer (Figure 2.6). The results were revealing of the effectiveness of VR Distraction based on video

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[10] Phlebotomy is the process of making an incision in a vein with a needle.

[11] Venepuncture is the process of obtaining intravenous access for the purpose of intravenous therapy or for blood sampling of venous blood.

[12] Fifth Dimension Technologies, Irvine, CA.

games. VR Distraction could be used as an alternative form of analgesia with minimal side effects and little impact on the physical hospital environment. This study also proved the long-term effectiveness of VR Distraction on pain management for children.

Figure 2.6: To the left: Illustration of the Use of the Equipment. To the right: a Scene from the Game.

To conclude, these studies (Das et al., 2005; Gold et al., 2005 and 2006) prove the effectiveness of VR Distraction in reducing pain perception in paediatric patients.

In general, it was found that Distraction via VR can be an effective tool in pain reduction for children and adults. In comparison to previous research which yielded mixed findings regarding the effectiveness of Distraction on pain management, these studies almost unanimously demonstrated the effectiveness of Distraction via VR, since the results were mostly associated with positive outcomes.

2.3.3.2 Mirror Therapy

Apart from Distraction strategy, a number of studies have also investigated the use of Mirror Visual Feedback therapy (MVF), also known as Mirror Therapy (MT), in the treatment of pain for patients with an affected body part. In MVF therapy the patient is instructed to be seated in front of a mirror. The mirror's orientation is parallel to the patient's midline. At this position, the patient is able to see through the mirror the reflection of her/his unaffected body part. The affected body part is hidden beside the mirror and under the mirror box (Figure 2.7). This position creates the visual illusion that the affected body part is working properly, since visual cues are created through the mirror and from the opposite side of the unaffected body part in response to the brain's commands (Ramachandran, 2005).

Figure 2.7: Illustration of the use of the Mirror Box.

MVF therapy is positively correlated to pain reduction based on brain imaging approaches, which suggest that pain expectations are associated with concomitant changes in nociceptive circuitry (see section 2.1) and based on the plasticity of the brain. Research has shown that the brain has the ability to alter well established neural connections (Purves et al., 2001). This can be achieved through the perceived visual feedback which can activate the brain areas that are involved in sensory-motor learning, termed as mirror neurons (Ramachandran, 2005; Ramachandran & Altschuler, 2009). The activation of the mirror neurons emerges from the subject's movement or from the observation of a movement (Rossi et al., 2002).

Based on this mechanism, it has been found that MVF therapy is positively correlated with the reduction of pain for chronic pain patients, via transferring visual stimuli to the brain. Chronic pain patients suffer from continuous pain which is highly unresponsive to medical treatments (McCabe, 2011; Sato et al., 2010). The use of MVF therapy has proved to be an effective non-pharmacological solution for reducing pain in chronic pain patients suffering from Complex Regional Pain Syndrome (CRPS) (Karmarkar & Lieberman, 2006; Lamont, Chin, & Kogan, 2011; McCabe et al., 2003; Sato et al., 2010; Selles, Schreuders, & Stam, 2008), Phantom Limb Pain (PLP) (Brodie, Whyte, & Niven, 2007; Chan et al., 2007; Hunter, Katz, & Davis, 2003; Lamont, Chin & Kogan, 2011; Ramachandran, 1994; Ramachandran, Rogers-Ramachandran, & Cobb, 1995), wrist fracture (Altschuler & Hu, 2008), hand surgery (Rosén & Lundborg, 2005) and partial spinal cord injury (Sumitani et al., 2008). It was also found that MVF therapy could be a successful solution for motor rehabilitation in stroke patients (Altschuler et al., 1999; Yavuzer et al., 2008; Sütbeyaz, Yavuzer, Sezer, & Koseoglu, 2007).

As explained above, MVF therapy was mostly used with CRPS and PLP patients and was commonly correlated with positive outcomes in regards to pain reduction. Particularly, it was found that MVF therapy not only mitigates patient's pain but also reduces the number and the duration of the pain episodes. It also emerged that MVF therapy had a long-lasting effect on the patients; even four weeks after MVF therapy, the patient still reported lower rates of pain (Chan et al., 2007).

To conclude, MVF therapy manipulates and reduces pain. This reduction is the result of brain functions, which are in turn influenced by the alteration of the visual feedback. Having this in mind and going a step further, research has corroborated the fact that the visual feedback could be responsible for altering the awareness of the body. A particularly good example was given by Ramachandran and Rogers-Ramachandran (2007), who showed that when the subject sees her or his own healthy hand through reducing lens, the subject not only sees but also feels her/his hand as being actually smaller. Moreover, this study has shown that the visual feedback given to the subject through the reducing lens can also cause a curious alienation of the hand. Testing this theory with PLP patients, it was found that the optical reduction of the visual feedback reduced the patients' perceived pain on the phantom limb (Ramachandran, Brang, & McGeoch, 2009).

VR and Mirror Therapy

MVF therapy was originally developed to reduce or even in some cases to eliminate pain in patients with CRPS and PLP. Its effectiveness is derived from the manipulation of the brain to react to visual feedbacks as if the phantom limb exists and moves again. However, MVF has some limitations which can be overcome with the use of VR. In particular, MVF requires from the user high levels of attention in order to perceive the visual illusion as if it were real. In other words, MVF therapy requires the sense of presence and immersion, which are significant components for VR systems (Lamont, Chin, & Kogan, 2011). Additionally, in MVF therapy the user is able to perform only single-handed tasks. VR can provide an advanced and entertaining way of multi-handed tasks (Murray et al., 2006). Having said that, an advanced VR-MVF system may increase analgesia effect on subjects in pain (Sato et al., 2010).

VR-MVF is an elaborated MVF system, which replicates the traditional mirror box in a technologically advanced version. More specifically, the mirror box is replaced by the VE and sensors to reproduce the movements of the unaffected hand. As shown in Figure 2.8, most of the VR-MVF tasks are target-oriented motor Control tasks, in which the patient is instructed to “reach”, “pick up”, “touch” and “carry” objects with her/his unaffected hand. However, with the help of VE, the task is presented as being performed by the affected hand, which is not allowed to be moved (Fukumori, Gofuku, Isatake, & Sato, 2014; Sato et al., 2010). Similarly to the traditional form of the MVF, the results indicate that the VR-MVF is a promising alternative solution for the treatment of CRPS and PLP, since it is reported to reduce the perceived pain by 50% and 38% respectively (Mercier & Sirigu, 2009; Sato et al., 2010).

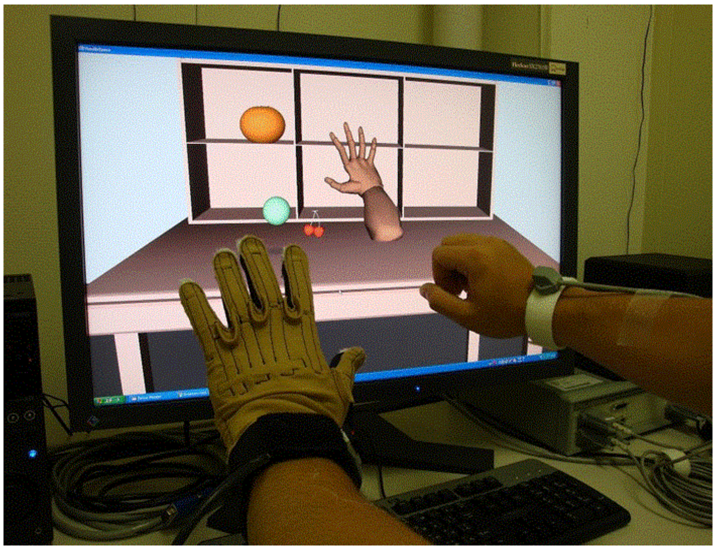

Figure 2.8: Illustration of the Use of the VR-MVF.

As explained above, neurological evidence has proved the effectiveness of MVF (Ramachandran, 2005; Ramachandran & Altschuler, 2009; Rossi et al., 2002). A comparison between MVF and VR-MVF on 20 healthy participants via fMRI has shown that the VR-MVF was more effective than the MVF. In response to the actual movement, the fMRI has revealed that the VR-MVF produces stronger activation in the primary sensorimotor cortex contralateral in comparison to the traditional MVF (Diers et al., 2015). However, even though VR-MVF therapy has yielded positive and promising results, further research needs to be conducted in order to establish its effectiveness (Lamont, Chin, & Kogan, 2011; Sato et al., 2010), as VR-MVF is still in its infancy.

2.4 Systematic Literature Review on Immersive Virtual Reality, and Pain Management

The present thesis aims to provide insights into the way VR may affect the perception of pain. The primary focus of the analysis lies in the effect of low-cost fully immersive VR technology on the perception of pain. As inferred from the previous sections (see sections 2.3, 2.3.1, 2.3.2 and 2.3.3), VR's effectiveness has been proved by several experimental and clinical studies. However, most of these findings were based on non-immersive or semi-immersive VR systems. Therefore, there is a need to distinguish between the different kinds of VR technologies, since literature on the clinical use of VR often treats any form of computer-generated virtual world as VR. Consequently, a systematic literature review has been carried out with the aim of investigating fully the core components of this thesis. The results of this systematic literature review have been published in the British Journal of Neuroscience Nursing (Matsangidou et al., 2017).

Although the relationship between VR and pain management has already preoccupied a number of scholars in their reviews, the present review offers new insights into this area in the following ways:

- It focuses on the technological aspects of VR and how they are applied in real-world clinical settings. In particular, it looks at the clinical usages of low-cost consumer VR.

- Whereas past reviews examine the general bibliography on VR and pain management, this review looks at the effects of VR on different types of pain and populations, and VR content design strategies.

- This review focuses exclusively on immersive VR and HMD solutions, as opposed to past reviews, which adopted a broader definition of VR. Therefore, it presents a focused definition of immersive VR on pain management.

- Finally, this review examines the use of novel interactive devices which may affect user experience and hence clinical outcomes. For instance, VR systems based on a keyboard and mouse may hamper the sense of immersion compared to gesture-based systems, where users interact with VR more naturally with their hand and head movements.

According to a systematic literature review (Figure 2.9), only 29 studies were found to investigate the relationship between fully-immersive VR head-mounted technologies and pain. Specifically, the systematic literature review is based on Bargas-Avila & Hornbæk (2011) and Cochrane's methodology (Higgins & Green, 2011; Khan, Ter Riet, Glanville, Sowden, & Kleijnen, 2001) and is delivered in five phases as explained below.

Phase 1. Potentially relevant publications identified

Electronic libraries: Six electronic libraries were searched. These cover a balanced range of disciplines, including computer science/engineering, medical research, and multidisciplinary sources. The libraries searched for this review were: ACM Digital Library; Google Scholar; IEEE Xplore; MEDLINE; Sage; and ScienceDirect.

The search was restricted to a timeframe of eight years (2009-17), as the review concerned recent technologies. Consumer VR technologies have advanced significantly in the past five years.

Search terms: Two precise queries were used when searching all the libraries, as the aim was to cover VR pain management through immersive VR technology. Non-immersive and semi-immersive technologies were excluded. The search terms were:

- Virtual Reality AND Pain

- Head Mounted Display AND Pain

Search procedure: The search terms were used in searches by article title, abstract and/or keywords.

Search results: The searches returned in phase 1 are shown in Table 2.1.

Table 2.1: Results per library and in total.

	ACM	**Google Scholar**	**IEEE Explore**	**MEDLINE**	**Sage**	**ScienceDirect**
Virtual Reality AND Pain	13	148	19	0	13	32
Head Mounted Display AND Pain	4	33	2	0	1	3
Total findings	268					

Phase 2. Identifying papers for detailed evaluation

First exclusion: All search results from phase 1 were imported into Paperpile software. Three entries with the wrong years were excluded manually. This narrowed the results down to 265 papers.

Second exclusion: Duplicate publications between each library (when different libraries produced the same result) and within each library (when different terms produced the same result into the same library) were removed. Fifteen duplicate publications between each library were removed, which left 250 papers. Then, 41 duplicates within each library were removed. This left 209 papers.

Third exclusion: Entries were then narrowed down to original full papers that were written in English. Papers were excluded if the researchers did not have access to the full article. Also excluded were papers that were not original full papers, such as workshop reports, poster presentations, speeches, reviews, magazine articles and generally grey literature without formal peer review. As a result, 107 more papers were excluded.

The 102 remaining papers comprised: 79 journal articles, 21 conference papers, and two book chapters.

Phase 3. Publications to be included in the analysis

Final exclusion: Since the focus on this review is on consumer VR we excluded studies which used bulky experimental VR equipment not suitable for clinical use (e.g., CAVE). We also excluded studies which did not use HMD and immersive technology. As aforementioned, since consumer solutions which has released by companies (Table 2.1) are using HMD and immersive technologies, we believe that similar studies to these technologies will add knowledge in the field and provide clinical environments and patients with portable, accessible and usable technologies in the future. If this portable, accessible and usable VR systems appear to be effective, this will lead to the improvement of healthcare and pain management since individuals will be able to manage pain and improve their physical activity.

Based on these criteria, in this phase we excluded any irrelevant paper that appeared in the first phase and were not excluded through the second phase filtering. These papers may appear in our findings, because they contain relevant words to the one that we searched but did not match to the specific technology content (e.g., used CAVE instead of HMD systems).

Through these restrictions, 73 irrelevant publications were removed. This left 29 relevant papers (27 journal articles and two conference papers) (Figure 2.9). At the end of this phase, all corresponding PDFs were downloaded for analysis.

Phase 4. Data gathering

In this phase, all relevant information was extracted for analysis. Information from each study was organised using an Excel spreadsheet. This covered: type of pain; type of VE content/environment; type of HMD; make and model of interactivity devices used; sample size; methodology; instruments; and key findings. In addition, each study was categorised by the result as positive, negative or neutral.

Phase 5: Data analysis

The data, collected in phase 4, was analysed using descriptive statistics. The literature was then reviewed to support and enhance knowledge. Thematic analysis was used as an extra methodology to categorize the findings of this study based on the themes. The themes included the types of HMD, the type of VE content, interactivity devices and the design strategies.

Intercoder reliability between the researcher and the research assistant was assessed; Cohen’s kappa was used to calculate the similarity between the researcher and the research assistant. The similarity was 0.89.

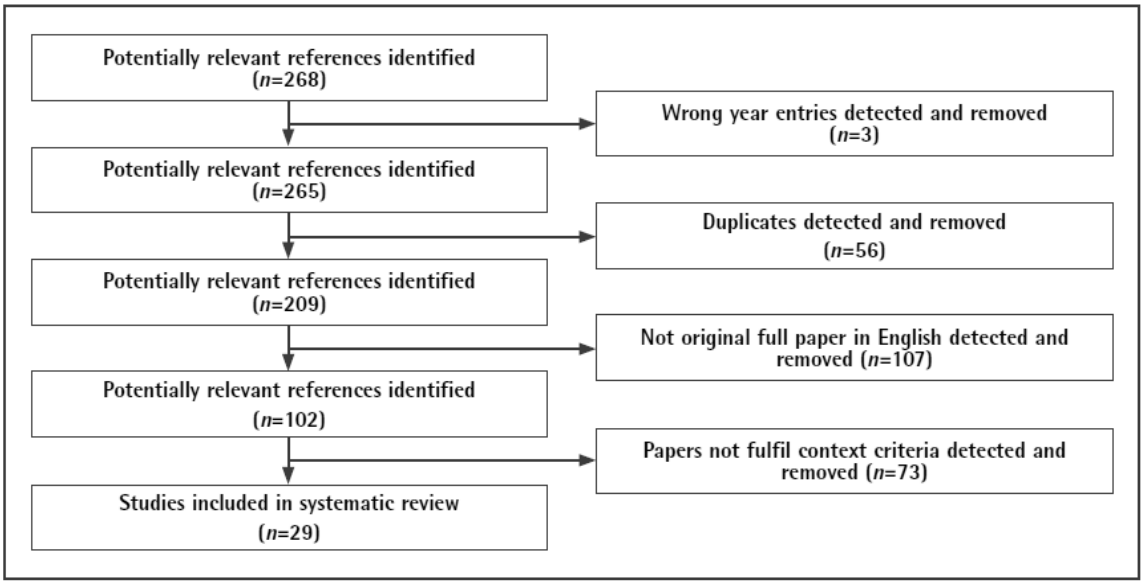

Figure 2.9: Identification and Selection of Studies.

As can be seen in Table 2.2, most of the studies (20/29) on VR pain management were Controlled studies, where participants were allocated in two groups, the VR and the Non-VR group (normally non-computerised intervention). Most (60%) of the Controlled experiments seem to have a positive effect on pain management in contrast to Non-VR treatments. In addition, most of the negative results (62.5%) involved real patients with pain problems (as opposed to healthy participants exposed to painful stimuli).

Only one Controlled study (Bahat, Takasaki, Chen, Bet-Or, & Treleaven, 2015) investigated the relationship between VR treatment and chronic pain in a long-term period. The findings revealed that even though VR treatment was more effective than Non-VR, the VR effect did not last in the follow up evaluation. Therefore, one key area of further investigation is to explore how VRs are able to provide a suitable long-lasting solution for pain management.

Whilst most Controlled studies showed positive outcomes, all five case studies detected in this systematic literature review, revealed positive results. These studies dealt with patients with a specific type of pain (e.g., burn, phantom limb, arm hemiplegic stroke, and dental pain). Consequently, the case studies on VE were focused on the specific characteristics of the type of pain, resulting in positive outcomes.

Overall, VR seems to show some potential for pain management. However, as stated above, specific characteristics on pain treatment and impermanent outcomes may affect the effectiveness of VR on pain treatment.

Table 2.2: Characteristics of VR Studies.

Study	**Type of Study**	**Virtual Environment**	**Outcomes**
Burn Care			
Carrougher et al. (2009)	Controlled	Icy 3D canyon surrounded by a river, a waterfall and snowflakes	Positive
Czub & Piskorz (2012)	Controlled	Prince of Persia & Split Second	Negative
Czub & Piskorz (2014)	Non-Controlled	Hit White and avoid Red Spheres Game	Neutral
Dahlquist et al. (2009)	Controlled	Free Dive	Negative
Dahlquist et al. (2010)	Controlled	Need for Speed Underground 2TM	Positive
Dahlquist, Herbert, Weiss, & Jimeno (2010)	Controlled	Ice Age 2: The Meltdown	Negative
Hoffman et al. (2014)	Case Study	SnowWorld	Positive
Kipping, Rodger, Miller, & Kimble (2012)	Controlled	Chicken LittleTM Need for SpeedTM	Positive
Maani et al. (2011)	Controlled	SnowWorld	Positive
Markus et al. (2009)	Non-Controlled	SnowWorld	Neutral
Morris, Louw, & Crous (2010)	Controlled	VR Game	Negative
Rutter, Dahlquist, & Weiss (2009)	Controlled	Catch Dory	Positive
Schmitt et al. (2011)	Controlled	SnowWorld	Positive
Sil et al. (2014)	Controlled	Sand Oasis	Positive
Wender et al. (2009)	Controlled	SnowWorld	Positive
Chronic Pain			
Bahat, Takasaki, Chen, Bet-Or & Treleaven (2015)	Controlled	Pilot flying an airplane	Positive: Not lasting

Bolte, de Lussanet & Lappe (2014)	Controlled	Basketball arena	Positive
Chen, Ponto, Sesto & Radwin (2014)	Non-Controlled	To align a butterfly image with a net image	Positive
Harvie et al. (2015)	Controlled	4 outdoor video 2 indoor video	Positive
Sano, et al. (2015)	Case Study	Reaching task	Positive
Wake, et al. (2015)	Case Study	Reaching task	Positive
Wiederhold, Gao, Sulea, & Wiederhold (2014)	Not specified	Relaxing video of natural areas	Positive
Dental Pain			
Aminabadi, Erfanparast, Sohrabi, Oskouei, & Naghili (2011)	Controlled	Tom and Jerry Episode	Positive
Wiederhold, Gao & Wiederhold (2014)	Case Study	Relaxing video of natural areas	Positive
Other Types of Pain			
Crosbie, Lennon, McGoldrick, McNeill, & McDonough (2012)	Controlled	Reaching task	Negative
Gordon, Merchant, Zanbaka, Hodges, & Goolkasian (2011)	Controlled	Ringo	Negative
Schneider, Kisby, & Flint (2011)	Controlled	Multiple VR scenarios, Patient choose the scenario	Positive
Spyridonis, Gronli, Hansen & Ghinea (2012)	Case Study	VR model with body parts interaction	Positive
Walker et al. (2014)	Controlled	SnowWorld	Negative

2.4.1 Virtual Reality HMD Technologies

From the reviewed papers, a range of VR HMD used in the studies were identified. Some of them are considered low-cost consumer solutions (lower than 1,000 USD), whilst others are high-end technologies often used only in the lab for scientific studies. This thesis aims to examine the use of low-cost VR system as an effective solution for reducing perceived pain in resistance exercise among a healthy population. I believe that if low-cost VR systems appear to be effective, then it will be practical to carry out this type of intervention at home. I therefore further hypothesize that this will lead to the improvement of healthcare and pain management since individuals will be able to manage pain and improve their physical activity on a daily basis using their own personal device. Based on this thinking patterned, VR HMD, were categorised based on their cost.

Low-cost solutions include VR Goggles, i-glasses 920HR, Vuzix Wrap 1200V, Oculus Rift and eMagin z800 3DVisor. The total cost of the HMD was between 14.95USD – 900USD. High–cost solutions include Kaiser SR-80, Nvis nVisor MH60, ProView VO35, 5DT: 800-26 and VFX3D and total cost ranges from 1,800 USD to 35,000USD (Figure 2.10).

Figure 2.10: To the left: Low-Cost VR HMD. To the right: High-Cost VR HMD.

Most of the papers reviewed (14/29) used a low cost (cost < $1000) immersive VR solutions (Aminabadi et al., 2011; Bahat et al., 2015; Chen et al., 2014; Czub & Piskorz, 2012 and 2014; Harvie, et al., 2015; Hoffman et al., 2014; Kipping et al., 2012; Maani et al., 2011; Morris et al., 2010; Sano, et al., 2015; Schneider et al., 2011; Spyridonis et al., 2012; Wake et al., 2015), few used high-cost (cost > $1800) professional immersive VR solutions (9/29) (Carrougher et al., 2009; Dahlquist et al., 2009 and 2010; Dahlquist, Herbert, Weiss, & Jimeno, 2010; Rutter et al., 2009; Sil, et al., 2014; Gordon et al., 2011; Markus et al., 2009; Wender et al., 2009) and the rest of the studies did not specify the type of HMD they used (7/29).

Some (37.9%) of the interactivity and HMD devices were connected to a desktop computer, portable computer (laptop) or a videogame console. To begin with, 13.8% of the studies used a Desktop computer to run the experiments (Czub & Piskorz, 2012; Dahlquist et al., 2009; Dahlquist, Herbert, Weiss, & Jimeno, 2010; Crosbie et al., 2012). At the same rate, 13.8% of the studies used a videogame console, such as PlayStation 2 (Dahlquist et al., 2010; Rutter et al., 2009), Nintendo Wii (Sil, et al., 2014) and Xbox 360 (Chen et al., 2014). And finally, 10.3% used a portable computer (Maani et al., 201; Markus et al., 2009; Morris et al., 2010).

2.4.1.1 Low-Cost VR HMD

The commonest low-cost HMD, which was used in 38.5% of the studies reviewed, was Oculus Rift (Chen et al., 2014; Harvie et al., 2015; Hoffman et al., 2014; Sano et al., 2015; Wake et al., 2015).

Patients who experience chronic pain in specific body parts, such as the neck, are usually also dealing with kinesiophobia, the fear of movement. The Oculus Rift was used to influence the way patients perceived neck movement during physiotherapy and had positive results (Chen et al., 2014; Harvie et al., 2015).

Studies looking into the treatment of phantom limb pain using Oculus Rift also showed promising results. Limb amputation often leads to an intense pain felt in the missing body part; patients experience a strong chronic pain in the missing part as if that part of the body still exists. Medical–pharmacological analgesics often fail to alleviate phantom pain. This review identified two studies (Sano et al., 2015; Wake et al., 2015) on phantom limb pain and VR neurorehabilitation. Both studies used Oculus Rift and the same VE, with a few slight differences. This system could be used for pain management within flexible neurorehabilitation regimens for patients with phantom limb pain (Sano et al., 2015; Wake et al., 2015). Finally, Hoffman et al. (2014) used Oculus Rift for burn pain with positive results.

Several studies (31%) into burn care and thermal stimuli used the eMagin z800 3DVisor (Czub & Piskorz, 2012 and 2014; Kipping et al., 2012; Morris et al., 2010). The eMagin z800 3DVisor yielded negative results and made no significant improvement to burn pain, whereas differences between the VR and non-VR interventions had minor differences (Morris et al., 2010). Czub & Piskorz (2012) even reported that the participants felt more pain when they were using the eMagin z800 3DVisor.

However, the eMagin z800 3DVisor has had positive results, showing statistically significant reductions in pain scores during dressing removal in burn-injured patients who received VR Distraction, compared to those receiving standard Distraction (Kipping et al., 2012).

i-Glasses 920HR were used for alleviating pain in wheelchair users and during dental treatment (Aminabadi et al., 2011; Spyridonis et al., 2012). Both studies reported positive results. Children who received dental treatment with VR Distraction reported less pain and anxiety during the VR intervention compared to those not using VR Distraction (Aminabadi et al., 2011). In addition, smartphone-based VR application (PainDroid) reduced pain in wheelchair users (Spyridonis et al., 2012).

Only one study (Bahat et al., 2015) deployed a VR system that could potentially be used as a home-based rehabilitation tool—the Vuzix Wrap 1200 HMD. This study investigated kinematic impairments in patients with chronic neck pain. Patients who used the VR HMD over a short-term period felt less pain than Controls. However, the VR effect did not last through the five-week training. In other words, over a long-term period, the VR group did not benefit more than the Controls.

Maani et al. (2011) used what is possibly the cheapest VR HMD-Goggles Cardboard, which is made of cardboard and powered by a Google Android smartphone. This reduced pain perceived during the burn care wound cleaning process. Even though this study used the lowest cost VR HMD device, it had significantly positive results.

To conclude, low-cost VR HMD (Table 2.3) are suitable healthcare solutions for pain management. Although only one study looked into the use of VR in home settings, other studies suggest that low-cost VR solutions could probably also be carried out at home. Further studies need to be conducted in patients' home to improve home-based pain management and identify the effectiveness of VR in this setting. This could improve healthcare and pain management, since patients will be able to manage pain and improve their physical rehabilitation on a daily basis. Not only will this increase patients' ability to have a more frequent physical therapy but it will also reduce clinical costs. Patients will be able to carry out more therapeutic sessions on their own. This may improve patients' health and provide clinicians with extra time, since they will not have to participate in each therapeutic session.

Table 2.3: Low-Cost VR Technologies.

VR technology	Cost (in 2017)	Company	Website
Google Cardboard	$14.95 - $120	Google, US	www.google.com/get/cardboard/
Gear VR	$99	Samsung, US	www.oculus.com/en-us/gear-vr/
i-glasses 920HR	$299	i-O Display Systems, CA	www.i-glassesstore.com/i-3d.html
Sony PlayStation	$399	Sony, Australia	www.playstation.com/en-au/explore/playstation-vr/
Vuzix Wrap 1200VR	$500	Vuzix, NY	https://www.vuzix.com/
Oculus Rift	$599	Oculus, US	www.oculus.com/en-us/rift/
HTC Vive	$799	HTC, US	www.htcvive.com
eMagin z800 3DVisor	$ 900	eMagin, NY	http://www.emagin.com/

2.4.1.2 High-Cost VR HMD

Almost half of the high-cost HMD studies (44.5%) used 5DT: 800-26 (Dahlquist et al., 2009 and 2010; Dahlquist, Herbert, Weiss, & Jimeno, 2010; Rutter et al., 2009; Sil et al., 2014). All these studies used healthy people to identify how VR affects the perception of induced pain and the tolerance of cold stimuli. The results were mixed, with two studies reporting non-statistically significant differences between the VR and the non-VR groups (Dahlquist et al., 2010; Dahlquist, Herbert, Weiss, & Jimeno, 2010), and two studies reporting VR’s positive effects on pain management (Rutter et al., 2009; Sil et al., 2014).

The VFX3D HMD device was used when cold stimuli were applied (Dahlquist et al., 2010), with mixed results. Findings suggest that VR can help to distract some children, something that underlines the importance of understanding the participants’ individual characteristics to identify a suitable VR solution for them. However, VFX3D HMD had negative results where electrical stimulation was used to cause pain (Gordon et al., 2011).

More expensive solutions such as Nvis nVisor MH60 and ProView VO35 dealt with burn care rehabilitation and pain management (Carrougher et al., 2009; Markus et al., 2009). The results of these experiments suggest a significant decrease in pain (Carrougher et al., 2009) and, importantly, allow more time to be spent on procedures (Markus et al., 2009).

The most expensive VR HMD was used to examine tolerance of pain caused by heat stimuli. This study (Wender et al., 2009) used the Kaiser SR–80 and SnowWorld VE in a healthy population. The level of interaction during sessions with immersive VR technology was found to increase participants' pain tolerance (Wender et al., 2009).

Although these HMD are high-cost solutions (Table 2.4), they were included in this systematic review because they are portable. The headsets can be connected by a wire to a laptop, unlike systems like CAVE that take up a whole room. While these studies used high-cost HMD solutions for VR pain management, their results could be applied to low-cost HMD technologies. A conclusion from the review is that the cost of the HMD does not affect the effectiveness of the VR system.

Table 2.4: High-Cost VR Technologies.

VR technology	**Cost (2017)**	**Company**	**Website**
Kaiser SR-80	$35000	Tek Gear	http://www.tekgear.com/proview-sr80.html
Nvis nVisor MH60	$ 23900	NVIS	http://www.nvisinc.com
ProView VO35	$5500	Ultimate3DHeaven	http://www.ultimate3dheaven.com/
5DT: 800-26	$ 3995	5DT	http://www.5dt.com/?page_id=36
VFX3D	$1800	IISVR	http://www.stereo3d.com/vfx3d.htm

2.4.2 Interactive Devices

In additional to the HMD devices, 65.5% of the studies used other interactive devices to help the user interact with VR. Such devices included keyboard, computer mouse, trackball hand controller, joystick, Microsoft Kinect, and CyberGlove II[13] (Figure 2.11).

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[13] Microsoft Kinect (https://developer.microsoft.com/en-us/windows/kinect) and Cyberglove II (www.cyberglovesystems.com/cyberglove-ii). Unfortunately, the articles do not provide us with the version of Keyboard, Computer mouse, Track ball hand controller, Joystick so as to be able to provide the URL.

Figure 2.11: Interactivity Devices.

The commonest interactive solution were the keyboard (used by two studies), used for burn care treatment (Carrougher et al., 2009; Schmitt et al., 2011), and the computer mouse which was used in four burn care studies (Hoffman et al., 2014; Maani et al., 2011; Markus et al., 2009; Schmitt et al., 2011) and one cold stimuli experiments (Czub & Piskorz, 2014).

Joysticks were also used in five burn pain studies. They were used for burn pain (Kipping et al., 2012; Morris et al., 2010), cold stimuli (Dahlquist et al., 2009 and 2010; Dahlquist, Herbert, Weiss, & Jimeno, 2010) and electrical stimulation (Gordon et al., 2011) experiments. The joystick is an input device consisting of a stick that spins on a base and reports its direction to the HMD device it is controlling. Two types of joysticks were used in these experiments: a wired Logitech joystick for burn care and cold stimuli experiments, and a wireless joystick for the electrical stimulation experiment.

A trackball hand controller is a pointing device consisting of a ball secured by a hole full of sensors to detect its rotation. Two studies used a trackball hand controller to interact and navigate in the VR— during cystoscopy (Walker et al., 2014) and heat stimuli (Wender et al., 2009).

More advanced options were CyberGlove II and Microsoft Kinect, which were used in two and three studies respectively. Both interaction devices were used for phantom limb pain (Sano et al., 2015; Wake et al., 2015), whereas Microsoft Kinect was also used for a cold stimuli experiment (Czub & Piskorz, 2014). CyberGlove II is a wireless glove that captures the hand motion, whereas Microsoft Kinect captures the movement of the whole body.

2.4.3 Intervention Strategies

Depending on the type of pain and the recommended treatments, the studies reviewed differ considerably in the VE therapy and the strategies for developing and delivering it. Two main strategies were identified:

- Distraction strategy
- Altered Visual Feedback strategy.

2.4.3.1 Distraction Strategy

Patients with burn injuries have to deal with painful physical therapeutic processes. These processes are fundamental components of rehabilitation because they improve functional outcomes and minimize persistent disabilities. However, patients with burns usually avoid to fully participate in physical therapies due to acute procedural pain (Ehde, Patterson & Fordyce, 1998; Patterson & Sharar, 2001). Many studies on burn care examined suitable VR solutions of procedural pain management through physical therapy (Carrougher et al., 2009; Hoffman et al., 2014; Kipping et al., 2012; Maani et al., 2011; Schmitt et al., 2011).

VR burn care studies employed Distraction as a way of managing procedural pain (Figure 2.12). VR Distraction is usually based on Video-Game which distracts the patients from the painful process by asking them to play a game through a VR interactive environment. A particularly good example was given by Kipping et al. (2012). In their study patients played a software game that was appropriate to their age limit; younger patients played Chicken Little[14] and older patients were immersed in the Need for Speed II environment (Figure 2.12). Playing a simple game distracted them from painful burn care procedures.

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[14] The article does not provide us with the URL. Several versions of this game exist online.

Several studies provided a complementary feature of Distraction by providing an environment that appeared cold, such as an icy 3D canyon like that used in SnowWorld (Figure 2.12). Patients interacted with the VE by throwing snowballs, and gained a cooling feeling from the icy features of the environment (Carrougher et al., 2009; Hoffman et al., 2014; Maani et al., 2011; Markus et al., 2009; Schmitt et al., 2011). Thus, VR with snowy VE created an illusion of a cooling effect. This VE provides the user with a useful, complementary feature on Distraction strategy, as it creates a 'virtual cooling sensation' (Table 2.5).

Research has shown that Distraction with ice features incorporated in the VE significantly reduced procedural pain. Functional magnetic resonance imaging (fMRI) showed a great reduction in participants' pain-related brain activity while they were using the SnowWorld game during a thermal experiment (Hoffman et al., 2004 and 2007).

Figure 2.12: To the left: Need for Speed, Underground II (Electronic Arts, Inc., Redwood City, CA). To the right: SnowWorld, (University of Washington, Seattle, WA).

The use of SnowWorld in burn care is well known; it has also been tested for the management of procedural pain management during cystoscopy (Walker et al., 2014). Cystoscopy is a common ambulatory procedure performed in urology and can be associated with moderate pain. Forty-five male patients aged 18–70 participated in the experiment. Twenty-two patients had cystoscopy with a VR Distraction, while the remaining 23 in the Control group had a normal cystoscopy. No significant differences between the two groups were found. SnowWorld and VR Distraction with ice features did not alleviate pain in men during cystoscopy. Thus, while VR is useful in pain management, it does not work for all types of pain.

Although evidence supports the use of VR for pain management in burn care and thermal stimuli through Distraction and a cold VE, little has been written about the use of VR for treating patients with chronic pain and even less about using consumer VR solutions for chronic pain management. Chronic pain is any type of pain lasting more than 12 weeks. It can persist for months or years. Because of the complexity of chronic pain, there is less evidence on its management.

It has been found that VR, via Distraction, can also reduce significantly painful symptoms from patients with chronic pain. Specifically, a VE showing natural environments enhanced with relaxing music seems to decrease pain significantly (Wiederhold et al., 2014).

One study (Bahat et al., 2015) examined a solution that could be used for home-based pain management and rehabilitation. This study investigated kinematic impairments in patients with chronic neck pain. The sample of this study consisted of 32 adult patients with chronic neck pain (disability index NDI>10%).

Participants were divided randomly into two groups: kinematic (KT) and VR kinematic (KTVR). Both groups completed 4–6 sessions over a five-week period. The training sessions were consistent for both groups, and included head movements (fine, active and quick) and stability tasks, and lasted 30 minutes. The KT group did the activities with a head-mounted laser pointer and a poster, while the KTVR group used HMDs interacting with a VE. The VE consisted of a virtual pilot flying a red airplane controlled by the patient’s head motion. The results showed that patients who used the VR HMD felt less pain than KT patients over the short term. However, the VR effect did not last throughout the five-week programme (the study did not state the duration of the effect). In other words, in the long term, the KTVR group did not benefit more than the KT group.

Table 2.5: Characteristics of VR Distraction Strategy.

Study	Participants	Intervention	Virtual Environment
Burn Care and Thermal Stimuli			
Carrougher et al. (2009)	39 Inpatients, Aged: 21-57	VR-Distraction / Non-VR	Icy canyon in a river, a waterfall, and snowflakes
Hoffman et al. (2014)	1 Patient, Aged: 11	VR-Distraction / Non-VR	SnowWorld
Kipping et al. (2012)	41 Patients, Aged: 11-17	VR-Distraction / Non-VR	Chicken LittleTM Need for SpeedTM
Maani et al. (2011)	12 Patients, Aged: 18+	VR-Distraction / Non-VR	SnowWorld
Markus et al. (2009)	12 Patients, Aged: 18+	-	SnowWorld
Morris et. al. (2010)	11 Patients, Aged: 23-54	VR-Distraction / Non-VR	Chicken LittleTM
Schmitt et al. (2011)	54 Patients, Aged: 19+	VR-Distraction / Non-VR	SnowWorld
Chronic Neck Pain			
Bahat et al. (2015)	32 Patients Aged: 18+	VR-Distraction / Non-VR	Pilot flying an airplane
Chronic Phantom Limb Pain (PLP)			
Sano et al. (2015)	6 Patients	-	Reaching task
Wake et al. (2015)	5 Patients	-	Reaching task
Non- Specified			
Wiederhold et al. (2014)	40 Patients, Aged: 22-68	-	Relaxing scenes of natural areas

2.4.3.2 Altered Visual Feedback Strategy (AVF)

Kinesiophobia can occur in patients with chronic pain and leads to a reduction in physical activity. Kinesiophobia has been detected in patients with chronic back and neck pain. To eliminate kinesiophobia and improve physical movement and rehabilitation, several VRs that alter the visual feedback of the patient to change motor behaviour have been developed (Bolte et al., 2014; Chen et al., 2014; Harvie et al., 2015).

A promising VE that used AVF is a virtual basketball arena (Bolte et al., 2014) (Figure 2.13). The participants stood in the centre of the virtual arena and perform a virtual basketball-catching task based on their body rotation. The participants' feet are stable on the ground. The visual feedback was amended slightly to alter the way the neck, back, and hips contributed to the catching rotation. The results showed that VR and AVF may increase the degree of back movement in patients with chronic back pain.

Figure 2.13: Illustration of the Virtual Basketball Arena.

Based on this idea and with the aim of dealing with chronic neck pain and kinesiophobia, a VE was designed to alter patients' perception of neck motion (Chen et al., 2014). The patient performed a target-aiming task that involved moving the neck. The goal was to align with the images of a butterfly and a net using neck movements. The results of this study suggest that AVF influences patients' movement and, as a consequence, eliminates kinesiophobia.

Positive findings on AVF strategy were also reported by Harvie and partners (2015). In an experiment made in the framework of a study on movement pain, altered visual cues were used. Patients with chronic neck pain were asked to rotate their heads. However, the visual feedback Overstated or Understated the real rotation by 20%. The results revealed that AVF may increase or decrease pain perception depending on the visual proprioceptive feedback (Table 2.6).

Table 2.6: Characteristics of AVF strategy.

Study	Participants	Virtual environment / Task
Chronic Back Pain		
Bolte et al. (2014)	17 Patients, Aged: 16-63 18 Healthy participants, Aged: 20-30	Virtual basketball arena
Chronic Neck Pain		
Chen et al. (2014)	10 Healthy participants	Head-neck rotational task
Harvie et al. (2015)	24 Patients, Mean Age: 45	Head-neck rotational task (Virtual rotation was equal or 20% less or more than actual physical rotation)

2.5 Summary and Conclusion

The findings of this review indicate that VR can be a useful tool for pain management. However, its effectiveness depends on the design strategy, the VR content and the type of pain.

The move from high-cost VR hardware to low-cost and portable types for practical clinical use has been considered. The development of VR technologies in recent years has resulted in more accessible and less expensive solutions that can yield positive results. Indicatively, one study in this review (Maani et al., 2011) used what is possibly the cheapest VR HMD, Google Cardboard, which is made of cardboard and has a starting price of $14.95. However, even an inexpensive VR HMD device had positive results on pain management. Consequently, it is conceivable that VR technologies can be used more widely in clinical settings, complementing traditional therapy and medical treatment.

Low-cost solutions are often portable, which means that the VR HMD can be plugged into a laptop computer or a smartphone; as opposed to the requirements of a CAVE VR system, there is no need to install sensor devices in the entire room. In addition to the hardware, it was found that several portable interactive devices, such as trackball hand controller, joysticks, Microsoft Kinect and CyberGlove, can be adapted to VR HMD. This can result in the development of a holistic portable, accessible and usable system for pain management.

Depending on the type of pain and the recommended treatments, VE content as well as the design strategies used to develop and deliver content will differ considerably. Two main strategies were identified in relation to VR pain management: Distraction and AVF strategy. Both have their merits.

Distraction is an effective strategy that allows patients to concentrate on the virtual experience, thus distracting themselves from nociceptive signals and pain. This is by far the most commonly used strategy in pain management in general literature. The AVF strategy triggers the patient’s visual feedback and influences the perception of pain. The effectiveness of each strategy depends on several factors, such as the type of pain, the existing physical rehabilitation process, and participant demographics.

Drawing from the above review, it is not far-fetched to note that there is a paucity of robust data generated by high-quality research methodology to review the role of VR in pain management. Of all the studies subject to review, only one looked into the use of VR treatment in patients’ home settings. Given the continuous advances in the usability of VR technologies and accompanying interactive devices, it is conceivable that, in the future, VR rehabilitation could easily be carried out at home with minimal clinical supervision. This will improve healthcare and pain management, since patients will be able to manage pain personally and improve their physical rehabilitation in their daily lives in a real-life context.

Chapter 3: Presentation of Equipment, Virtual Environments, and Methodology

As explained previously (see sections 1.3 and 1.4), this thesis looks into the way VR may affect the perception of Exercise Pain (EP). More specifically, emphasis is placed on the use of a low-cost VR technology and its impact on the perception of task difficulty and exercise performance. Also, the present research seeks to investigate how VR may influence the level of pain and discomfort caused by an exhaustive muscle contraction.

To investigate the above and answer the research questions set out in section: 1.3, I have carried out five studies involving a total of 130 participants (Figure 3.1).

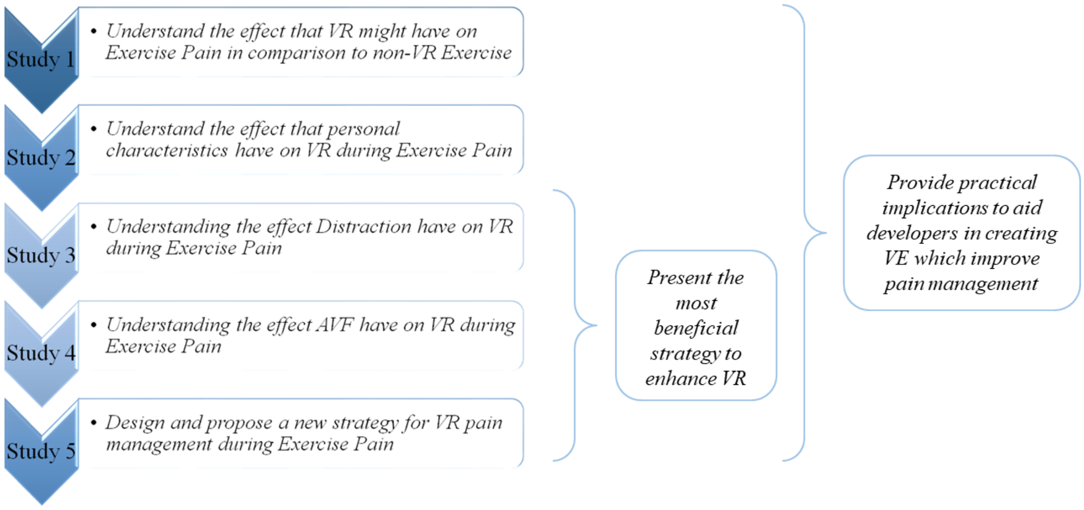

Figure 3.1: Flowchart of studies stages.

To avoid repetitions in the chapters that follow, this chapter presents the hardware and software equipment used in all studies in order to investigate whether VR may affect the perception of Exercise Pain. This chapter also sets out the experimental procedure for calculating the 1RM (one-repetition maximum) and the instruments which were widely used in all five studies thesis. Finally, this chapter presents the familiarisation session which was also common to all five studies.

3.1 Virtual Environment

For the purposes of the studies carried out in this project, VR systems were developed using Unity3D-5[15] to work with Samsung Gear VR[2] and Samsung Galaxy S6 phone. The 3D models (human upper body, the virtual room, and barbells) (Figure 3.2) were created in Maya version 2016[16]. The system was developed to allow the researcher to customize the VR scenarios, including the gender of the human body, dominant hand, skin colours, colours of the t-shirt, the weights of the barbells, and the VE surrounding the user. In order to create a sense of embodiment, a Microsoft Band's gyroscope[17] was used to animate the virtual arm, reflecting the movement of the participant's arm (rotation X and Y).

Through the Samsung Galaxy Gear HMD device, the participant was able to see the virtual body sitting on a chair in a neutral looking virtual room (Figure 3.2). A table with a yoga mat on it was present in the virtual room, simulating the conditions of the actual environment.

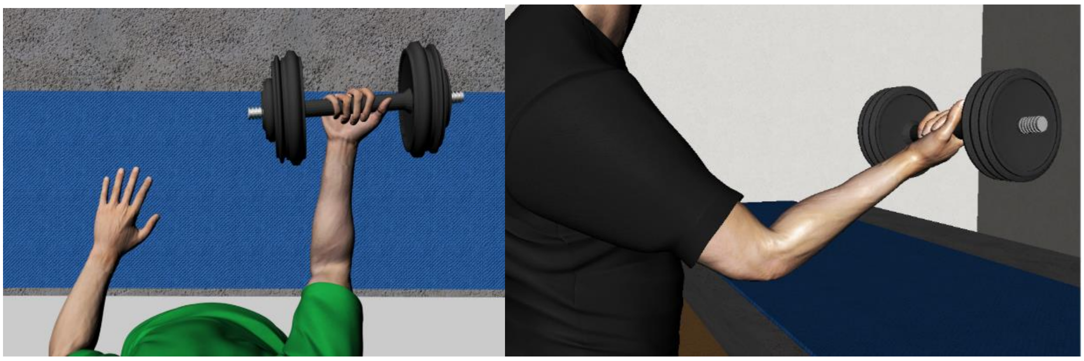

Figure 3.2: To the left: Human 3D model – User's Perception. To the right: Representation of the Actual Environment.

Four types of Virtual Environment were created for the five studies. Table 3.1 summarise the studies each Virtual Environment was used in:

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[15] https://unity3d.com/unity/whats-new/unity-5.0

[16] https://www.autodesk.co.uk/products/maya/free-trial-dts

[17] http://www.dyadica.co.uk/controlling-virtual-experiences-using-biometrics/

Table 3.1: Virtual Environments Employed to Each Studies.

Virtual Environment	Study
Control environment	1, 2, 3, 4, 5
Game Distraction	3, 5
Nature Distraction	3, 5
Advanced Distraction	5

The first VE was mostly used as the Control environment. The virtual room was void of any distracting visual information, since different environmental factors might cause a degree of Distraction (Figure 3.3).

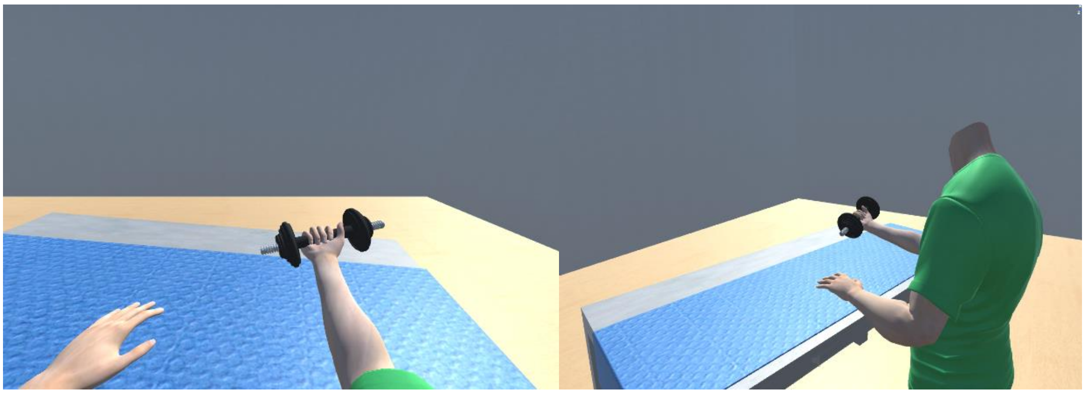


Figure 3.3: Illustration of the Void Virtual Environment: To the left: Human 3D model – User's Perception. To the right: Representation of 3D model (user's avatar) in the Environment – detached point of view.

The second VE was a Game Distraction environment. This VE was based on previous studies, according to which interactive video games result in increased levels of energy expenditure and physical activity with positive health benefits (Epstein & Roemmich, 2001; Graves et al., 2007 and 2008; Jacobs et al., 2011; Maloney et al., 2012; Smith et al., 2011; Warburton et al., 2007). In addition, it was found that when VR incorporate Game features into Distracting VE this reduces perceived pain during the painful process (Dahlquist et al., 2010; Kipping et al., 2012; Rutter et al., 2009; Sil et al., 2014). Consequently, combining the positive findings about video games and VR Distraction strategy, a VR intervention was designed to examine whether this would reduce perceived pain and negative exercise-based sensation, which have been considered as a limiter of exercise capacity and a potential barrier to physical activity (Mauger, 2014).

To do so, I used a virtual ball in order to improve participant's concentration. The virtual ball randomly entered the VE and asked the participant to follow its movement and count its jumps all over the virtual space. Based on the Gate Control Theory (Melzack & Wall, 1965) (see section 2.3.3.1), this type of Distraction is expected to reduce the levels of attention the individual pays to the sensory signal pain, since the participant will concentrate in counting correctly the number of jumps each virtual ball will make (Figure 3.4). The rest of the virtual room was empty without any other distracting visual information.

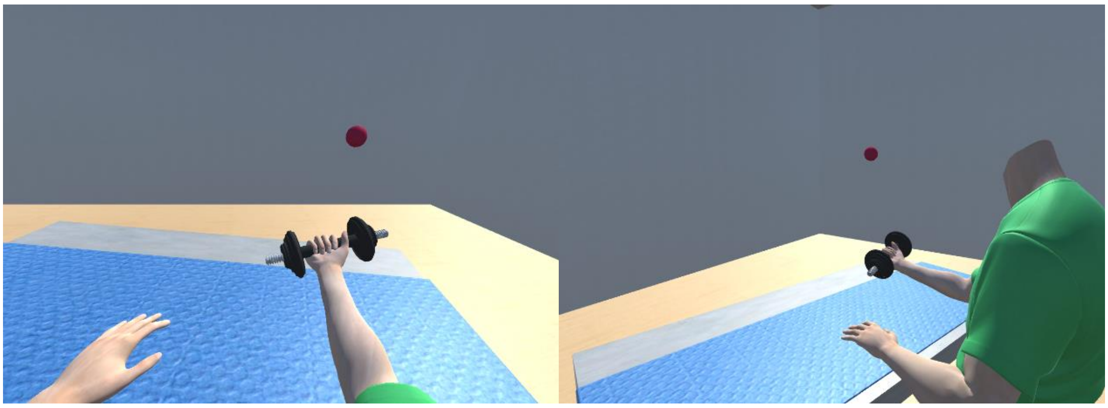


Figure 3.4: Illustration of the Game Distraction Virtual Environment: To the left: Human 3D model – User's Perception. To the right: Representation of 3D model (user's avatar) in the Environment – detached point of view.

The third VE was a Nature Distraction environment. This VE was based on previous studies suggesting that viewing nature can improve physiological and psychological responses, enhance emotional well-being, aid recovery from stress, and improve health (heart rate and blood pressure tend to decline within a few minutes of viewing nature) (Altman & Wohlwill, 2012; Maller, Townsend, Pryor, Brown, & St Leger, 2006; Pretty, Peacock, Sellens, & Griffin, 2005; Parsons, 1991; Ulrich, 1979, 1981, 1983, 1984, 1991, 1992 and 2002; Verderber, 1986; Ulrich et al., 1991; White & Heerwagen, 1998). Furthermore, research has suggested that exercise in a natural environment motivates positively the individual (Gladwell et al., 2013) and offers a more pleasant experience with positive psychological and psychological effects, such as decrease in tension, confusion, anger, and depression, whereas it increases the energy levels and exercise intensity (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Calogiuri & Chroni, 2014; Thompson Coon et al., 2011).

Finally, research showed that, when exercise is performed in the presence of nature, attention to sensory signal of pain, fatigue and perceived exertion diminish, since the attention is shifted onto the natural environment (Calogiuri, Nordtug, & Weydahl, 2015; Harte & Eifert, 1995).

Apart from the positive effects that exposure to natural scenes has, several studies demonstrated that environmental factors can enhance Distraction and reduce perceived pain. Natural features were found to have a positive effect on specific types of pain. Specifically, for burn care patients and experimental pain that was associated with thermal stimuli, snowy VE were found to create an illusion of a cooling effect (Carrougher et al., 2009; Hoffman et al., 2014; Maani et al., 2011; Markus et al., 2009; Schmitt et al., 2011). The above observation was further corroborated by fMRI which reported a great reduction in participants' pain-related brain activity while they were using this type of VE during a thermal experiment (Hoffman et al., 2004 and 2007) (see section 2.4.3.1).

Taking into consideration the above findings, the VE which was created for the study depicted a forest park and included birds singing (Figure 3.5).

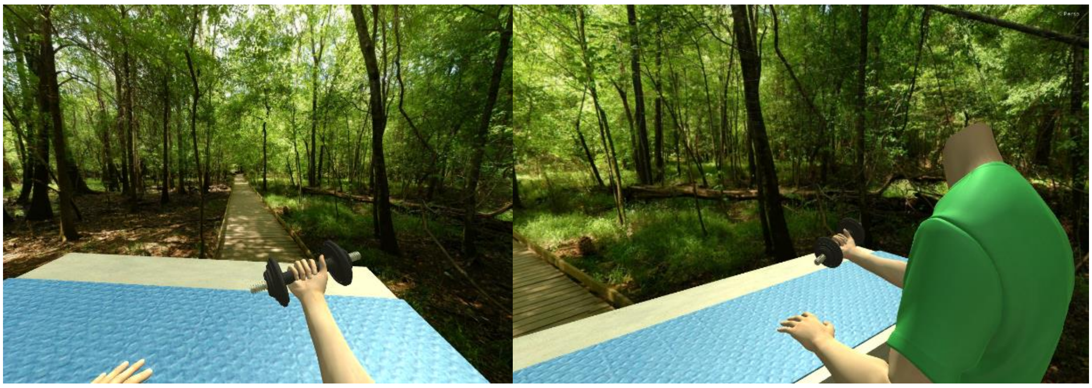


Figure 3.5: Illustration of the Nature Distraction Virtual Environment: To the left: Human 3D model – User's Perception. To the right: Representation of 3D model (user's avatar) in the Environment – detached point of view.

In order to combine all the positive effects of affirmation, the fourth VE was a combination of Game and Nature Distraction. This VE was called Advanced Distraction. The VE was a forest park enhanced with birds singing. A virtual ball was added into the VE and asked the participant to follow its movements and count its jumps (Figure 3.6).

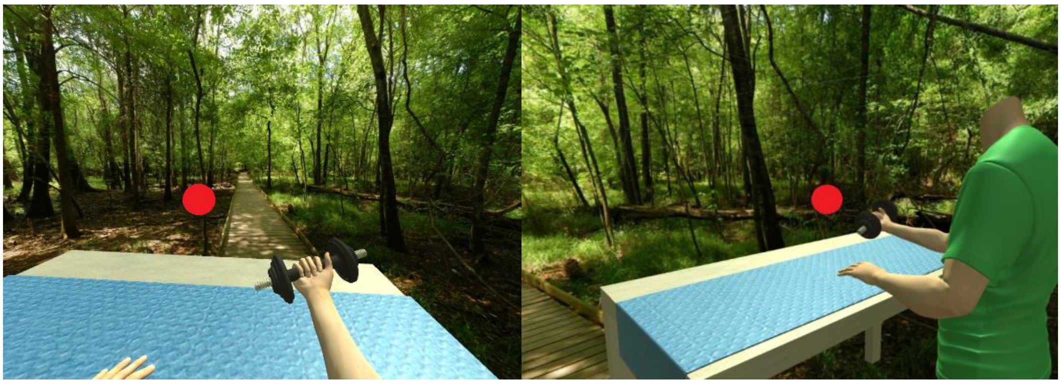


Figure 3.6: Illustration of the Altered–Advanced Distraction Virtual Environment: To the left: Human 3D model – User's Perception. To the right: Representation of 3D model (user's avatar) in the Environment – detached point of view.

3.2 Instruments and Calculation

When participants visited the laboratory for session 1, they were asked to stand with their back straight against the wall and with their elbow and wrist joint at a 180º angle. From this position, they were asked to bicep curl a dumbbell through a full range of motion (180º-full flexion-180º), as shown in Figure 3.7. Mass was added to the dumbbell until the participant was not able to perform a 180º-full flexion-180º. The heaviest mass a participant was able to lift was set as their 1RM. A mass that was equal to 20% of each participant's 1RM was then set as their Baseline Mass for the familiarisation session.

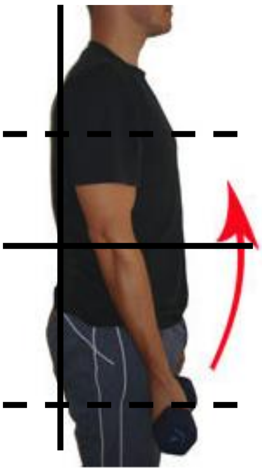


Figure 3.7: Illustration of Bicep curl 180º-full flexion-180º.

Once this process was completed, participants were asked to rest for 10 minutes before moving to the familiarisation session. During the familiarisation session, they were instructed to sit on a chair with their elbow rested on a table in front of them. A yoga mat was placed under their elbow to ensure that the position was comfortable. Participants in the VR group were asked to put on a Samsung Galaxy Gear[2] HMD. Then, participants in both groups were instructed to hold their Baseline Mass in an isometric contraction for as long as they could with their elbow at an angle of 90º flexion (Figure 3.8).

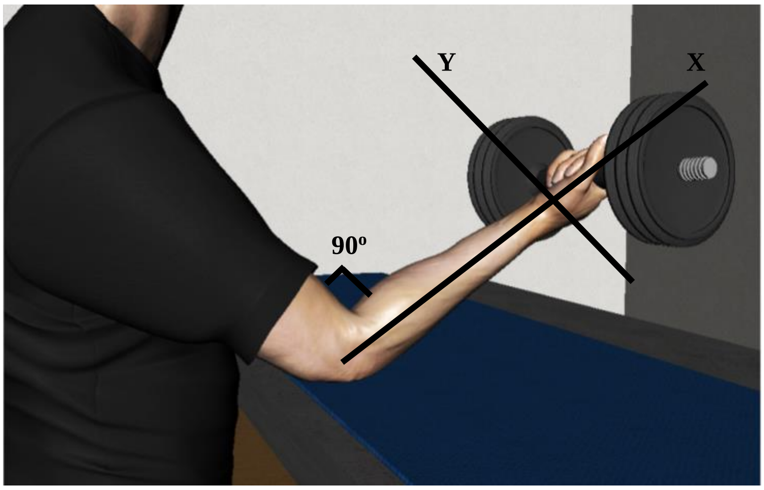


Figure 3.8: Illustration of Bicep curl Isometric Position.

During all the experimental sessions of the five studies, the following data were collected (see Appendix 1-3 for the full version of the instruments):

- **Heart Rate (HR):** HR was continuously measured with a telemetric device, which was a Polar digital HR monitor and a Polar Wear-link chest strap (with 2 electrodes) (Polar Electro, N2965, Finland). HR has been used in several previous studies on pain and also provides a measure of the psychological anticipation of exercise (e.g. McGrath et al., 2008; von Baeyer & Spagrud, 2007).

- **Time to Exhaustion (TTE):** TTE was measured based on the amount of time the participants spent holding the weight. Time to occurrence of pain has been previously assessed during a continuous pain task (Dahlquist et al., 2010; Rutter et al., 2009; Sil et al., 2014). A time to exhaustion task, together with parallel measures of Exercise Pain (EP), has been previously used to assess the effect of EP on exercise performance (Astokorki & Mauger, 2017). For health and safety reasons, the maximum experimental time was set up to 15.00 minutes.

- **Pain Intensity Rate (PIR):** Participants were asked to verbally report their level of perceived pain every 60 seconds, using the 1-10 Cook Scale (Cook et al., 1997) (see Appendix 3.1 for the Scale and the Instructions distributed to participants). Participants were instructed to report their PIR based on the feeling of pain during exercise rather than on other non-exercise type pain (e.g. dental pain).

- **Rating of Perceived Exertion (RPE):** Participants were asked to verbally report their rating of perceived exertion, using the 6-20 Borg Scale (Borg, 1998) (see Appendix 3.2 for the Scale and the Instructions distributed to participants), every 60 seconds of the exercise task. Specifically, participants were asked to report how much effort they had to put to keep their arm in a 90º flexion, irrespective of feelings of discomfort.

- **Immersive Experience:** A self-report questionnaire completed after the exercise task in the VR group was used to assess immersive experience. The questionnaire (see Appendix 1 for the Questionnaire distributed to participants) refers to several factors such as Presence and Hand Ownership, is based on the individual's impression of realistic experience, and uses a 7-point Likert scale.

3.3 Ethical Considerations

All the studies were approved by University of Kent SSES Research Ethics & Advisory Group. All participants signed a consent form prior to the study and the study was performed in accordance with the Declaration of Helsinki. Table Table 3.2 summarizes the reference numbers of the ethical approvals, provided by University of Kent SSES Research Ethics & Advisory Group for each study.

Table 3.2: Reference number of Ethics Approval by University of Kent SSES Research Ethics & Advisory Group for each study.

Study	Reference Number
1	77_2016_17
2, 3 and 5	50_2016_17
4	112_2015_2016

3.4 Participants

Participants in all studies were healthy, with normal vision, and no disability that could affect their performance in the exercise task. In addition, no participant reported taking any chronic medication or having any cardiovascular, mental, or brain condition that could affect their performance.

3.5 Data Analysis

All the Heart Rate (HR), Pain Intensity Rates (PIR), and Ratings of Perceived Exertion (RPE) data were analysed based on ISO time-points which is the shortest time to task failure across all participants and all groups of each study. ISO time-based data points provide a convenient solution to consistent data across all participants and has been widely used in analysing exercise data in the general bibliography (Angius, Hopker, Marcora, & Mauger; Angius, Mauger, Hopker, Pascual-Leone, Santarnecchi, & Marcora, 2018; Astokorki & Mauger, 2017; Mauger, Taylor, Harding, Wright, Foster, & Castle, 2014).

The shortest time to task failure across participants and groups for study 1 (chapter 4), study 2 (chapter 5),and study 3 (chapter 6.1), were 2 minutes, and so ISO time analysis was completed on minute 1 and minute 2 of the exercise task (HR1, PIR1, RPE1 and HR2, PIR2, RPE2). Similarly, the shortest time to task failure across participants and groups for study 4 (chapter 6.2), was 3 minutes, and so ISO time analysis was completed on minute 1, minute 2 and minute 3 of the exercise task (HR1, PIR1, RPE1, HR2, PIR2, RPE2 and HR3, PIR3, RPE3). Finally, study's 5 (chapter 7), ISO time was 4 minutes, and so ISO time analysis was completed on minute 1 to minute 4 of the exercise task (HR1, PIR1, RPE1, HR2, PIR2, RPE2, HR3, PIR3, RPE3, HR4, PIR4, RPE4).

Participants' HR, PIR, and RPE were also recorded when they withdrew from the task (fHR, fPIR, fRPE). The mean HR, PIR, and RPE across the exercise task for each participant were also calculated (mHR, mPIR and mPRE), which was consistent for all the five studies of this PhD (chapter 4-7).

Exploratory factor analysis was used to examine the structure of presence and hand ownership questionnaire in study 1. Descriptive statistics were then performed to identify the levels of Immersive Experience (Presence and Hand Ownership), comfort motivations and familiarity in all five studies.

In study 1 (chapter 4), an analysis of paired sample t-test and an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted to examine how VR affects HR, PIR and RPE, based on ISO time-points, measured at task failure and mean HR.

In study 2 (chapter 5), a median split on PBC scores was conducted separately for the VR and non-VR groups to classify participants into high and low PBC groups. Following this, comparisons were made for the ratings of immersive experience for high vs. low PBC within the VR group.

This was followed by an independent samples t-test were conducted to assess the effect of PBC on Immersive Experience (Presence and Hand Ownership), HR, PIR and RPE, based on ISO time points, measures at task failure, and mean HR.

In studies 3 (chapter 6.1), study 4 (chapter 6.2), and study 5 (chapter 7), a paired sample t-test was then used to compare the difference between TTE of individuals who identified the modification and individuals who failed to identify it. Also, an ANOVA analysis with repeated measures followed by Bonferroni post hoc test was conducted to examine the differences reported by the participants on HR, PIR, and RPE in the three sessions for ISO time points, and at task failure and mean HR.

All statistical tests were carried out using the Statistical Package for the Social Sciences (SPSS) version 24. Data are reported as mean (M) and Standard Deviation (SD), and statistical significance was accepted when $p < 0.05$

Chapter 4: A Comparison between the Virtual and "Real" Experience of Exercise Pain

In Chapter 2, a review of previous studies was conducted to examine if patients and healthy population can engage with VR technology and how this technology could be beneficial for the treatment of pain (see sections 2.3.3, 2.3, 2.3.1 and 2.3.2). Then, the enhancement of VR with different intervention strategies based on the type of pain was discussed, whereas different treatments were recommended (see sections 2.3, 2.3.1 and 2.3.2). The results of the systematic literature indicated that VR could be a useful tool for pain management. However, its effectiveness was only examined based on the existing psychological intervention strategies and, to my knowledge, none of the existing studies have examined how VR technology on its own impacts on the experience of pain. Therefore, in an attempt to fill this gap, the present study is the first to consider the effectiveness of VR as a technology and to investigate the extent to which it can benefit users by reducing EP.

To investigate whether VR technology (without the use of any specific psychological interventions strategies) can have an effect on the experience of pain, I carried out a study involving 20 participants, who were allocated to a VR and a non-VR group. The findings of the VR group were then analysed in relation to the non-VR group. This was done to determine if and how VR technology on its own affects the experience of pain.

The aim of the study was to investigate if and how VR technology on its own have an impact on the experience of pain.

4.1 Participants

Twenty healthy participants, equally selected from both genders (10 males and 10 females), with a mean age of 23 years (M= 23.20, SD = 7.54) participated in the study. All 20 participants performed both VR and non-VR intervention in a counterbalanced design. Participants' 1RM for 180^o of dominant arm elbow flexion ranged from 4 to 25 kg with a mean of 12.38 kg (SD = 6.91). Approximately 2/3 of the participants reported engaging in no regular, structured resistance or aerobic exercise (no resistance = 70%, no aerobic = 70 % during the testing week). Participants who reported engaging in the regular structured exercise had a weekly mean workout time of 3.20 hours (SD = 5.06).

4.2 Procedure

The experiment required each participant to pay two separate visits to the laboratory. The first session involved establishing each participant's 1RM (i.e. the heaviest weight they could lift) and carrying out the VR familiarisation session. The second session involved the main experimental sessions (VR and non-VR sessions). The VR and non-VR sessions were performed in a counterbalanced design, which means that half of the participants performed first the VR session and then rested for 10 minutes before moving to the non-VR session. The other half performed first the non-VR session and then, after resting for 10 minutes, moved to the non-VR session (Figure 4.1).

Figure 4.1: Illustration of the Study 1 Procedure.

4.3 Study Results

4.3.1 Virtual Reality (VR) measurements (see Appendix 1)

Overall, the participants reported high rates of Immersion in VR. Based on their ratings, the VR application produced a high degree of Presence, Hand Ownership and Comfort. In addition, most participants reported that the VR application motivated them positively. The specifics of the results are presented as follows:

Presence

Exploratory factor analysis was used to examine the structure of presence. Presence yielded a solution that explained 48.05% of variance and had structural coefficients > .50 for all factors. Varimax rotation yielded one factor, consisting of six items. Furthermore, the analysis revealed a high degree of both reliability and validity. Notably, the internal consistency of the factor was measured by Cronbach alpha, α was .761 with an eigenvalue of 2.88. With respect to the findings, during the VR exercise session, participants reported high levels of presence (M = 5.67, SD = 0.94).

Hand Ownership

Exploratory factor analysis was also used to examine the structure of hand ownership. Hand ownership yielded a solution that explained 85.821% of variance and had structural coefficients > .50 for all factors. Varimax rotation yielded one factor consisting of three items. Furthermore, the analysis revealed a high degree of both reliability and validity. Notably, the internal consistency of the factor was measured by Cronbach alpha, α was .917 with an eigenvalue of 2.575. Participants reported moderate to high levels of hand ownership during the VR exercise session (M = 4.40, SD = 1.80).

Ratings of Comfort, Motivation and Prior Use of VR

During the VR exercise session, participants reported high levels of comfort (M = 5.95, SD = 0.94), which means that they felt comfortable with the set up and it was easy for them to lift the weight and perform the exercise through the VR glasses. Furthermore, the positive attitudes of participants toward VR technology and their willingness to use it on a daily basis was evident in their high levels of motivation (M = 4.90, SD = 2.10). Participants stated that they could imagine themselves using the VR exercise app daily to motive themselves, even though most of the participants were not familiar with the use of VR technology. VR technology was a new experience for most of them. Therefore, participants reported moderate to low levels of VR prior use during the VR session (M = 3.00, SD = 2.51).

4.3.2 Pain Measurements

Heart Rate (HR)

To investigate whether there was a difference in participants' mean HR (mHR) between the VR and the conventional non-VR exercise, an analysis of paired sample t-test was conducted. The analysis revealed a significant difference between HR and in two sessions (t(19) = 2.63, p < .05), with participants' HR showing significant reduction during the VR exercise (M = 85.46, SD = 12.77) in comparison to the conventional non-VR exercise (M = 91.09, SD = 12.02) (Figure 4.2).

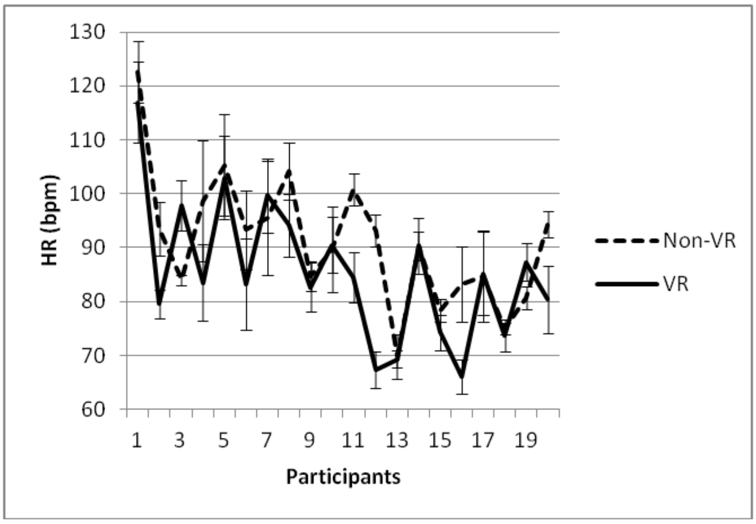


Figure 4.2: Mean HR during the Conventional non-VR and the VR session.

Additional analysis of an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted to investigate whether there was a difference between participants' HR in the two sessions (VR and conventional non-VR) based on the ISO time. The analysis brought out a significant difference for the HR during the two sessions at the the first minute: HR1 (F(1,19) = 4.57, p <.05); and at the second: HR2 (F(1,19) = 15.31, p <.001). As can be seen in Table 4.1, the results were in line with the general mean HR, with participants' HR being significantly lower during the VR exercise in comparison to the conventional non-VR exercise. Interestingly, as time passed, the data revealed a growing HR trend during the conventional non-VR exercise, in contrast to VR exercise where the HR data remained at similar rates during both minutes.

Table 4.1: HR: Effects for VR and Convectional non-VR exercise during ISO time.

Dependent Variable	**Intervention**	**Mean (bpm)**	**SD**
HR1	VR exercise	82.50	12.67
	Conventional non-VR exercise	87.60	14.06
HR2	VR exercise	82.50	11.53
	Conventional non-VR exercise	90.25	12.24

The above trend was further supported by the final HR, with the VR exercise revealing significantly (t(19) = 8.22, p < .05) lower fHR (M = 88.2, SD = 14.08) in comparison to the conventional non-VR fHR (M = 95.05, SD = 12.15).

Time to Exhaustion (TTE)

Important differences were reported in terms of Time to Exhaustion (TTE) between the VR and the conventional non-VR exercise (t(19) = -6.54, p < .001). The data indicated that, when the exercise was performed with the use of VR, it lasted significantly longer (M = 7.08, SD = 3.08) in comparison to conventional non-VR exercise (M = 4.23, SD = 1.59). During the VR exercise, the minimum time to exhaustion for a participant was 3.45 and the maximum 15.00 minutes, whereas during the conventional non-VR exercise the corresponding minutes were 2.33 and 10.29.

Pain Intensity Rate (PIR)

To investigate whether there was a difference in participants' mean and final PRI (mPIR, fPIR) between the VR and the conventional non-VR exercise, an analysis of paired sample t-test was conducted. The analysis revealed no significant difference between the perceived pain reported during the VR and the conventional non-VR exercise (Table 4.2).

Additional analysis of an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted to investigate whether there was a difference in participants' PIR in the two sessions (VR and conventional non-VR) based on the ISO time. The analysis brought out a remarkable difference for the PIR during the two sessions at the first minute: PIR1 (F(1,19) = 28.36, p <.001); and at the second: PIR2 (F(1,19) = 25.62, p <.001). Further analysis based on the means indicated that, during the conventional non-VR exercise, at each minute point the PIR ratings given by participants were significantly higher (PIR1 (M = 3.08, SD = 2.41) and PIR2 (M = 5.95, SD = 3.17), in comparison to the exercise with the VR technology (PIR1 (M = 1.48, SD = 1.83) and PIR2 (M = 3.80, SD = 3.02) (Figure 4.3).

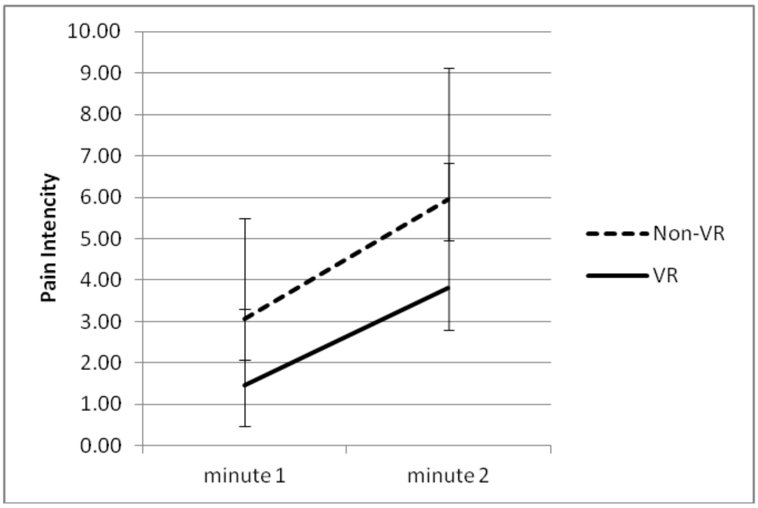


Figure 4.3: Mean number of PIR for two sessions, for each ISO minute.

Rating of Perceived Exertion (RPE)

To investigate whether there was a difference in participants' mean and final PRI (mRPE, fRPE) between the VR and the conventional non-VR exercise, an analysis of paired sample t-test was conducted. The analysis revealed no substantial difference in the perceived pain participants reported during the VR and the conventional non-VR sessions (Table 4.2).

Additional analysis of an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted to investigate whether there was a difference in participants’ ratings of perceived exertion (RPE) in the two sessions (VR and conventional non-VR) based on the ISO time. The analysis determined a significant difference for the RPE during the two sessions at the the first minute: RPE1 (F(1,19) = 38.97, p <.001); and at the second: RPE2 (F(1,19) = 25.77, p <.001). Further analysis based on the means indicated that exercising with the use of VR can decrease the participants’ sensation of how hard they were driving their arm in order to maintain the muscle contraction (RPE1 (M = 8.05, SD = 2.54) and RPE2 (M = 10.95, SD = 3.75) in comparison to the conventional non-VR exercise (RPE1 (M = 9.70, SD = 2.90) and RPE2 (M = 14.20, SD = 3.79) (Figure 4.4).

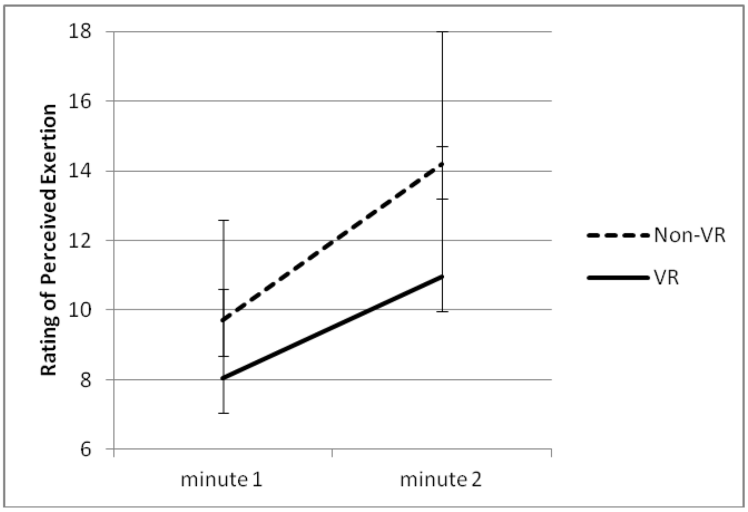


Figure 4.4: Mean number of RPE for two sessions, for each ISO minute.

Table 4.2: PIR and RPE: Effects for VR and Conventional non-VR exercise.

Dependent Variable	**Intervention**	**Mean**	**SD**	**T**
PRI				
mPRI	VR exercise	6.38	1.42	n.s.
	Conventional non-VR exercise	6.65	1.48	n.s.
fPRI	VR exercise	9.75	0.55	n.s.
	Conventional non-VR exercise	9.65	0.59	n.s.
RPE				
mPRI	VR exercise	14.81	1.85	n.s.
	Conventional non-VR exercise	15.01	1.83	n.s.

fPRI	VR exercise	19.55	0.83	n.s.
	Conventional non-VR exercise	19.50	0.95	n.s.

4.4 Study summary

This chapter contained the results of a study which sought to investigate how the use of VR technology influences the level of pain and discomfort caused by an exhaustive muscle contraction in comparison to a conventional non-VR exercise. To examine this, participants were asked to hold their Baseline Mass in an isometric contraction for as long as they could with their elbow at an angle of 90º flexion, with and without the use of VR technology.

The key findings of this analysis are the following:

- Participants reported high levels of Immersion into the VE. According to their subjective ratings, the VR application produced a high degree of Presence, Hand Ownership and Comfort. What was more interesting was that most of the participants reported that the VR application motivated them positively and that they would like to exercise on a regular basis using this VR application.

- Participants' HR was significantly lower when the exercise was performed with the use of VR technology in comparison to conventional non-VR exercise. In particular, the data showed that VR technology is able to decrease significantly participants' HR by 6 bpm.

- TTE was significantly longer during the VR exercise session in comparison to the conventional non-VR exercise session. Interestingly, it was found that VR technology has the ability to improve the duration of the exercise by 3 minutes.

- The reported rates of pain intensity (PIR) were notably lower during the VR exercise session in comparison to the conventional non-VR. Specifically, it was found that when the exercise is made using VR, participants' perception of pain intensity was approximately 50% lower than when the exercise is performed without the use of VR technology.

- Similarly to PIR, the reported rates of perceived exertion (RPE) were also remarkably lower during the VR exercise session. Specifically, it was found that via VR technology participants’ ratings of perceived exertion dropped significantly in comparison to conventional non-VR exercise.

Whilst several studies were carried out to examine if VR technology can successfully accompany various psychological strategies aiming to reduce pain (see sections 2.3.3 and 2.4.3), this study focused on the effect that VR technology alone can have on the experience of pain when no psychological intervention strategies (e.g., Distraction, AVF) are used. The findings have brought to the surface a number of unique trends regarding the use of VR technology for pain management in weight-lifting exercises, and thus they provide a broader understanding of the way VR technology can influence the perception of task difficulty, endurance performance and the perceived levels of pain intensity during exercise.

Overall, the results of this study show that VR technology is an effective technology which can yield positive outcomes even without the use of psychological intervention strategies. Results are further discussed in Chapter 9. In the next chapter, another study is presented; which examines the relationship between the awareness of personal internal body sensations and the effectiveness of VR in terms of the perception of task difficulty, endurance performance and pain experienced during exercise.

Chapter 5: Personal Characteristics and their effect on Virtual Reality and the Experience of Exercise Pain

In the previous chapter, I examined whether VR technology can have an effect on the experience of pain through a study of 20 participants allocated to a VR and non-VR group. The findings suggested that VR technology has positive effects, as it contributes to the reduction of perceived pain in comparison to conventional exercise. The next study, presented below, elaborates further on these positive effects by investigating the extent to which personal characteristics, such as internal body sensations, can impact in any way on these positive results. As stated above (see sections 2.1 and 2.1.1), pain perception is not always directly related to tissue damage, but it might be affected by psychological and emotional factors. This implies that different levels of pain intensity may occur among individuals and situations.

Private Body Consciousness (PBC) has proved to affect the perception of pain (see section 2.1). Given that those with a higher PBC are believed to be better attuned to their internal physiology and are more affected by disruptions to these (Fenigstein et al., 1975), it may be expected that induced changes to perceptions of pain and effort during VR exercise may be more pronounced in those with higher PBC. Currently, there are no studies examining whether PBC can reduce the positive effect of VR on exercise capacity. Therefore, the purpose of the current study is to measure PBC and examine the effect that it has on the effectiveness of VR during exercise pain. It is expected that participants with high PBC will report different levels of pain and effort during VR exercise in comparison to participants with low PBC. Similarly, the levels of presence and immersion reported by participants with high PBC are also likely to be different from those reported by participants will low PBC.

The aim of this study is to examine whether PBC affects the effectiveness of VR on exercise pain.

The results of the study have been published in the form of a long article at the Psychology of Sport and Exercise in June 2018 (Matsangidou et al., 2018).

5.1 Participants

Nine males and 31 females with a mean age of 23 years (M = 23.58, SD = 5.35) participated in the study. Participants' one-repetition maximum (1RM) for 180° of dominant arm elbow flexion ranged from 5 to 30 kg, with a mean of 12.35 kg (SD = 6.35). Approximately half of the participants reported engaging in no regular, structured resistance or aerobic exercise (no resistance = 52.5%, no aerobic = 47.5% during the testing week). Participants who reported engaging in regular structured exercise had a weekly mean workout time of 2.91 hours (SD = 3.69).

5.2 Procedure

Participants were asked to visit the laboratory so that their 1RM could be established. They also attended VR familiarisation and experimental sessions (Figure 5.1).

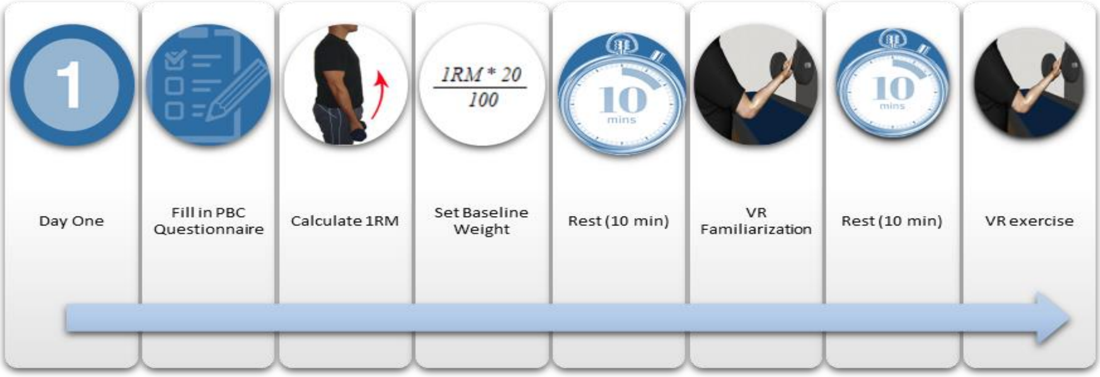


Figure 5.1: Illustration of the Study 2 Procedure.

5.3 Additional Instruments

Apart from the common instruments that were used in all five studies (see section 3.2), in this study participants were asked to complete a questionnaire regarding their Private Body Consciousness.

Private Body Consciousness (PBC) was only measured in study 2. PBC scores (Miller et al., 1981) were obtained through a self-report scale consisting of 5 statements, which aimed at capturing the level of awareness of one's internal body sensations. Statements are rated using a 5-point Likert scale ranging from 0 (Extremely uncharacteristic) to 4 (Extremely characteristic).

5.4 Results

5.4.1 Virtual Reality (VR) measurements

Overall, the participants reported high rates of Immersion in VR. According to their ratings, the VR application produced a high degree of Presence, Hand Ownership and Comfort. Most of the participants were not familiar with the use of VR technology, since it was the first time they used it. However, most participants reported that they could imagine motivating themselves to use the VR on a daily basis to exercise. Results revealed no significant differences between individuals with low and high PBC (Table 5.1).

Table 5.1: VR: Means and SDs for low and high PBC.

Dependent Variable	PBC	Mean	SD	t
Presence	Low PBC	3.76	1.27	n.s.
	High PBC	4.40	1.07	n.s.
Hand Ownership	Low PBC	3.13	1.65	n.s.
	High PBC	3.93	1.38	n.s.
Comfort	Low PBC	5.80	1.08	n.s.
	High PBC	5.73	1.24	n.s.
Motivation	Low PBC	4.14	2.22	n.s.
	High PBC	4.53	1.65	n.s.
Prior Use of VR	Low PBC	2.17	2.49	n.s.
	High PBC	3.26	2.35	n.s.

5.4.2 Pain Measurements

Heart Rate (HR)

Analyses were carried out on dependent variables derived from the Heart Rate measure. Specifically, in separate indented t-tests, the effects of PBC on the mean heart rate (mHR), the ISO HR, and the final HR (fHR) were examined with no significant differences to result from the levels of PBC. For simplicity, the results from these analyses are presented in Table 5.2.

Table 5.2: HR: Effects for low and high PBC.

Dependent Variable	PBC	Mean (bpm)	SD	t
mHR	Low PBC	87.56	11.96	n.s.
	High PBC	87.11	11.29	n.s.
fHR	Low PBC	89.33	12.01	n.s.
	High PBC	90.21	11.38	n.s.
HR1	Low PBC	86.19	12.22	n.s.
	High PBC	85.32	11.56	n.s.
HR2	Low PBC	87.86	12.35	n.s.
	High PBC	85.95	11.76	n.s.

Time to Exhaustion (TTE)

To investigate whether there was a difference between participants in terms of Time to Exhaustion (TTE), paired sample t-test was conducted. The analysis revealed no significant difference for the TTE across the levels of PBC (t(38)= -.255, p > .05), in the scores for Low PBC (M= 4.32, SD= 1.54) and High PBC (M= 4.41, SD= 1.50).

Pain Intensity Rate (PIR)

An analysis was carried out on dependent variables derived from the Pain Intensity measure. Specifically, in separate indented t-tests, the effects of PBC on the mean PIR (mPIR) and the final PIR (fPIR) were examined; significant differences were reported to result from the levels of PBC. The effects of PBC on the ISO PIR were also examined, but no significant differences resulted from the levels of PBC. For simplicity purposes, the results of this analysis are presented in Table 5.3.

Table 5.3: PIR: Effects for low and high PBC.

Dependent Variable	PBC	Mean	SD	t
mPIR	Low PBC	5.17	1.58	-3.27**
	High PBC	6.60	1.13	
fPIR	Low PBC	8.05	1.43	-5.5**
	High PBC	9.89	0.32	
PIR1	Low PBC	2.33	1.85	n.s.
	High PBC	2.24	1.51	

PIR2	LOW PBC	4.24	2.47	n.s.
	High PBC	5.03	2.37	

***p<.001; **p<.005; *<.05

Rating of Perceived Exertion (RPE)

An analysis was carried out on dependent variables derived from the Pain Intensity measure. Specifically, in separate indented t-tests, the effects of PBC on the mean RPE (mRPE) and the final PIR (fRPE) were examined; significant differences resulted from the levels of PBC. The effects of PBC on the ISO RPE were also examined, but no significant differences resulted from the levels of PBC. For simplicity purposes, the results of this analysis are presented in Table 5.4.

Table 5.4: RPE: Effects for low and high PBC.

Dependent Variable	**PBC**	**Mean**	**SD**	**t**
mRPE	Low PBC	12.24	2.67	-3.20**
	High PBC	14.52	1.67	
fRPE	Low PBC	15.95	3.12	-5.57***
	High PBC	19.89	0.32	
RPE1	Low PBC	9.00	2.97	n.s.
	High PBC	8.68	1.83	
RPE2	LOW PBC	10.95	3.11	n.s.
	High PBC	12.16	3.04	

***p<.001; **p<.005; *<.05

5.5 Study summary

The first study presented in Chapter 4 showed that the use of VR during exercise has positive results in reducing exercise pain and perception of effort. However, pain is a subjective experience, and as such it can be affected by factors such as Private Body Consciousness (PBC), which is a measure of the awareness of internal body sensations (see section: 2.1). Thus, as presented in this chapter, a further study was carried out which aimed to examine whether PBC can lessen the effectiveness of VR on pain and effort during exercise. The main aim was to investigate how the levels of

PBC may influence the positive effects that VR technology can have on pain and discomfort caused by an exhaustive muscle contraction.

The key findings of this analysis are the following:

- PBC and the subjectivity of inner sensation can affect the levels of Immersion that participants felt during the VR exercise. According to participants' subjective ratings, the VR application produced a higher degree of Presence and Hand Ownership for those with a higher PBC. However, the differences between the two groups were not significant.
- The findings reveal no significant discrepancies in terms of HR, meaning that the effectiveness of VR technology on HR is not affected by the levels of PBC.
- The findings reveal no significant discrepancies in terms of TTE, meaning that the effectiveness of VR technology on time is not moderated by the levels of PBC.
- The reported PIR was significantly lower for individuals with low PBC in comparison to participants with high levels of PBC. Specifically, it was found that perception of pain intensity for participants with low PBC levels was reduced by around 10%.
- Similarly to PIR, RPE was significantly lower for participants with low PBC in comparison to participants with high levels of PBC. Specifically, it was found that perceived exertion was reduced by around 15% for participants with low PBC levels.

Although several studies have already been concerned with the relationship between personal inner sensations and the experience of pain (Ahles et al. 1987; Martin et al., 1991; Ferguson & Ahles, 1998; Pincus et al., 2002; Mehling et al., 2009), this study focuses on the relationship between personal characteristics and the effect of VR technology on the experience of pain in weight-lifting exercises. The findings derived from this study bring to the surface a number of unique trends which enhance our understanding of the way personal inner sensations affect the positive impact of VR technology and influence participants' perception of task difficulty, endurance performance and the perceived levels of pain intensity during exercise.

More specifically, findings suggest that the effectiveness of VR during exercise with reference to pain management is not strongly affected by the levels of PBC. The results of this study are further discussed in Chapter 9. The chapter that follows is concerned with two studies, seek to examine the effect of well-known VR psychological intervention strategies on the perception of task difficulty, endurance performance, and pain experienced during exercise.

Chapter 6: Virtual Reality enhanced with Psychological Intervention Strategies on Exercise Pain

The studies described in Chapters 4 and 5 analyse how VR technology on its own contributes to the experience of pain and how personal characteristics such as PBC can affect the outcomes of VR. The results of Study 1 indicated that VR could be a useful tool for pain management and that its effectiveness is not dependent on any psychological intervention strategy. In addition to that, Study 2 showed that VR's effectiveness is not substantially affected by personal characteristics such as the level of awareness of internal sensations.

The literature review carried out in Chapter 2 demonstrated that previous studies proved that Distraction and Alter Visual Feedback are the most effective strategies against pain (see sections 2.4.3.1 and 2.4.3.2). To investigate how different intervention strategies in Virtual Reality influence the perception of task difficulty, endurance performance and pain experienced during exercise, two additional studies involving 50 participants were carried out. This was done to determine the effect VR might have on exercise pain when being enhanced with intervention strategies. At the same time, the merits of each psychological intervention strategy will be identified and knowledge and understanding in the field will be improved.

The aim of the two studies described below are the following:

1. To investigate how Distraction may influence the level of pain and discomfort caused by an exhaustive muscle contraction. This is reported in Section 6.1.

2. To investigate how visual cues may influence the level of pain and discomfort caused by an exhaustive muscle contraction (INTERACT Conference publication). This is reported in Section 6.2.

The results of the Alter Visual Feedback strategy have been published in the form of a long article at the INTERACT Conference in September 2017 (Matsangidou et al., 2017).

6.1 Virtual Reality and the Impact of Distraction on the Experience of Exercise Pain

6.1.1 Participants

Twenty healthy participants (5 males and 15 females), with a mean age of 24 years (M = 24.25, SD = 6.03), participated in the study. All 20 participants performed all three conditions (Figure 6.1) in a counterbalanced design. Participants' one-repetition maximum (1RM) for 180° of dominant arm elbow flexion ranged from 5 to 30 kg with a mean of 12.70 kg (SD = 6.53). Approximately half of the participants reported engaging in no regular, structured resistance or aerobic exercise (no resistance = 55%, no aerobic = 40% during the testing week). Participants who reported engaging in regular structured exercise had a weekly mean workout time of 2.95 hours (SD = 3.98).

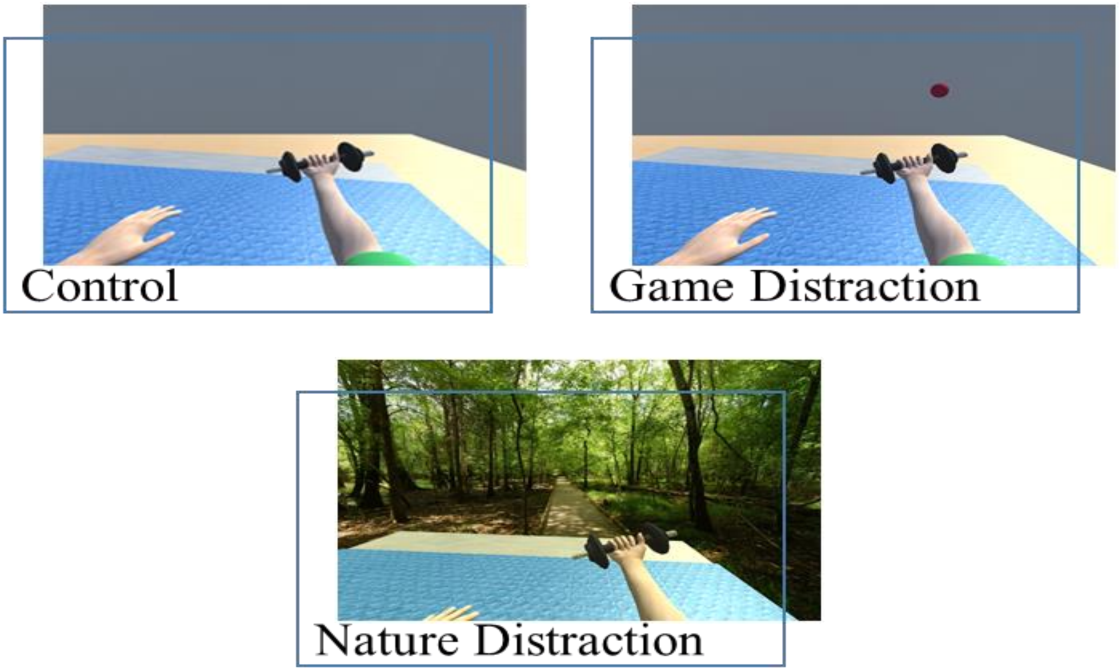


Figure 6.1: Illustration of Distraction VEs.

6.1.2 Procedure

The experiment required that participants paid two separate visits to the laboratory. On the first day of the experiment, the 1RM of each participant was calculated. That was followed by a 10-minute rest and then participants moved on to the VR familiarisation, as explained in chapter 3 (see section 3.2.2). Subsequently, participants rested once again for 10 minutes and performed one of the experimental sessions (Control or Game or Nature Distraction). In the second visit, the participant performed the remaining sessions. The three sessions were carried out in a counterbalanced design to reduce the change in the order of the sessions adversely influencing the results (Figure 6.2).

Figure 6.2: Illustration of the Study 3 Procedure.

6.1.3 Results

6.1.3.1 Virtual Reality (VR) measurements

Overall, participants reported moderate rates of Immersion in VR (> 3.5). According to their ratings, this VR application produced a moderate to high degree of Presence, Hand Ownership, and Comfort. In addition, most participants reported that the VR application motivated them positively, meaning that most participants reported they could imagine motivating themselves to use the VR (Table 6.1). The results revealed no significant differences between the types of Distraction and Presence (F(2, 38) = 1.22, p >.05 with Greenhouse-Geisser correction), Hand ownership (F(2, 38) = 1.01, p >.05), Comfort (F(2, 38) = .67, p >.05), and Motivation (F(2, 38) = 2.94, p >.05). Finally, most of the participants were not familiar with the use of VR technology (M = 2.80, SD = 2.53).

Table 6.1: VR: Means and SDs for Distraction.

	Presence		**Hand Ownership**		**Comfort**		**Motivation**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Control	3.74	1.30	3.06	1.67	5.75	1.07	4.05	2.14
Game Distraction	4.12	1.41	3.58	1.91	5.55	1.28	4.55	1.16
Nature Distraction	3.99	1.07	3.52	1.74	5.70	1.21	4.85	1.81

6.1.3.2 Pain Measurements

Heart Rate (HR)

To investigate whether there was a difference in participants’ overall mean HR across the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed no significant difference in HR (F(2, 38) = 1.06, p >.05 with Greenhouse-Geisser correction), but the mHR in the Control session was four bpm lower (M = 80.35, SD = 20.28) than in Nature Distraction session (M = 84.65, SD = 11.94) and Game Distraction session (M = 84.95, SD = 10.72).

To investigate whether there was a difference in participants’ final HR across the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed no significant difference between HR during the three sessions (F(2, 38) = .78, p >.05). However, the fHR in the Control session was the lowest one (M = 85.40, SD = 12.72) compared to those in Nature Distraction (M = 88.60, SD =11.05) and Game Distraction (M = 86.05, SD = 13.43).

Additional analysis was conducted to investigate whether there was a difference in participants’ HR across the three sessions based on the ISO time. The analysis revealed no significant differences for the HR during the three sessions during the first two minutes (ISO time). However, in general, the lowest HR was recorded during the Control session, meaning that a neutral looking virtual room, which is void of any visual information, may improve participant's HR reduction (Table 6.2).

Table 6.2: HR: Effects for VR - Distraction on ISO time.

	Session	Mean (bpm)	SD	95% Confidence Interval		F	p
				Lower Bound	Upper Bound		
HR1	Control	81.65	22.74	71.21	92.09	0.39	n.s.
	Game Distraction	84.75	10.65	78.41	91.09		
	Nature Distraction	84.90	13.23	79.04	90.76		
HR2	Control	82.20	21.95	71.93	92.47	0.11	n.s.
	Game Distraction	83.50	12.87	77.48	89.52		
	Nature Distraction	84.20	12.73	78.24	90.16		

Time to Exhaustion (TTE)

To investigate whether there was a difference in participants' Time to Exhaustion (TTE) across the three sessions, an analysis of repeated measures ANOVA followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference in terms of TTE during the three sessions (F(2, 38) = 6.46, p <.05 with Greenhouse-Geisser corrections). Post-hoc paired comparisons with Bonferroni corrections indicated that the mean TTE in the Game Distraction (M = 6.06, SD = 2.39) and the Nature Distraction sessions (M = 5.12, SD = 1.42) was significantly longer than that in the Control session (M = 4.25, SD = 1.57).

During the Game Distraction session, the minimum time to exhaustion for a participant was 3.20 and the maximum was 13.53 minutes. The minimum time to exhaustion for the Nature Distraction session was 2.56 and the maximum was 8.06 minutes, whereas for the Control session it was 2.07 and 9.20 minutes respectively.

Pain Intensity Rate (PIR)

To investigate whether there was a difference in participants' PIR across the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference for the mPIR (F(2, 38) = 15.52, p <.001), the PIR1 (F(2, 38) = 6.86, p <.005), the PIR2 (F(2, 38) = 5.80, p

<.005) and the fPIR (F(2, 38) = 8.80, p <.005 with Greenhouse-Geisser corrections). Post-hoc paired comparisons with Bonferroni corrections indicated that the lowest pain intensity rates were recorded during the Nature Distraction (Table 6.3).

Table 6.3: PIR: Effects for VR - Distraction.

	mPIR		**PIR1**		**PIR2**		**fPIR**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Control	5.35	1.77	2.65	2.03	4.60	2.80	8.15	1.57
Game Distraction	6.10	1.65	2.50	2.16	4.40	2.60	9.25	1.21
Nature Distraction	4.71	1.50	1.48	1.65	3.38	2.04	8.05	1.90

Rating of Perceived Exertion (RPE)

To investigate whether there was a difference in participants' RPE across the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference for the mRPE (F(2, 38) = 12.52, p <.001), the RPE1 (F(2, 38) = 9.75, p <.001), the RPE2 (F(2, 38) = 9.29, p <.005) and the fRPE (F(2, 38) = 9.78, p <.001). Post-hoc paired comparisons with Bonferroni corrections indicated that the lowest RPE was recorded during the Nature Distraction (Table 6.4).

Table 6.4: RPE: Effects for VR - Distraction.

	mRPE		**RPE1**		**RPE2**		**fRPE**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Control	12.71	2.91	9.25	2.99	11.75	3.54	16.55	3.47
Game Distraction	13.41	2.92	8.45	3.33	11.00	4.36	18.40	2.14
Nature Distraction	11.34	2.63	7.35	2.16	9.30	3.16	15.90	3.60

6.1.1 Study summary

This chapter describes the results of a study which examines how VR technology and the Distraction psychological intervention strategy influence the perception of task difficulty and reduce perceived pain. The main aim was to investigate how VR technology and the use of Game and Nature Distraction in weight-lifting exercises may reduce acute pain experienced during exercise. To examine this, participants were asked to hold their Baseline Mass in an isometric contraction for as long as they could with their elbow at an angle of 90º flexion. Via VR and distracting visual signals, I aimed to divert participants' attention from the painful sensory signal.

The key findings of this analysis are the following:

- Participants' subjective ratings of immersion for the VR application in terms of Presence and Hand Ownership were slightly lower than those in other studies (see sections 4.5.1, 5.6.1, and 6.2.5.1). However, if the results of the Distraction session are compared to those of the Control session, it emerges that additional visual cues, such as an induced pleasant environment and game task, improve the rating of Presence and Hand Ownership. Therefore, when VR is enhanced with Distraction strategy it becomes more effective.

- Participants' HR revealed no significant differences between the types of Distraction, meaning that any type of Distraction affects similarly the HR. However, there was a trend towards a slightly lower HR during the Control session. This leads to the conclusion that the use of VR without additional distracting visual cues might have positive effects on HR.

- TTE was significantly longer during the Game Distraction in comparison to that reported in the Control session and the Nature Distraction. Interestingly, it was found that during the Game Distraction, the time to exhaustion was two minutes longer than that in the Control session, as well as one minute longer during the Nature Distraction. What was even more interesting here is the fact that during the Game Distraction the maximum TTE was up to 14 minutes, which is six minutes more than that reported in the Nature Distraction and five minutes more than that reported in the Control session. This means that VR's effectiveness is enhanced when Game Distraction elements are added to the virtual environment.

- The reported PIR during the Nature Distraction was significantly lower than those in the Game Distraction and the Control session. The highest PIR in this experiment was given during the Game Distraction. Specifically, the participants' mean report about the perceived pain was around 15% more during the Game Distraction in comparison to that reported in Nature Distraction and around 8% higher compared to that reported in the Control session. These results suggest that viewing a spectacular nature may decrease perceived pain and improve VR's effectiveness.

- Similarly to PIR, RPE reported during the Nature Distraction, which referred to participants' sensation of how hard they were driving their arm in order to maintain the muscle contraction, was considerably lower than those reported during the Game Distraction and the Control session.

Although several studies were carried out to examine whether VR technology can be a natural form of analgesia and a successful tool in reducing pain via distracting game or via environmental complementary features (see sections 2.3, 2.3.1.1 and 2.3.3.1), none of the existing studies examine the effect of Distraction on how well a participant can tolerate a given level of exercise intensity. Therefore, this study addressed this issue and identified characteristics which can lead to the design of a successful virtual environment. More specifically, the study aimed to provide a broader understanding of the way VR technology, when enhanced with Distraction, can reduce the intensity of negative perceptions of pain and effort associated with exercise increase and can therefore increase the individual's willingness to continue to exercise for longer.

Overall, the results of this study suggest that Distraction via VR technology is an effective intervention strategy with positive outcomes. However, mixed findings were presented with regard to the types of Distraction. Specifically, in terms of HR, it was found that both types of Distraction included in the Control session resulted in approximately similar bpm. In addition to that, it was found that Game Distraction is the most beneficial way to increase the duration of physical activity (TTE) and thus promote a healthier lifestyle, but this results into increased rates of PIR and RPE. If the main focus is to reduce perceived pain, then Nature Distraction appears to be the most beneficial, but this signifies the reduction of TTE as well. Finally, the results suggested that the use of Distraction strategy improves VR's effectiveness regarding pain analgesia. Results will be discussed in more detail in Chapter 9. In the study that follows, I examine the effect of VR Alter Visual Feedback strategy on the perception of task difficulty, endurance performance, and pain experienced during exercise.

6.1.2 Virtual Reality and the Impact of an Altered Visual Feedback on the Experience of Exercise Pain

6.1.3 Participants

Thirty healthy participants, equally selected from both genders (16 males and 16 females), with a mean age of 35 years (M = 35.60, SD = 7.05), participated in the study and performed all three conditions (Figure 6.3) in a counterbalanced design. All 30 participants were members of a sports centre with one-repetition maximum (1RM), for 180^o of dominant arm elbow flexion, ranged from 4 to 25 kg with a mean of 13.92 kg (SD = 5.77). More than 1/3 of the participants reported engaging in no regular, structured resistance or aerobic exercise (no resistance = 56%, no aerobic = 33% during the testing week). Participants who reported engaging in regular structured exercise had a weekly mean workout time of 4.93 hours (SD = 4.66).

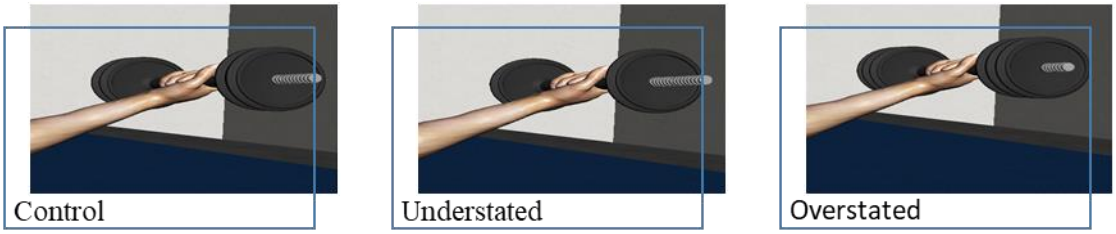


Figure 6.3: Illustration of Altered Visual Feedback's Virtual Dumbbells.

6.1.4 Procedure

The experiment required that participants paid four separate visits to the laboratory. On the first day of the experiment, the 1RM of each participant was calculated, a 10-minute rest followed, and then VR familiarisation, as explained in Chapter 3 (see section 3.2.2), was carried out.

In the second, third and fourth day, participants came to the lab believing that they would do the same exercise again in three separate sessions. There was a Control session which was exactly the same as the familiarisation session. However, in the two other sessions, the VR visual feedback was modified, unbeknownst to the participants. Specifically, the visual weight as presented in the VR Understated or Overstated the real weight by 50% compared to the Control session (Figure 6.4). The real weight that was actually lifted remained the same in all three sessions. The three sessions were carried out in a counterbalanced design so that results would not be affected by the changes in the order of the sessions. At the end of the experiment, participants were asked whether they could identify any difference between the three sessions and, if so, what the difference was.

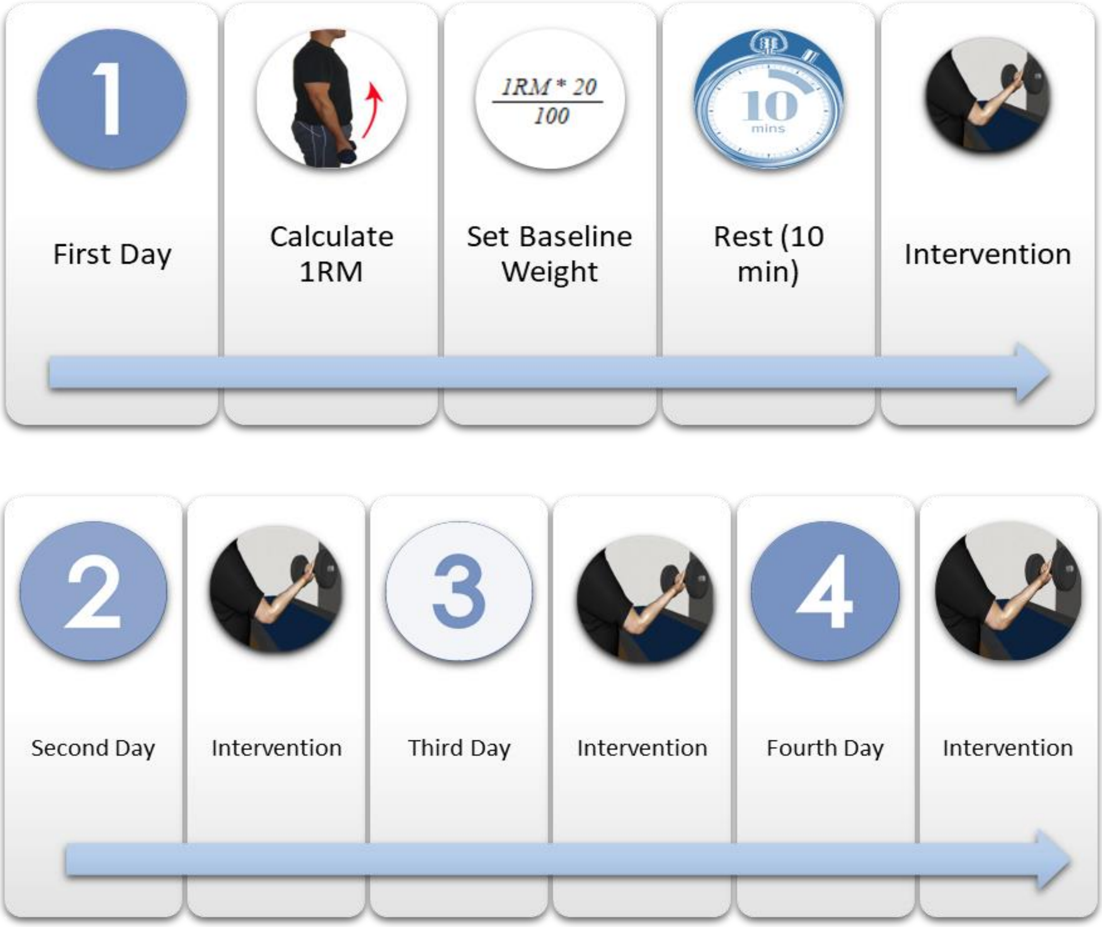


Figure 6.4: Illustration of the Study 4 Procedure.

6.1.5 Results

6.1.5.1 Virtual Reality (VR) measurements

Overall, participants reported high rates of Immersion (> 3.5). According to their ratings, the VR application produced a high degree of Presence, Hand Ownership and Comfort. In addition, most participants reported that the VR application motivated them positively. Finally, most of the participants were not familiar with the use of VR technology, since it was a new experience for most of them (Table 6.5).

Table 6.5: VR: Means and SDs for AVF.

	Mean	SD
Presence	5.20	1.67
Hand Ownership	4.22	1.61
Comfort	6.13	1.96
Motivation	5.30	1.93
Prior Use of VR	3.15	2.35

6.1.5.2 Pain Measurements

Heart Rate (HR)

To investigate whether there was a difference in participants' mean HR across the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed significant differences during the three sessions (F(2, 58) = 14.73, p <.001). Post hoc tests using the Bonferroni correction revealed that there was a significant difference between the mHR in the Understated session (M = 74.07, SD = 8.58) and the Control session (M = 80.93, SD = 10.50). There was also a notable difference between the Understated (M = 74.07, SD = 8.58) and the Overstated session (M = 79.73, SD = 11.21) (Figure 6.5).

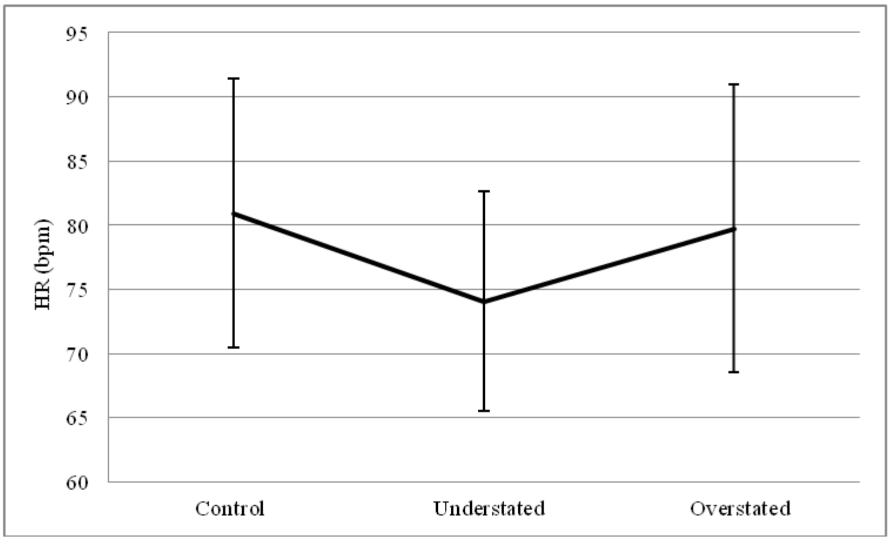


Figure 6.5: Mean HR during the three sessions.

Additional analysis was conducted to investigate whether there was a difference in participants' HR across the three sessions based on the ISO time. The analysis showed a significant difference for the HR during the three sessions at the first three minutes (ISO time) (F(2, 58) = 15.37, p <.001). Post-hoc paired comparisons with Bonferroni corrections indicated that the mean HR in the Understated session (M = 72.29, SD = 9.09) was significantly lower in comparison to those in Control (M = 79.34, SD = 11.63) and Overstated (M = 77.97, SD = 11.43) sessions. For simplicity purposes, the results of this analysis are presented in Table 6.6.

Table 6.6: HR: Effects for VR - AVF on ISO time.

	Session	**Mean (bpm)**	**SD**	**95% Confidence Interval**		**F**	**p**
				Lower Bound	**Upper Bound**		
HR1	Control	78.47	12.53	73.79	83.15	13.75	0.000
	Understated	70.83	10.26	67.00	74.67		
	Overstated	76.43	11.56	72.12	80.75		
HR2	Control	79.03	11.65	74.68	83.38	12.92	0.000
	Understated	72.50	8.68	69.26	75.74		
	Overstated	78.00	11.22	73.81	82.19		
HR3	Control	80.53	10.70	76.54	84.53	14.27	0.000
	Understated	73.53	8.32	70.43	76.64		
	Overstated	79.47	11.52	75.17	83.77		

There was also a significant difference between the final HR in the three sessions (F(2, 58) = 15.20, p <.001), the most striking between between the Understated (M = 76.47, SD = 9.37), and the Control (M = 83.50, SD = 9.40) sessions. There was also a significant difference between the Understated (M = 76.47, SD = 9.37) and the Overstated (M = 83.2, SD = 10.76) sessions.

Time to Exhaustion (TTE).

To investigate whether there was a difference between participants' Time to Exhaustion (TTE) in the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference for the TTE during the three sessions (F(2, 58) = 23.50, p <.001 with Greenhouse-Geisser correction). Post-hoc paired comparisons with Bonferroni corrections indicated that the mean TTE in the Understated session (M = 7.45, SD = 3.15) was significantly longer than during the Control (M = 5.46, SD = 2.25) and the Overstated (M = 5.47, SD = 2.46) sessions.

During the Understated session, the minimum time to exhaustion for a participant was 3.29 minutes and the maximum was 13.21 minutes. The minimum time to exhaustion for the Control session was 2.59 minutes and the maximum was 8.11 minutes, whereas for the Overstated session 3.03 and 7.50 minutes respectively.

Pain Intensity Rate (PIR).

To investigate whether there was a difference in the participants' overall mean PIR across the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference between mPIR during the three sessions (F(2, 58) = 9.85, p <.001), the most important one being between the Understated (M = 4.81, SD = 1.37), and the Overstated session (M = 5.66, SD = 0.93). But no significant difference during the Control session was identified (M = 5.25, SD = 1.22).

To investigate whether there was a difference between the Pain Intensity Rate reported by participants in the three sessions for the ISO time, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference for the PIR during the three sessions for the first three minutes (F(2, 58) = 9.45, p <.001 with Greenhouse-Geisser correction). Post-hoc paired comparisons with Bonferroni corrections indicated that the mean PIR in the Understated session at each minute (Mmin1 = 0.65, SD = 0.93), (Mmin2 = 1.78, SD = 1.84), (Mmin3 = 3.30, SD = 2.18) was significantly lower than the Control (Mmin1 = 1.23, SD = 0.88), (Mmin2 = 2.93, SD =1.70), (Mmin3 = 4.92, SD =2.30) and the Overstated (Mmin1 = 1.48, SD = 0.98), (Mmin2 = 3.40, SD = 1.49), (Mmin3 = 5.48, SD = 2.17) sessions (Figure 6.6).

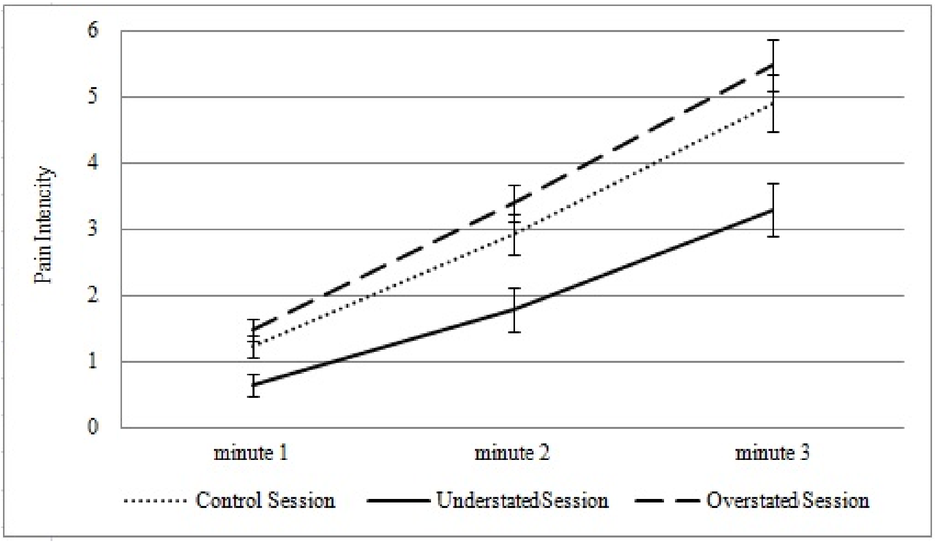


Figure 6.6: Mean PIR rates for three sessions, for each ISO minute.

To investigate whether there was a difference in participants' final PIR across the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed no significant difference (F(2, 58) = 2.52, p >.05). Post hoc tests using the Bonferroni correction indicated that participants' fPIR was approximately the same all sessions (Control session: M = 9.26, SD = 0.94; Understated session; M = 9.33, SD = 0.92, and Overstated session: M = 9.63, SD = 0.56).

Rating of Perceived Exertion (RPE)

To investigate whether there was a difference in participants' overall mean RPE across the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference between mRPE during the three sessions (F(2, 58) = 6.91, p <.005). Post hoc tests using the Bonferroni correction revealed that there was a significant difference between the mRPE in the Understated session (M = 13.41, SD = 1.58) and the Overstated session (M = 14.36, SD = 1.33), but no significant difference was identified during the Control session (M = 13.82, SD = 1.66).

To investigate whether there was a difference in the Rating of Perceived Exertion (RPE) reported by participants during the three sessions for ISO time (ISO time = 3), an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference for the RPE during the three sessions in the first three minutes (F(2, 58) = 4.56, p < .005). Post-hoc paired comparisons with Bonferroni corrections indicated that the mean RPE in the Understated session at each minute point (Mmin1 = 7.30, SD = 1.70), (Mmin2 = 9.13, SD = 2.66), (Mmin3 = 11.53, SD = 2.76) was significantly lower than that in the Control (Mmin1 = 8.27, SD = 1.66), (Mmin2 = 10.97, SD = 2.40), (Mmin3 = 13.83, SD = 2.63) and the Overstatedd (Mmin1 = 8.93, SD = 1.93), (Mmin2 = 11.60, SD = 2.51), (Mmin3 = 14.13, SD = 2.66) session (Figure 6.7).

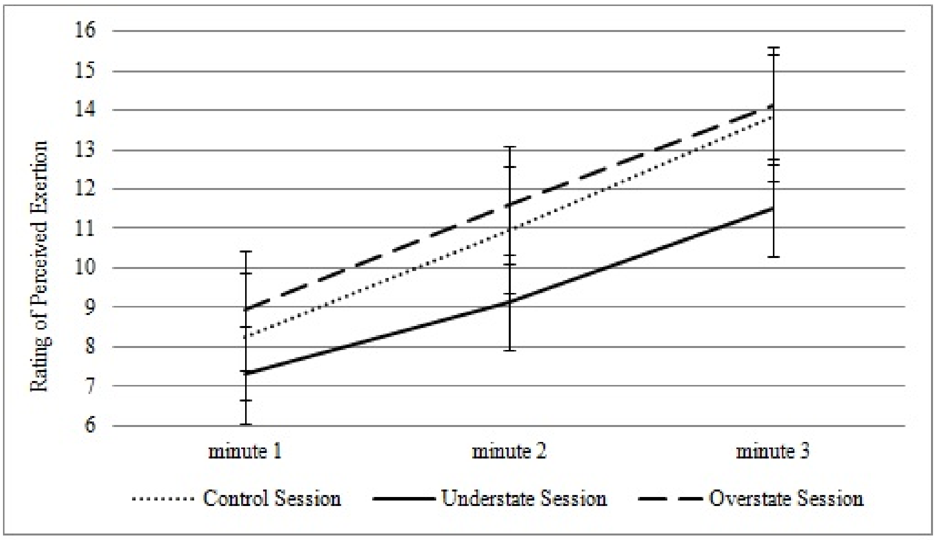


Figure 6.7: Mean number of Rating of Perceived Exertion for three sessions, for each ISO minute.

To investigate whether there was a difference in participants' final PIR across the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed no significant difference (F(2, 58) = .43, p >.05 with Greenhouse-Geisser correction). Post hoc tests using the Bonferroni correction indicated that participants' fRPE was approximately the same for all sessions (Control session: M = 18.73, SD = 3.17, Understated session: M = 19, SD = 1.53, and Overstated session: M = 19.13, SD = 1.56).

Awareness of Visual Feedback Modification

Six out of thirty participants reported that they were aware of the visual feedback modification (i.e. they knew that the physical weight was the same in all three conditions), which was a significant part of this sample (t(29) = 24.23, p < .001). A paired sample t-test was used to compare the difference between TTE of individuals who identified the modification and individuals who failed to identify it. The results showed that awareness of visual feedback modification produced significant differences on TTE during Understated (t(28) =1.39, p < .05), Control (t(28) = 1.39, p < .005) and Overstated (t(28) = 1.35, p < .005) sessions (Table 6.7).

Table 6.7: Mean TTE for the three sessions, based on the identification of the visual feedback modification.

	Mean Time (min): Control Session	**Mean Time (min): Understated Session**	**Mean Time (min): Overstated Session**
Identified the visual feedback modification	06.59	09.23	07.07
Did not identify the visual feedback modification	05.28	07.21	05.27

6.1.6 Study summary and Chapter implications

This chapter describes the results of a study which examines how VR technology influences the perception of task difficulty and may reduce perceived pain. The main aim of this study is to investigate how VR technology and the use of specific visual cues, such as the size of the object in weight-lifting exercises, may reduce acute pain experienced during exercise. To examine this, participants were asked to hold their Baseline Mass in an isometric contraction for as long as they could with their elbow at an angle of 90º flexion. Via VR visual stimulation technology, participants' expectations about the size of the weight lifted were frustrated.

The key findings of this analysis are the following:

- Participants were highly immersed in the VE. According to their subjective ratings, the VR application produced a high degree of Presence, Hand Ownership and Comfort. Interestingly, the motivation levels were increased by up to 20% in comparison to previous studies (see sections 4.5.1, 5.6.1, and 6.1.5.1). This might be explained based on the general interest participants had in exercise, as the population of this study consisted of members of a sports centre. Therefore, the general interest the participants had on exercise might be responsible for this result.

- Participants' HR was significantly lower by 5-7 bpm in the Understated session.

- The TTE was significantly longer during the Understated session in comparison to those in the Control and Overstated sessions. Interestingly, it was found that when vision Understated the real weight, the time to exhaustion was two minutes longer. What was even more interesting here was that, even though during the Understated sessions some of the participants knew that the visual feedback was modified, their TTE still lasted approximately two minutes longer than in the Control and Overstated sessions.

- The reported PIR during the Understated session was significantly lower than that in the Control and Overstated sessions. Specifically, it was shown that VR enhanced with AVF strategy led to a significant decrease in participants' rates of perceived pain. Interestingly, during the Understated session, the mean pain intensity given by the participants in the first minute was approximately 50% lower than the mean PIR during the Control and Overstated sessions. The difference of PIR among the three sessions during the next minutes was decreased, but still existed.

- There was a significant decrease in participants' rating of perceived exertion (RPE) during the Understated session compared to the Control and Overstated sessions. Participants' sensation of how hard they were driving their arm in order to maintain the muscle contraction was considerably lower during the Understated session.

The extent to which VR technology can reduce pain via altering the visual feedback of the user has already been examined by previous studies (Bolte et al., 2014; Harvie et al., 2015). However, some limitations have been identified. For example, the visual feedback manipulation of previous studies was small (up to 20%). This raises the need to conduct an experiment that will clearly manipulate the visual feedback of the participant (e.g., 50%) so that the effect of AVF strategy can be inferred more conspicuously. In addition, both existing studies examined if the participants overcame kinesiophobia and rotated their neck, back and hip a bit more with the help of the visual manipulation. However, although an improved range of movement may benefit some patients in terms of engaging in physical activity, it does not necessarily mean that it can help them exercise for longer and acquire a greater training stimulus. As a result, there is a need to conduct an experiment that will address the effect of AVF on how well a participant can tolerate a given level of exercise intensity. Given that in the present study participants were asked to perform a static exercise task with and without the use of AVF strategy, the effect of AVF on the naturally occurring pain during exercise could be explored with greater accuracy.

To conclude, the results of this study reveal that AVF strategy can improve the positive effects of VR technology, increase the level of physical activity, and promote a healthier lifestyle by reducing HR, PIR, and RPE and by increasing TTE via a pleasurable and motivational context. In this respect, current findings offer new insights into the way VR technology and visual-proprioceptive information can modulate the individual's willingness to continue to exercise for longer, primarily by reducing the intensity of negative perceptions of pain and effort associated with exercise. The results of this study are further discussed in Chapter 9. In the next chapter, another study is presented, which seeks to examine whether the combination of characteristics of well-known VR psychological intervention strategies can have positive effects on the perception of task difficulty, endurance performance, and pain experienced during exercise.

Chapter 7: Virtual Reality and the Impact of an Altered-Distraction Psychological Strategy on the Experience of Exercise Pain

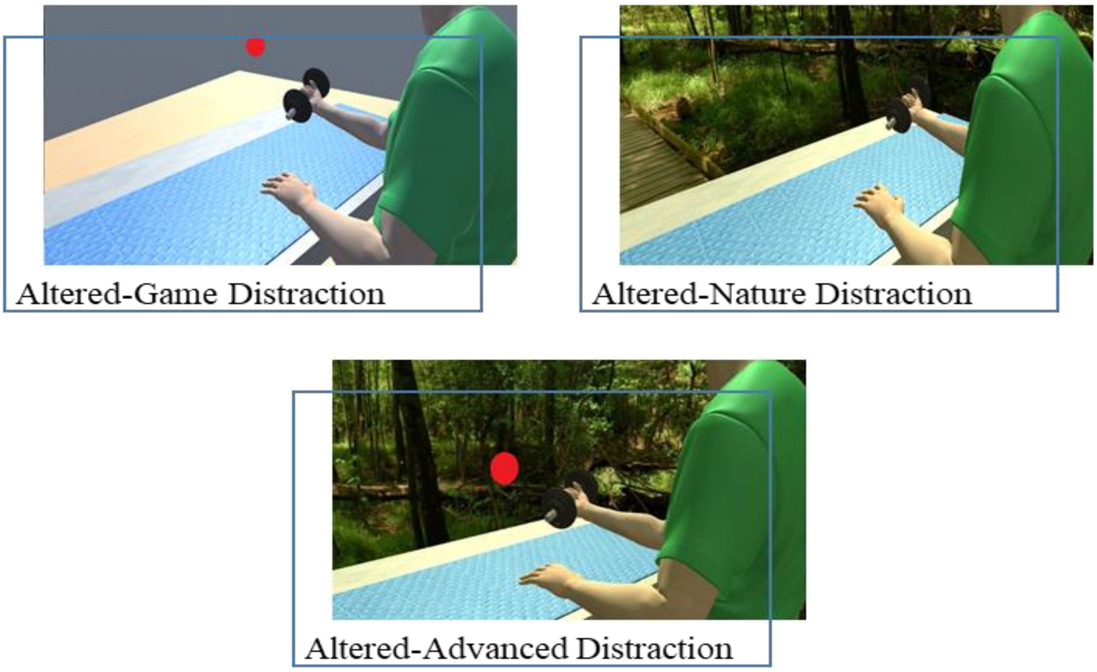
In Chapter 6, I examined how VR technology and well-established intervention strategies influence the perception of task difficulty, endurance performance, and pain experienced during EP. The results of both interventions (Distraction and Alter Visual Feedback) corroborated once again the effectiveness of VR and enhanced pain management through the use of psychological intervention strategies during an exhaustive muscle contraction. More specifically, the studies described in the previous chapter suggested that VR becomes more effective when it is enhanced with psychological intervention strategies. In addition, it emerged that each intervention strategy has its merits, but its effectiveness is related to the expected outcomes. For example, each type of Distraction presented significant results in different components. Game Distraction increased the duration of physical activity (TTE) and Nature Distraction decreased the perceived pain and effort.

To investigate whether one single intervention strategy can boost even more the effectiveness of Virtual Reality by influencing the perception of task difficulty, endurance performance, and pain experienced during EP, another study involving 20 participants was carried out. This study examines how a combination between the two successful types of Distraction and the Understated session of the Alter Visual Feedback would impact task performance, effort, and pain perception.

In this study, a new type of intervention strategy is proposed, which could enhance the effectiveness of Virtual Reality. Specifically, I examined the following three intervention strategies (Figure 7.1):

- Altered-Game Distraction: For this intervention I used the Game Distraction virtual environment along with an Understated dumbbell.
- Altered–Nature Distraction: For this intervention, I used the Nature Distraction virtual environment along with an Understated dumbbell.

- Altered–Advanced Distraction: For this intervention I used the Game Distraction virtual environment along with the Nature Distraction virtual environment and an Understated dumbbell.



Altered-Game Distraction

Altered-Nature Distraction

Altered-Advanced Distraction

Figure 7.1: Illustration of Altered-Distraction VEs.

The aim of the study was to investigate how the combination of the most beneficial characteristics of the well-known psychological intervention strategies may influence the level of pain and discomfort caused by an exhaustive muscle contraction.

7.1 Participants

Twenty healthy participants (4 males and 16 females), with a mean age of 22 years (M = 22.4, SD = 4.45), participated in the study. All 20 participants performed all three conditions (Altered–Game Distraction, Altered–Nature Distraction, and Altered–Advanced Distraction) in a counterbalanced design. Participants' one-repetition maximum (1RM) for 180^{o} of dominant arm elbow flexion ranged from 5 to 20 kg with a mean of 9.28 kg (SD = 3.76). Approximately 2/3 of participants reported engaging in no regular, structured resistance or aerobic exercise (no resistance = 80%, no aerobic = 70% during the testing week). Participants who reported engaging in regular structured exercise had a weekly mean workout time of 1.55 hours (SD = 3.1).

7.2 Procedure

The experiment required that participants paid two separate visits to the laboratory. On the first day of the experiment, the 1RM of each participant was calculated. Participants then rested for 10 minutes before moving on to the VR familiarisation (see the section: 3.2.2) and one of the experimental sessions (Altered–Game Distraction, Altered–Nature Distraction, and Altered–Advanced Distraction). On the second visit, the participants performed the remaining sessions. The real weight that was actually lifted remained the same in all three sessions. The three sessions were carried out in a counterbalanced design to avoid any adverse impact of the change in the order of the sessions on the results (Figure 7.2).

Figure 7.2: Illustration of the Study 5 Procedure.

7.3 Study Results

7.3.1 Virtual Reality (VR) measurements

Overall, participants reported moderate to high levels of Immersion in VR (> 3.5). According to their ratings, the VR application produced moderate to high degree of Presence, Hand Ownership, and Comfort. In addition, most participants reported that the VR application motivated them positively (Table 7.1). The results revealed significant differences between the types of Altered–Distraction and Presence (F(2, 38) = 3.84, p <.05), but no significant differences for Hand ownership (F(2, 38) = 0.71, p >.05), Comfort (F(2, 38) = 0.42, p >.05 with Greenhouse-Geisser correction) and Motivation (F(2, 38) = 0.17, p >.05). Finally, most of the participants were not familiar with the use of VR technology (M = 2.30, SD = 1.81).

Table 7.1: VR: Means and SDs.

		Mean	**SD**
Presence	Altered–Game Distraction	4.77	1.27
	Altered–Nature Distraction	4.62	1.51
	Altered–Advanced Distraction	4.20	1.54
Hand Ownership	Altered–Game Distraction	3.72	1.80
	Altered–Nature Distraction	3.72	1.77
	Altered–Advanced Distraction	3.45	1.56
Comfort	Altered–Game Distraction	5.45	1.23
	Altered–Nature Distraction	5.60	1.27
	Altered–Advanced Distraction	5.30	1.34
Motivation	Altered–Game Distraction	4.30	1.66
	Altered–Nature Distraction	4.40	1.90
	Altered–Advanced Distraction	4.30	1.81

7.3.2 Pain Measurements

Heart Rate (HR)

To investigate whether there was a difference between participants HR in the three sessions, an analysis of repeated measures ANOVA followed by Bonferroni post hoc test was conducted. The analysis revealed significant difference between the HR1 (F(2, 38) = 16.73, p <.001) and the three sessions, but not for the mHR (F(2, 38) = 0.24, p < .05), the HR2 (F(2, 38) = 0.82, p >.05), the HR3 (F(2, 38) = 0.97, p >.05), the HR4 (F(2, 38) = 0.20, p >.05) and the fHR (F(2, 38) = 0.18, p >.05) (Table 7.2).

Table 7.2: HR: Effects for Altered Distraction.

		mHR	**HR1**	**HR2**	**HR3**	**HR4**	**fHR**
Altered–Game Distraction	Mean (bpm)	86.60	73.80	82.45	80.90	82.15	86.10
	SD	9.44	7.72	7.04	9.60	8.96	9.00
Altered–Nature Distraction	Mean	86.74	83.45	85.15	83.35	83.10	86.05
	SD	9.00	10.84	11.55	9.01	11.17	9.44
Altered–Advanced Distraction	Mean	85.74	73.40	84.20	81.45	83.40	84.95
	SD	11.26	8.85	10.89	11.09	10.58	11.26

Time to Exhaustion (TTE)

To investigate whether there was a difference in participants' Time to Exhaustion (TTE) across the three sessions, an analysis of repeated measures ANOVA followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference for the TTE during the three sessions (F(2, 38) = 6.37, p <.005). Post-hoc paired comparisons with Bonferroni corrections indicated that the mean TTE in the Altered–Advanced Distraction (M = 11.46, SD = 3.01) was significantly longer than in Altered–Nature Distraction (M = 9.43, SD = 3.04). Also, a relationship was identified between the Altered–Game Distraction (M = 11.24, SD = 3.25) and the Control: Altered–Nature Distraction (p =.056).

During the Altered–Advanced Distraction, the minimum time to exhaustion for participants was 6.31, for Altered–Nature Distraction 4.34 and for Altered–Game Distraction 4.14. The maximum time to exhaustion for participants in all three sessions was 15 minutes, which is the maximum allowed time a participant could hold the weight.

Pain Intensity Rate (PIR)

To investigate whether there was a difference in participants' PIR across the three sessions, an analysis of repeated measures ANOVA followed by Bonferroni post hoc test was conducted. The analysis revealed no significant difference between mPIR (F(2, 38) = 1.06, p >.05), the PIR1 (F(2, 38) = 0.95, p >.05 with Greenhouse-Geisser correction), the PIR2 (F(2, 38) = 0.50, p >.05), the PIR3 (F(2, 38) = 0.32, p >.05), the PIR4 (F(2, 38) = 1.12, p >.05) and the fPIR (F(2, 38) = 0.60, p >.05) (Table 7.3).

Table 7.3: PIR: Effects for Altered Distraction.

		mPIR	**PIR1**	**PIR2**	**PIR3**	**PIR4**	**fPIR**
Altered–Game Distraction	Mean	5.04	1.00	1.80	2.66	3.63	8.65
	SD	1.98	1.30	1.51	2.03	2.65	2.58
Altered–Nature Distraction	Mean	4.72	0.65	1.75	2.98	4.30	8.35
	SD	1.66	1.04	1.29	2.08	2.36	2.43
Altered–Advanced Distraction	Mean	5.08	0.83	1.50	2.60	3.75	8.45
	SD	2.01	1.27	1.87	2.28	2.69	2.67

Rating of Perceived Exertion (RPE)

To investigate whether there was a difference in participants' RPE across the three sessions, an analysis of repeated measures ANOVA followed by Bonferroni post hoc test was conducted. The analysis revealed no significant difference between mRPE (F(2, 38) = 2.33, p >.05), the RPE1 (F(2, 38) = 0.25, p >.05 with Greenhouse-Geisser correction), the RPE2 (F(2, 38) = 0.45, p >.05), the RPE3 (F(2, 38) = 0.59, p >.05), the RPE4 (F(2, 38) = 0.36, p >.05) and the fRPE (F(2, 38) = 1.29, p >.05) (Table 7.4).

Table 7.4: RPE: Effects for Altered Distraction.

		mRPE	**RPE1**	**RPE2**	**RPE3**	**RPE4**	**fRPE**
Altered–Game Distraction	Mean	13.09	6.95	8.20	9.60	10.85	18.75
	SD	2.57	1.50	2.55	3.44	4.07	2.61
Altered–Nature Distraction	Mean	12.26	6.90	8.25	9.85	11.30	18.10

	SD	1.84	1.59	1.80	3.12	3.42	2.53
Altered–Advanced Distraction	Mean	13.01	6.70	7.85	9.10	10.60	18.60
	SD	2.54	1.45	2.16	3.11	3.70	2.96

7.4 Study summary

This chapter outlines the results of a study which intended to examine whether a combination of the effective characteristics of Distraction and AVF strategies can boost the effectiveness of Virtual Reality by influencing the perception of task difficulty and the levels of pain and discomfort caused by an exhaustive muscle contraction. To examine this, participants were asked to hold their Baseline Mass in an isometric contraction for as long as they could with their elbow at an angle of 90º flexion. Via VR technology, distracting, and altered visual signals, I aimed to divert participants' attention from the painful sensory signal.

They key findings of this analysis are the following:

- Participants engaged in high levels of Immersion in the VE. According to their subjective ratings, the VR application produced a high degree of Presence, Hand Ownership, and Comfort. What was more interesting was the fact that most of the participants reported that they could imagine motivating themselves to use the VR in a daily basis. Worth mentioning is the fact that the population in this study had little interest in exercise. In particular, only 20% of the participants reported engaging in regular, structured resistance exercise during the week. Therefore, the high levels of motivation expressed by such population evidences the beneficial effects of VR technology. Finally, it was found that there were significantly higher levels of presence when only one type of Distraction was incorporated to the VE. The results suggested that Game or Nature Distraction along with an Understated dumbbell produce higher levels of presence compared to having both types of Distraction simultaneously.

- Participants' HR revealed no significant differences between the three sessions, meaning that any type of VE which consists of an altered visual weight enhanced with distracting visual cues affects participants' HR in a similar way.

- TTE was significantly longer during the Altered–Advanced Distraction in comparison to the Altered–Nature Distraction session. However, the most interesting finding of this study was that the maximum TTE was set to 15 minutes, which was the maximum allowed time during all studies.

- Participants' PIR and RPE revealed no significant differences between the three sessions, meaning that any type of VE which includes an altered visual weight enhanced with distracting visual cues has a similar effect on participants' perception of pain intensity and their sensation of how hard they were driving their arm in order to maintain the muscle contraction.

Overall, this study aimed to fill a conspicuous gap in existing research by providing the research community with a unique strategy to tolerate a given level of exercise intensity. In other words, the aim was to apply the holistic approach of a psychological intervention strategy that could moderate the naturally occurring pain during exercise. The findings, which are further discussed in Chapter 9 lead to the conclusion that this new type of psychological intervention strategy can enhance VR's effectiveness.

In the next chapter, I will present a meta-analysis of the three psychological intervention strategies, so as to articulate clearly which psychological intervention strategy is best at reducing the perception of task difficulty, endurance performance, and pain experienced during exercise.

Chapter 8: Evaluation and Meta-analysis of psychological intervention strategies during the Experience of Exercise Pain

In Chapter 6, I examined how VR technology and well-established intervention strategies, such as Distraction and AVF, can influence the perception of task difficulty, endurance performance, and pain experienced during exercise. In Chapter 7, I proposed a new type of psychological intervention strategy, called Altered Distraction, which successfully combines and exploits the positive characteristics of Distraction and AVF strategies (Figure 8.1). The results of these studies highlighted once again the effectiveness of VR and enriched our knowledge on practices and strategies that can be beneficial for pain management during an exhaustive muscle contraction. The aim of this chapter is to further analyse the data which were collected in studies 3, 4, and 5 (see chapters 6 and 7) in order to identify the most effective intervention strategy regarding the physiological (HR, TTE) and the subjective (PIR, RPE) rates given by the participants.

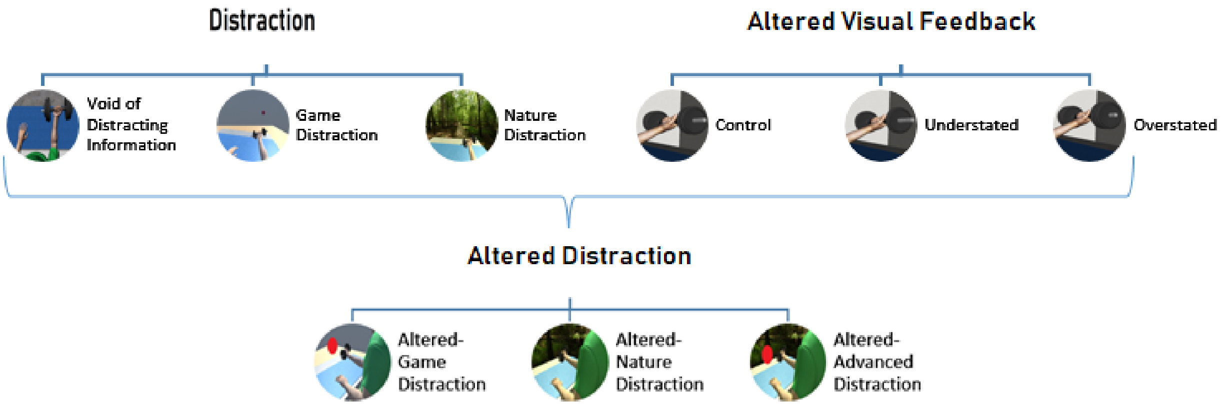


Figure 8.1: Flowchart of the Three Psychological Intervention Strategies.

The objective of this chapter is to investigate which intervention strategy is the most effective in regards to the level of pain and discomfort caused by an exhaustive muscle contraction.

8.1 Data Analysis

The meta-analysis was done based on time-based measures (HR, PIR, and RPE) and was carried out using ISO time-points. The shortest time to task failure in participants across the three strategies was 2 minutes, and so ISO time analysis was completed on minute 1, and minute 2 of the exercise task (HR1, PIR1, RPE1, HR2, PIR2, RPE2). Participants' HR, PIR, and RPE were also analysed based on when they withdrew from the task (fHR, fPIR, fRPE). The mean HR, PIR, and RPE across the exercise task for each participant were also calculated (mHR, mPIR and mPRE).

Descriptive statistics were then performed to identify the levels of Immersive Experience (Presence and Hand Ownership), comfort motivations, and familiarity.

An ANOVA analysis with repeated measures followed by Bonferroni post hoc test was conducted to examine how VR affects HR, PIR and RPE, based on ISO time points, and measured at task failure and mean HR. All statistical tests were carried out using the Statistical Package for the Social Sciences (SPSS) version 24. Data are reported as mean and SD, and statistical significance was accepted when $p < 0.05$.

8.2 Results

8.2.1 Virtual Reality (VR) measurements

Immersive Experience

One-way ANOVA revealed significant differences between the three strategies in terms of Presence (F (2, 67) = 4.66, $p < .05$), but no significant differences in terms of Hand Ownership (F (2, 67) = 2.46, $p > .05$). With respect to the findings, participants engaged more strongly during the AVF (M = 5.20, SD = 1.67), where they reported the highest levels of presence, followed by the Altered Distraction (M = 4.53, SD = 1.33) and the Distraction (M = 3.95, SD = 1.10). Similarly, the highest levels of Hand Ownership were reported during the AVF (M = 4.22, SD = 1.61), followed by the Altered Distraction (M = 3.63, SD = 1.58) and the Distraction (M = 3.39, SD = 1.62).

Ratings of Comfort and Motivation

One-way ANOVA revealed no significant differences in the means of the three strategies and the components of Comfort (F (2, 67) = 2.50, p >.05) and Motivation (F (2, 67) = 1.99, p >.05), meaning that the type of psychological intervention strategy does not affect the usability of the system and the motivation that participants felt. Despite the absence of any significant differences, AVF strategy (M = 6.13, SD = 1.96), (M = 5.30, SD = 1.93) still had the highest rate for the components of Comfort and Motivation respectively. The AVF strategy was followed by Distraction (M = 5.67, SD = 1.10), (M = 4.48, SD = 1.89) and the Altered Distraction (M = 5.45, SD = 0.97) (M = 4.33, SD = 1.72).

8.2.2 Pain Measurements

Heart Rate (HR)

To investigate whether there was a difference in the mean, ISO, and final HR during the three strategies, an analysis of repeated measures ANOVA followed by Bonferroni post hoc test was conducted. Significant differences were detected between mHR (F(4, 134) = 3.94, p <.005), fHR (F(4, 134) = 2.92, p <.05) and HR1 (F(4, 134) = 6.98, p <.001 with Greenhouse-Geisser correction), but not for the HR2 (F(4, 134) = 1.6, p >.05) during the three strategies (Table 8.1). Differences were detected between the AVF strategy and the Distraction and Altered Distraction.

Table 8.1: HR: Means and SDs for AVF, Distraction and Altered Distraction.

Strategy	**mHR**		**HR1**		**HR2**		**fHR**	
	Mean (bpm)	SD	Mean (bpm)	SD	Mean (bpm)	SD	Mean (bpm)	SD
Distraction	83.32	14.31	83.17	15.54	83.30	15.85	86.68	12.40
AVF	78.24	10.10	75.24	11.45	76.51	10.52	81.06	9.84
Altered Distraction	86.36	9.90	76.88	9.14	83.93	9.83	85.70	9.90

Further analysis was conducted to investigate whether there was a difference in the participants' mean, ISO, and final HR during the nine sessions of the three strategies. An analysis of a Generalized Linear Model (GLM) 3x3 independent Repeated Measure ANOVA followed by Bonferroni post hoc test revealed significant differences for the mHR (F(8, 152) = 7.32, p <.001 with Greenhouse-Geisser correction), with differences being detected between the Understated session and all the other sessions of the three strategies (Table 8.2).

Significant differences were also detected for the HR1 (F(8, 152) = 2.82, p <.05) and HR2 (F(8, 152) = 3.51, p <.05 with Greenhouse-Geisser correction). During the first minute (HR1), significant differences were detected between the Altered-Nature Distraction and the Understated and Game Distraction sessions. During the second minute (HR2), significant differences were detected between the Understated session, the Game Distraction session and all the three sessions of the Altered Distraction strategy (Table 8.2).

Finally, significant differences were also revealed in terms of fHR (F(8, 152) = 3.76, p <.005 with Greenhouse-Geisser correction) between the Understated and Altered–Game Distraction sessions (Table 8.2).

Table 8.2: HR: Means and SDs for All the Sessions of Each Strategy.

		mHR		**HR1**		**HR2**		**fHR**	
Strategy	**Session**	Mean (bpm)	SD	Mean (bpm)	SD	Mean (bpm)	SD	Mean (bpm)	SD
Distraction	Control	80.35	20.28	81.65	22.74	82.2	21.95	85.4	12.72
	Game Distraction	84.95	10.72	84.75	10.65	83.5	12.87	86.05	13.43
	Nature Distraction	84.65	11.94	84.9	13.23	84.2	12.73	88.6	11.05
AVF	Control	80.93	10.5	78.47	12.53	79.03	11.65	83.5	9.4
	Understated	74.07	8.58	70.83	10.26	72.5	8.68	76.47	9.37
	Overstated	79.73	11.21	76.43	11.56	78	11.22	83.2	10.76
Altered Distraction	Altered–Game Distraction	86.60	9.44	73.80	7.72	82.45	7.04	86.10	9.00
	Altered–Nature Distraction	86.74	9.00	83.45	10.84	85.15	11.55	86.05	9.44
	Altered–Advanced Distraction	85.74	11.26	73.40	8.85	84.20	10.89	84.95	11.26

Overall, from the above analysis, it can be seen that the AVF strategy and especially the Understated session can decrease participants’ HR significantly.

Time to Exhaustion (TTE)

To investigate whether there was a difference between the three strategies in terms of the TTE, an analysis of repeated measures ANOVA followed by Bonferroni post hoc test was conducted. Significant differences were detected between the Altered Distraction and the two other strategies (F(4, 134 = 15.71, p <.001 with Greenhouse-Geisser correction) (Table 8.3).

Table 8.3: TTE: Means and SDs for AVF, Distraction and Altered Distraction.

Strategy	Minimum Time (min)	Maximum Time (min)	Mean Time(min)	SD
Distraction	02.61	10.26	05.14	1.79
AVF	02.97	09.61	06.13	2.62
Altered Distraction	04.93	15.00	10.71	3.10

Further analysis was conducted to investigate whether there was a difference between participants' TTE during the nine sessions of the three strategies. An analysis of a GLM 3x3 independent Repeated Measure ANOVA followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference for the TTE during the three strategies and the nine sessions (F(8, 152) = 20.79, p <.001 with Greenhouse-Geisser correction). As shown in Table 8.4, the results suggest that Altered Distraction can increase significantly TTE.

Table 8.4: TTE: Means and SDs for All the Sessions of Each Strategy.

Strategy	Session	Minimum Time (min)	Maximum Time (min)	Mean Time(min)	SD
Distraction	Control	02.07	09.20	04.25	1.57
	Game Distraction	02.56	13.53	06.06	2.39
	Nature Distraction	03.20	08.06	05.12	1.42
AVF	Control	02.59	08.11	05.46	2.25
	Understated	03.29	13.21	07.45	3.15
	Overstated	03.03	07.50	05.47	2.46
Altered Distraction	Altered–Game Distraction	04.14	15.00	11.24	3.25
	Altered–Nature Distraction	04.34	15.00	09.43	3.04
	Altered–Advanced Distraction	06.31	15.00	11.46	3.01

Worth mentioning is the fact that for health and safety reasons, the maximum experimental time was set up to 15 minutes. Therefore, during the Altered Distraction strategy and all the three sessions, I had to terminate the study for the participant(s) who reached the time limit. As a consequence, the maximum time to exhaustion for the sessions of the Altered Distraction strategy might have been even longer if there were no time limitations set for health and safety reasons. It is evident from the result that this was not the case with the other two strategies and their six sessions; none of the participants in the AVF and Distraction strategy reached the maximum experimental time.

Pain Intensity Rate (PIR)

To investigate whether there was a difference between the three strategies with reference to the mean, ISO and final PIR, an analysis of repeated measures ANOVA, followed by Bonferroni post hoc test was conducted. Significant difference were detected between PIR1 (F(4, 134) = 8.80, p <.001 with Greenhouse-Geisser correction), PIR2 (F(4, 134) = 13.05, <.001), and fPIR (F(4, 134) = 3.45, p <.005) among the three strategies, but not for the mPIR (F(4, 134) = 2.10, p >.05) (Table 8.5). The results indicated that Altered Distraction strategy decreases significantly the perceived pain in comparison to Distraction and AVF strategies.

Table 8.5: PRI: Means and SDs for AVF, Distraction and Altered Distraction.

Strategy	**mPIR**		**PIR1**		**PIR2**		**fPIR**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Distraction	5.39	1.64	2.21	1.95	4.13	2.48	8.48	1.56
AVF	5.24	0.95	1.12	0.93	2.70	1.68	9.41	0.81
Altered Distraction	4.95	1.88	0.83	1.20	1.68	1.56	8.48	2.56

Further analysis was conducted to investigate whether there was a difference in participants' mPIR, PIR1, PIR2, and fPIR during the nine sessions of the three strategies. An analysis of a GLM 3x3 independent Repeated Measure ANOVA followed by Bonferroni post hoc test was conducted, but revealed no significant difference for the mPIR (F(8, 152) = 2.41, p >.05 with Greenhouse-Geisser correction) and fPIR. However, the analysis identified a significant difference for the first (PIR1) (F(8, 152) = 7.77, p <.001 with Greenhouse-Geisser correction) and second (PIR2) (F(8, 152) = 11.45, p <.001 with Greenhouse-Geisser correction) minute during the nine sessions (Table 8.6).

Table 8.6: PIR: Means and SDs for All the Sessions of Each Strategy.

Strategy	**Session**	**mPIR**		**PIR1**		**PIR2**		**fPIR**	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Distraction	Control	5.35	1.77	2.65	2.03	4.60	2.80	8.15	1.57
	Game Distraction	6.10	1.65	2.50	2.16	4.40	2.60	9.25	1.21
	Nature Distraction	4.71	1.50	1.48	1.65	3.38	2.04	8.05	1.90
AVF	Control	5.25	1.22	1.23	0.88	2.93	1.7	9.26	0.94
	Understated	4.81	1.37	0.65	0.93	1.78	1.84	9.33	0.92
	Overstated	5.66	0.93	1.48	0.98	3.4	1.49	9.63	0.56
Altered Distraction	Altered–Game Distraction	5.04	1.98	1.00	1.30	1.80	1.51	8.65	2.58
	Altered–Nature Distraction	4.72	1.66	0.65	1.04	1.75	1.29	8.35	2.43
	Altered–Advanced Distraction	5.08	2.01	0.83	1.27	1.50	1.87	8.45	2.67

Rating of Perceived Exertion (RPE)

To investigate whether there was a difference between the three strategies with reference to the mean, ISO and final RPE, an analysis of repeated measures ANOVA, followed by Bonferroni post hoc test was conducted. Significant difference was detected between the mRPE (F(4, 134) = 5.53, p <.001), RPE1(F(4, 134) = 5.39, p <.001), RPE2 (F(4, 134) = 5.06, p <.001) and fRPE (F(4, 134) = 4.15, p <.005 with Greenhouse-Geisser correction) during the three strategies (Table 8.7). The differences were detected between the Altered Distraction strategy and the other two strategies.

Table 8.7: RPE: Means and SDs for AVF, Distraction and Altered Distraction.

Strategy	**mRPE**		**RPE1**		**RPE2**		**fRPE**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Distraction	12.49	2.82	8.35	2.83	10.68	3.69	16.95	3.07
AVF	13.86	1.52	8.17	1.76	10.57	2.52	18.95	2.09
Altered Distraction	12.79	2.32	6.85	1.51	8.10	2.17	18.48	2.70

Further analysis was conducted to investigate whether there was a difference in participants' mRPE, RPE1, RPE2, and fRPE during the nine sessions of the three strategies. An analysis of a GLM 3x3 independent Repeated Measure ANOVA followed by Bonferroni post hoc test was conducted and revealed significant difference for the mRPE (F(8, 152) = 3.11, p <.05 with Greenhouse-Geisser correction), the RPE1 (F(8, 152) = 4.94, p <.005 with Greenhouse-Geisser correction), RPE2 (F(8, 152) = 7.63, p <.001 with Greenhouse-Geisser correction) and fRPE (F(8, 152) = 3.58, p <.05) during the nine sessions (Table 8.8). The differences were detected between the Overstated and Control sessions against all the other sessions.

Table 8.8: RPE: Means and SDs for All the Sessions of Each Strategy.

Strategy	**Session**	**mRPE**		**RPE1**		**RPE2**		**fRPE**	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Distraction	Control	12.71	2.91	9.25	2.99	11.75	3.54	16.55	3.47
	Game Distraction	13.41	2.92	8.45	3.33	11	4.36	18.4	2.14
	Nature Distraction	11.34	2.63	7.35	2.16	9.3	3.16	15.9	3.6
AVF	Control	13.82	1.66	8.27	1.66	10.97	2.4	18.73	3.17
	Understated	13.41	1.58	7.3	1.7	9.13	2.66	19	1.53
	Overstated	14.36	1.33	8.93	1.93	11.6	2.51	19.13	1.56
Altered Distraction	Altered–Game Distraction	13.09	2.57	6.95	1.50	8.20	2.55	18.75	2.61
	Altered–Nature Distraction	12.26	1.84	6.90	1.59	8.25	1.80	18.1	2.53
	Altered–Advanced Distraction	13.01	2.54	6.70	1.45	7.85	2.16	18.60	2.96

8.3 Chapter Summary

This chapter compares the results of study 3, 4, and 5, in which I examined how VR technology and psychological intervention strategies influence the perception of task difficulty that may reduce perceived pain. The main aim was to investigate which intervention strategy can be most beneficial to participants in weight-lifting exercises. To examine this, the data collected during studies 3, 4 and, 5 were analysed in depth, and a comparison was drawn between the three strategies and the nine sessions.

The key findings of this analysis are the following:

- There were significant differences with reference to presence. Participants reported to experience significantly higher presence during the AVF strategy in comparison to the Distraction and the Altered Distraction.

- Participants' HR was significantly lower during the AVF strategy. The mean HR during the AVF strategy was significantly lower than the mean HR during the Distraction and Altered Distraction strategy. Specifically, HR reduction by around 10 bpm was detected during the AVF and, more specifically, during the Understated session, meaning that a VE void of distracting visual information and a small-size dumbbell can decrease participants' HR.

- TTE was significantly longer during the Altered Distraction and especially during the Altered–Game Distraction and the Altered–Advanced Distraction sessions in comparison to the other two strategies and seven sessions. Interestingly, it was found that when vision Understated the real weight – and this was emphatically the case with Game and/or Nature Distraction – the time to exhaustion increased up to 50%.

The mean PIR and RPE were significantly lower when Nature Distraction enhanced with material illusions (Understated dumbbell) was incorporated into the virtual environment. Therefore, pain and exertion were found to decrease during the Nature Distraction, Understated (AVF) and the Altered–Nature Distraction.

Overall, this chapter has presented a meta-analysis of the psychological intervention strategies presented in chapters 6 and 7. The results have demonstrated that VR technology can increase the level of physical activity by reducing HR, PIR, and RPE and by increasing TTE. However, the type of the intervention strategy has a different impact on the positive outcomes. More specifically, it was shown that immersive experiments might be affected and improved through familiarity. Also, with regards to HR reduction, the Understated condition of the AVF strategy proved to be the most beneficial, whereas game elements can achieve the best results as far as TTE is concerned. Finally, virtual environment designed to imitate nature can help people reduce PIR and RPE during painful exercise. The results of this chapter are discussed in Chapter 9.

Chapter 9: Discussion and Conclusions

Pain is a multidimensional and complex experience, which refers to negative feelings (Arntz & Claassens, 2004; Merskey & Bogduk, 1994; Moseley, 2003; Price, 1999) that can arise during exercise, physiotherapy or any invasive medical process (see sections 2.1, 2.1, 2.1.1). Even though pain is a common and negative experience at a universal level (Malloy & Milling, 2010), research has encountered difficulties in its treatment due to its complexity and subjectivity (Gold et al., 2007; Mahrer & Gold, 2009) (see section 2.1). Therefore, it is an imperative need to find new and innovative ways to manage pain in our everyday life routine.

As discussed in Chapter 2, Virtual Reality technology could have positive effects on pain, since it has proved to be a promising alternative to pain treatment. Several studies have highlighted the potential of VR and psychological intervention strategies to mitigate pain. However, developing and designing successful virtual environments for pain management is a challenging process, since studies in the past have shown mixed results regarding VR's effect on pain (Crosbie et al., 2012; Czub & Piskorz, 2012 and 2014; Dahlquist et al., 2010; Dahlquist et al., 2009; Gordon et al., 2011; Markus et al., 2009; Morris et al., 2010; Walker et al., 2014) (see section: 2.4).

This chapter summarises and discusses the findings of a series of studies conducted in the framework of this PhD and attempts to illustrate how VR influences the perception of task difficulty during exercise and affects the perceived levels of pain and discomfort caused by it. In addition to that, this chapter discusses the way VR is affected by the individual characteristics and personal awareness of internal sensations (PBC), which might in turn influence individuals' adaptive behaviour to this technology. Moreover, the results derived from all three psychological intervention studies are synthesised with the aim of drawing a conclusion as to how they influence the effectiveness of VR during exercise pain. Finally, a set of recommendations are advanced, aiming to show how VR could best be designed to reduce pain during exercise. Table 9.1 sums up the main characteristics of the studies carried out in this thesis.

Table 9.1: Details of the studies carried out in this thesis.

Study	A study to investigate the effectiveness of:				
	VR	VR affected by PBC	Distraction via VR	AVF via VR	Altered Distraction via VR
Order in thesis	Chapter 4	Chapter 5	Chapter 6 Section 6.1	Chapter 6 Section 6.2	Chapter 7
Purpose/ Objectives	Examine how VR technology on its own contributes to the experience of pain.	Examine the effect PBC has on the effectiveness of VR during exercise pain.	Examine how Distraction influences the level of pain and discomfort caused by an exhaustive muscle contraction.	Examine how material properties influence the level of pain and discomfort caused by an exhaustive muscle contraction.	Examine if the combination of the most beneficial characteristics of Distraction and AVF strategies can lead to a new and successful psychological intervention strategy which may influence the level of pain and discomfort caused by an exhaustive muscle contraction.
Addresses research question	1	2	3	3	3
Approach	A controlled experiment where participants held their Baseline Mass in an isometric contraction for as long as they could with their elbow at an angle of 90º flexion. Physiological responses (HR and TTE) along with subjective rates of pain and exertion (PIR and RPE) were collected.				
Method	Statistical analysis of psycho-physiological data.				
No of participants	20	40	20	30	20
Main findings	1) VR can decrease HR, PIR, and RPE. 2) VR can	1) PBC affects subjective rates of pain and exertion (PIR and RPE).	1) Distracting information, such as natural environment and Game	1) People’s expectations about the size of a weight lifted decrease HR, PIR, and	1) The combination of the most beneficial characteristics of Distraction and AVF strategies

	increase TTE.	2) PBC does not affect Physiological responses (HR and TTE). 3) PBC affects the levels of immersion the individual feels but not significantly.	tasks, improve the levels of Immersion. 2) Distraction does not affect HR. 3) Game Distraction increase TTE. 4) Nature Distraction decrease PIR and RPE.	RPE and increase TTE.	result in a new successful strategy. 2) All types of Altered Distraction have approximately the same effect on HR, PIR, and RPE. 3) Altered–Advanced Distraction increases TTE.

9.1 Research questions addressed

Overall, this thesis has addressed four research questions:

- *How does Virtual Reality influence Exercise Pain?*

The first research question was addressed in the study as described in Chapter 4. The results show that VR technology can influence the perception of task difficulty, endurance performance and pain experienced during exercise. Most importantly, exercising through the use of VR technology revealed a significant decrease in Heart Rate (HR), Pain Intensity (PIR) and Perceived Exertion (RPE), and a significant increase in Time to Exhaustion (TTE). This was contrary to conventional non-VR exercise which was found to have a significantly higher Heart Rate (HR), Pain Intensity (PIR) and Perceived Exertion (RPE), and a significantly lower Time to Exhaustion (TTE).

Heart Rate (HR) has been considered to be an important, valid and objective physiological signal, for the assessment of clinical pain experiments (McGrath et al., 2008; von Baeyer & Spagrud, 2007). Clinical research often uses HR to validate self-report of pain (Lechner, Bradbury, & Bradley, 1998). Research has shown that there is a highly positive correlation between HR, pain intensity, and perceived exertion, with one shaping the other (Borg, 1962 and 1972; Borg, Ljunggren, & Ceci, 1985). This means that as pain level rises, HR rises accordingly (Tousignant-Laflamme, Rainville, & Marchand, 2005). In terms of exercise, HR allows to record physiological changes and correlations between exercise intensity (Mauger, 2014). Therefore, HR is an important measurement to assess pain intensity during exercise.

It is known that HR increases during exercise (Imai et al., 1994) and these automatic increases are influenced both by demographic characteristics, such as sex and age (Hossack & Bruce, 1982; Ogawa et al., 1992), and by the levels of physical activity (Ogawa et al., 1992). This means that trained individuals usually have lower resting HR than sedentary individuals (Ogawa et al., 1992), with younger males revealing higher normal HR than women (Hossack & Bruce, 1982). Age was found to affect this relationship; higher HR declines in men as they grow old, which brings old women to have higher heart rates than the old men (Hossack & Bruce, 1982).

Even though the normal HR differs between people, there is a healthy range of bmp, which should be close to resting HR means to be considered as efficient and healthy. In addition to that, HR recovery after exercise is accelerated in athletes but reduced in patients with chronic heart failure (Imai et al., 1994). Study 1 suggests that the use of VR technology offers the individual the ability to exercise for a longer period of time without burdening the heart, since the HR means remains closer to the resting one. This is the first time an application was found to be able to tolerate the increased HR during exercise without the use of any pharmacological medication. This is an important finding, since the application could be applied not only to healthy users but also, possibly, to individuals with heart diseases who could benefit from engaging in exercise. As has been explained above, individuals with heart diseases need an accelerated HR recovery after exercise and, at the same time, need to reduce the risk of an increased HR during exercise that can cause a heart failure. Therefore, the use of VR during exercise helps HR to increase only within tolerable levels and to return to the normal levels sooner.

The significantly lower HR in study 1 might be associated with an observation made in previous research studies, according to which the view of animated cartoons helped to reduce stress and anxiety in clinical environments (Cohen et al., 1997; Lee et al., 2012). In fact, in study 1 the virtual environment incorporated cartoonish features and representations of the virtual body, hand, and dumbbell, which might be responsible for the reduction of participants' stress and anxiety. In existing literature, HR is associated with perceived stress and anxiety (Sloan et al., 1994), which is however irrelevant to the personal levels of physical fitness (Dishman et al., 2000). On the contrary, psychological states, as well as emotional events and processes, can have a dramatic impact on HR and may result in increasing it without an accompanying increase in physical activity (Berntson & Cacioppo, 2004; Myrtek & Brügner, 1996). To conclude, stress and anxiety can cause alterations in HR (Friedman & Thayer, 1998) and their perceived level is an important factor which affects the fluctuations in HR in response to painful stimuli (see Arntz, Dreessen, & Merckelbach, 1991). The virtual environment which was used in the studies of this Ph.D. thesis was not photorealistic. Therefore, I believe that the animated cartoon features encouraged stress recovery, which in turn contributed to the reduction of HR.

As has been explained above, HR and responses to painful stimuli increase and decrease in the same direction, which means that when HR is rising the pain responses are rising as well (Borg, 1962 and 1972; Borg et al., 1985; Tousignant-Laflamme et al., 2005). Study 1 is in line with the above statement, since it was found that when HR was reduced, the perceived pain and exertion were reduced as well. This effect can be easily explained by the correlation made between HR and stress. Previous research has shown that stress and anxiety can increase perceived pain (Hoffman et al., 2000) and that VR has the ability to decrease situational anxiety related to painful chemotherapy (Schneider, Ellis, Coombs, Shonkwiler, & Folsom, 2003) and burn wound care (Hoffman et al., 2000) treatments. As a result, the cartoonish representation of the virtual environment might influence the anxiety levels and act as analgesic factors to pain and exertion.

Furthermore, research in psychoanalysis suggests that, unconsciously, individuals recall memories from their childhood and that such memories can shape their mood (Bower, 1981; Parrott & Sabini, 1990). Another study has demonstrated that individuals usually regulate negative mood by retrieving positive memories from the past (Rusting & DeHart, 2000). Therefore, participants might associate the cartoonish VE with happy childhood memories (see Bower, 1981; Martin & Metha, 1997), which might in turn mitigate the negative emotional experience of pain. This is further supported by a study which demonstrated that viewing an animated cartoon during venepuncture can reduce the levels of perceived pain in comparison to standard treatments (Yoo, Kim, Hur, & Kim, 2011).

Another possible interpretation of the positive effect VR has on pain intensity and perceived exertion could be given by Rubber Hand Illusion theory, according to which visual-proprioceptive information allows the individuals to perceive a fake hand as a part of their own body (Botvinick & Cohen, 1998). Research has shown that bodily self-consciousness is generated in the brain by sensory stimulation on a fake hand (Tsakiris, Hesse, Boy, Haggard, & Fink, 2006). Therefore, the Rubber hand illusion theory explains why the user may have the illusive feeling that the fake hand is a part of the real body (see sections 4.5.1, 6.1.5.1, 6.2.5.1, 7.5.1, and 8.2.1). Even though the fake hand was perceived as a real part of the body, the presentation of the hand via VR concealed visual stimuli that are perceived by the brain as signals of pain and exertion (e.g., veins swells, skin redness). This visual information might have minimised the perception of pain and exertion the individual felt. In addition to that, and as explained above, the level of interaction during sessions with immersive VR technology can increase participants' pain tolerance (Wender et al., 2009). Having in mind that the virtual hand was imitating the real move and tremulous, participants might have felt that interactivity levels were high, since the VR application produces natural moves, and therefore this might have had an effect on minimising the perceived pain and exertion.

Finally, a positive relationship was revealed between VR technology and time to exhaustion (TTE), since it was found that participants using VR exercised for approximately three minutes longer compared to those involved in conventional non-VR exercise (study 1). TTE has been considered to be an important, valid and objective physiological measurement for the assessment of pain. In the past, several studies have used time for the assessment of pain during a continuous pain task (Dahlquist, Herbert, Weiss & Jimeno, 2010; Rutter et al., 2009; Sil, et al., 2014) and during a continuous exercise pain task (Astokorki & Mauger, 2017).

Previous research has shown that VR technology can be used as an effective hosting platform to alter time perception via Distraction strategy both during chemotherapy and during therapy for individuals experiencing induced ischemic pain (Schneider & Hood, 2007; Schneider, Kisby, & Flint, 2011; Schneider & Workman, 2000; Schneider et al., 2003; Schneider, Prince-Paul, Allen, Silverman, & Talaba, 2004; Wiederhold & Wiederhold, 2007). Study 1 suggests that VR technology is not just a platform for the implementation of traditional and successful psychosocial intervention strategies. Rather, it can contribute to the alteration of time perception, the reduction of pain, and hence the increase of the duration of the painful process even when psychological intervention strategies are not used.

The positive effect of VR on TTE might be attributed to the interactive features incorporated by the virtual environment (e.g., hand and dumbbell were imitating the real move). It should be noted that additional interactive actions with the virtual world were not possible, since the participant had to remain in a stable condition so as the bicep curl exercise could be performed correctly and no other muscles (e.g., back muscles) should contribute to the resisters exercise. Therefore, the resistance exercise performed in the virtual environment allowed the user to interact with the virtual environment in real time and perform the exercise. This impacted on the levels of immersion the participants felt. Previous studies showed that participants' level of interactivity and immersion into the virtual world could affect the perception of time (Hoffman et al., 2004; Mahrer & Gold, 2009; Sharples et al., 2008). A comparison between interactive and passive VR technology for individuals experiencing cold pressor pain revealed that interactive condition was significantly more effective (Dahlquist et al., 2007). In addition, it was found that increased levels of immersion can reduce the level of pain reported by subjects (Hoffman et al., 2004). This means that users who are more deeply immersed in the virtual environment are more likely to experience feelings of time loss (Nordin et al., 2013; Wood, Griffiths, & Parke, 2007).

- *How does the awareness of personal internal body sensations influence the effect of Virtual Reality on the perception of task difficulty, endurance performance and pain experienced during exercise?*

The second research question was addressed during the study described in Chapter 5. The results show that personal characteristics of internal body awareness, such as Private Body Consciousness (PBC), do not influence the efficiency VR has on heart rate (HR) and time to exhaustion (TTE). This means that the effectiveness of VR technology on HR and time could not be influenced by personal characteristics of internal body awareness (PBC). This observation was corroborated by the mean, ISO time and end of exercise data, which reported that participants with high PBC experienced similar HR during and on completion of the exercise, compared to participants with low PBC.

In general, variations in the effect of biofeedback on heart rate, muscle contraction and pain (Surwit, Shapiro & Good, 1978; White, Holmes & Bennett, 1977) have been linked to the subjectivity of the person and her/his ability to alter physiological states through biofeedback (Turk, Meichenbaum & Herman, 1979). It was believed that PBC may be a major source of this variability (Miller et al., 1981), since subjects with a high PBC are well aware of physiological events and are therefore expected to be particularly susceptible to the effects of biofeedback. At the same time, individuals with low PBC are expected to report false feedback, because they tend to be unaware of their internal bodily states and therefore easily misled (Miller et al., 1981). However, this hypothesis had not been investigated prior to this research. This is the first time a study tried to investigate the correlation between HR and PBC. The results refute the hypothesis, since the group of high-PBC participants revealed similar HR to that of the opposite group.

A possible explanation could be that the attention of the participants was shifted from the observation of internal functions towards the virtual room and exercise. It is likely that long-term exposure to the VE might produce different results, since fatigue can reduce enthusiasm and shift attention more onto the internal sensations and less to the virtual environment. If this explanation is valid, differences are expected to be identified in HR and TTE as well.

However, as in real life, it was found that pain intensity (PIR) and perceived exertion (RPE) reports were significantly affected by individual characteristics and personal awareness of internal sensations. Research has shown that individuals with a higher

PBC are believed to be better attuned to their internal physiology and are more affected by disruptions to this (Fenigstein et al., 1975). As a consequence, in real life, individuals with high levels of PBC perceive and interpret more accurately and strongly the level of pain (Ferguson & Ahles, 1998). This was found to be the case in VR exercise as well. Therefore, it can be concluded that VR provides a new form of reality, where the individual's psychological responses are imitating the responses of real life. It is possible that the high levels of presence and hand ownership reported by the participants with low and high PBC might have made the virtual experience to be perceived as real; in this respect, the component of PBC behaves in the same manner as in everyday life.

- *How do different psychological intervention strategies in Virtual Reality influence the perception of task difficulty, endurance performance, and pain experienced during exercise?*

The third research question was addressed in three studies described in chapters 6, 7 and 8. The results show that the Understated condition of the Altered Visual Feedback strategy can influence significantly heart rate (HR), since results showed a significant decrease in Heart Rate (HR) in comparison to the Distraction and Altered Distraction strategies. On the other hand, the results suggest that the exercise duration is affected by Understated visual cues and Game Distraction. Thus, significant differences were reported between Understated, Game Distraction, Altered-Game Distraction, and Altered–Advanced Distraction from the other strategies. Finally, Understated visual cues and Nature Distraction can influence positively the pain and exertion experienced during exercise (PIR and RPE), since they were found to decrease significantly the perceived pain and exertion. Notable differences were identified between Understated, Nature Distraction, and Altered-Nature Distraction as compared to the other strategies. It emerges that psychological intervention strategies can influence positively the perception of task difficulty and endurance performance, since all strategies revealed positive results in different components.

The positive effect of VR on HR which was established in study 1 was further enhanced with the use of AVF. The AVF strategy and visual material properties were found to improve the effectiveness of VR and reduce significantly HR by 7 bpm, in comparison to the VR-only session. On the other hand, distracting visual cues were found to increase participants' HR only slightly. The mean HR during the VR-only session was approximately 4-6 bpm lower than the HR which was recorded during the Distraction and Altered Distraction strategies (see studies 3 and 5).

The explanations given in the framework of Research Question 1 can also be valid here, since the virtual environment in which the AVF strategy was examined was exactly the same as in study 1. Another convincing explanation would be that participants initially applied force to lift an object based on the visual material properties (Adelson, 2001; Johansson & Westling, 1988). Consequently, the significantly lower HR during the Understated session can be attributed to the perception of exercise difficulty the participants had during this session, which was moderated by the visual material properties. Therefore, the mental representation of pain intensity might have shaped the physiological response by decreasing participants' HR in a similar anticipatory manner.

The differences between the three psychological intervention strategies and the reduced HR can be explained based on two critical factors: (1) the population, and (2) the contents of the virtual environment. To begin with, as explained above, trained individuals usually have lower resting HR than sedentary individuals (Ogawa et al., 1992). This can explain the generally lower HR during AVF strategy in contrast to Distraction and Altered Distraction, since in study 4 the population was recruited from a sports centre, meaning that the population was much more trained than the population involved in the other two studies. Apart from this, the content of the virtual environment might have influenced results in the sense that virtual environments enhanced with distracting features (e.g., Game or Nature) were more likely to increase HR during the exercise, whilst virtual environments imitating the void of distracting visual information room (e.g., Control) were more likely to reduce HR. Contrary to previous research that suggests that heart rate tends to decline within a few minutes of viewing spectacular nature (see section 3.1), this study suggests that a void virtual room can reduce participants' HR even more. This might be the result of the cartoonish representation of the virtual environment, which as explain above, can encourage stress recovery and in turn reduce HR (see explanation in RQ1). Findings are likely to be altered if distractive virtual environments are compared to an augmented illustration of the environment.

Furthermore, it was also shown that VR’s effectiveness was positively enhanced by psychological intervention strategies. Both Distraction (see study 3) and AVF (see study 4) strategies benefit the participant in a similar way, increasing up to two minutes the duration of the exercise in comparison to the pure VR session. Interestingly, the combination of both strategies (see study 5) increased TTE up to 7 minutes.

These results are substantial for the research and design community, since the impact of time on the occurrence of pain during exercise is a vital factor. As explained above (see sections 1.1 and 2.1.1), exercise is an integral part of a healthy lifestyle, but prolonged exercise can cause a degree of discomfort and pain, which may terminate exercise. This could have negative consequences in the individual’s physical activity level and/or training stimulus. The studies carried out in the present thesis suggest that the use of VR, enhanced with psychological intervention strategies (Distraction, AVF and Altered Advanced Distraction), will offer individuals the opportunity to exercise for a longer period of time and will, by extension, contribute to the promotion of a healthier lifestyle.

Results are in line with previous studies which demonstrated the ability of VR to positively alter time perception during painful medical treatments, such as chemotherapy for women with breast cancer or therapy for healthy individuals with induced ischemic pain (Dahlquist et al., 2008; Magora, Cohen, Shochina, & Dayan, 2006; Schneider & Hood, 2007; Schneider et al., 2003, 2004 and 2011; Schneider & Workman, 2000; Wiederhold & Wiederhold, 2007). Some researchers have hypothesized that VR’s effectiveness on time tolerance is based on a sense of presence, which can improve virtual experience and can result in distracting the participant from perceiving high levels of pain (Schneider, 2007; Wiederhold & Wiederhold, 2007; Dahlquist et al., 2009). This is because the accurate perception of time requires high levels of attention to the duration of the painful process (Brown, 2008; Nordin et al., 2013; Wood, Griffiths, & Parke, 2007; Sturmer, Wong, &

Coltheart, 1968); thus, when the levels of presence are high, users are engaging more strongly in the virtual experience and are distracted from the painful process.

To further corroborate the above claim, several studies on digital games and time perception have shown that attentional resources towards time are limited when users engage in distracting digital games, since the cognitive capacity the individual has diminishes due to the distracting effects of the game (Myers, 1992; Nordin et al., 2013; Rau, Peng, & Yang, 2006; Sanders & Cairns, 2010). This means that the use of VR technology enhanced with Distraction can shift the levels of attention from the painful process onto the virtual experience. This may also underlie the results in studies 3 and 5, where participants focused on counting the ball jumps and at the same time were immersed in a virtual forest. Their attention was shifted towards the jumps and the additional distracting visual cues incorporated into the virtual environment. Therefore, only limited cognitive capacity remained for the assessment of pain. This resulted in an improvement of exercise duration, since the procedural pain during exercise was reduced.

Also, some researchers maintain that VR's effectiveness on time is based on the enjoyment that individuals feel during the process. Particularly, some studies demonstrated that VR during chemotherapy treatment is generally enjoyable, less stressful and mostly well received by patients (Schneider & Hood, 2007; Schneider & Workman, 2000; Schneider et al., 2003 and 2004). Therefore, enjoyability shapes patients' response towards the painful chemotherapy duration. Similarly, VR enhanced with psychological intervention strategies and particularly combined with distracting and Understated visual cues might have been perceived by the participants as more enjoyable and less stressful and this might have shaped their response towards the time to exhaustion.

Findings with reference to perceived pain and exertion reported by participants were in line with those related to HR and TTE. Pain Intensity (PIR) and Perceived Exertion (RPE) ratings are considered to be important subjective measurements for the assessment of pain (Borg, 1998; Cook et al., 1997) therefore, several studies on exercise pain have used PIR and RPE to assess the subjective side of perceived pain and exertion (Astokorki & Mauger, 2017; Hollander et al., 2010; Mauger et al., 2009;

Sgherza et al., 2002). As explained in RQ1, participants' perceived pain and exertion were reduced with the use of VR. Furthermore, the positive effects of VR on the perception of pain and exertion were enhanced by the use of psychological intervention strategies (see chapters 6-8).

Perception of pain and exertion during exercise has been characterise to be a significant component of patients' recovery process. As explained above (see section 2.4.3.1), patients with injuries deal with painful physical therapeutic processes. Even though these processes are fundamental components of rehabilitation because they improve functional outcomes and minimize persistent disabilities, patients usually neglect to participate fully in physical therapies due to significant procedural pain (Ehde et al., 1998; Patterson & Sharar, 2001). If pain perception could be offset during physical therapies, this would increase their willingness to participate fully in physical therapies.

Apart from patients, pain has been a prohibiting factors both for athletes and for healthy individuals who engage in regular exercise. As noted in sections 1.1 and 2.1.1, pain plays an important role in protecting the body from damaging stimuli through avoidance behaviour. Thus, pain during exercise may influence decision making, resulting either in a reduction of exercise intensity (so that pain is reduced) or in total withdrawal from exercise. In either scenario, this could have negative consequences for the individual's physical activity level and/or training stimulus. The studies carried out in the present thesis suggest that the use of VR along with specific psychological intervention strategies (Distraction, AVF and Altered Advanced Distraction) can offer individuals the possibility of offseting perceived pain and exertion during exercise, and allow them to increase their exercise intensity. The results are in line with previous studies that proved VR's ability to increase pain tolerance (Dahlquist, Herbert, Weiss & Jimeno, 2010; Kipping et al., 2012; Rutter et al., 2009).

In particular, Rutter and colleagues (2009) suggested that VR enhanced with psychological intervention strategies can decrease significantly the perceived pain and time spent thinking about it. The above findings were valid not only for healthy individuals but also for patients (Kipping et al., 2012). These positive effects of VR and psychological intervention strategies on pain reduction could be explained based on Gate Control Theory of pain (Melzack & Wall, 1965), which suggests that when users pay more attention to virtual reality and are distracted away from the painful experience, they are more effectively relieved from pain.

The findings of study 3 are in line with previous studies suggesting that distracting visual cues can minimise the perceived pain and exhaustion by increasing energy levels (Epstein & Roemmich, 2001; Graves et al., 2007 and 2008; Jacobs et al., 2011; Maloney, Threlkeld & Cook, 2012; Smith et al., 2011; Warburton et al., 2007) and motivate the participant positively (Gladwell, Brown, Wood, Sandercock, & Barton, 2013). It has also been demonstrated that the effectiveness of Distraction is based on the pleasurable experience which can improve exercise intensity (Bowler et al., 2010; Calogiuri & Chroni, 2014; Thompson Coon et al., 2011) and at the same time minimise the attention paid to sensory signal of pain, fatigue and perceived exertion, since the attention is shifted onto the natural environment (Calogiuri et al., 2015; Harte & Eifert, 1995).

Furthermore, based on Material-Weight Illusions theory (Seashore, 1899), AVF has enhanced VR’s effectiveness because individuals initially applied force to lift an object driven by visual material properties, e.g., the size (Adelson, 2001; Johansson & Westling, 1988). The perception of object weight is usually based on memory-driven expectations (Gordon et al., 1993) which are responsible for pain perception. Consequently, the dumbbell size can be characterised as an important factor which shapes the material expectations that are used to produce target force. Therefore, in study 4, the material expectations of pain intensity and exertion were moderated (by deception of object size) and, as a result, perceived pain and exertion were reduced.

All positive effects noted in previous studies were combined in study 5, which showed that the new and effective Altered Distraction strategy could enhance even more the effectiveness of VR technology.

- *How can effective Virtual Reality frameworks for pain management be designed?*

The final research question was addressed throughout the five studies carried out in this thesis. Their results, presented in chapters 4, 5, 6, 7 and 8, highlight the importance of designing better VEs for pain management during an exhaustive muscle contraction.

Drawing on the findings of these studies, it can be claimed that the effectiveness of a virtual environment depends on the requirements of the population. Different elements were found to support HR reduction and different elements were found to alter and reduce experience of pain. Therefore, designers of VR for pain management can derive some guidelines and recommendations from the present thesis. Table 9.2, summarises the suggestions that arise from the present research for each component and is based on the comparative presentation of results made in Chapter 8.

Table 9.2: Positive effects of virtual environment on the HR, PIR, RPE and TTE.

	Reduced HR	**Reduced PIR**	**Reduced RPE**	**Increased TTE**
Void of Distracting Visual Cues	✓			
Game Distraction				✓
Nature Distraction		✓	✓	
Understated visual cues	✓	✓	✓	✓
Altered–Game Distraction				✓
Altered–Nature		✓	✓	
Altered–Nature Distraction				✓

In particular, it was found that when a virtual environment was

(i) void of distracting visual information (e.g., a virtual environment similar to the one used in studies 1, 2, 4 and the control condition of study 3)

(ii) enhanced with cartoonish elements that facilitated the presentation of light material properties (e.g., Understated dumbbells), and

(iii) incorporated animated elements that did not depict fatigue and pain (e.g., did not depict the swell veins that normally appear on the limb during exercise),

then participants had a reduced HR during painful exercise. Therefore, designers of VR should not only focus on the virtual presentation of material properties that are to be used in exercise and that surround the user, but also on the proper design of the virtual human body and the part that will be involved in the performance of the exercise. Although the studies carried out in this research did not compare animated virtual environments to photorealistic ones, the positive findings should not be overlooked; animated virtual environments should be used by designers so that a reduced HR is achieved during resistance exercise.

In addition, it was found that when the design of a virtual environment is based on games which require from the individual high levels of attention, cognitive capacity and concentration (e.g. count correctly the jumps of a virtual ball), then the time spent engaging in a painful exercise is increased. Therefore, if designers of VR aim to increase the time people engage in painful exercise, they must focus on targeting the attentional resources of the individual. Based on Gate Control Theory (Melzack & Wall, 1965) and several game studies (Myers, 1992; Nordin et al., 2013; Rau et al., 2006; Sanders & Cairns, 2010), when the user concentrates on a mental game, the time passes faster and the perceived pain is reduced.

Finally, it was found that a virtual environment designed to imitate nature (e.g. forests) can help people reduce the pain perception during painful exercise. Therefore, designers of VR for exercise should not just focus on the actual activity (e.g. the types of interactions and physical exercise), but also on the appropriate design of the environment where those activities will take place. Although studies carried out in this thesis did not investigate the effects of different types of virtual environments, it is believed that they have to be personalised to suit specific preferences and circumstances. For example, green areas and forests can reduce pain arising from exercise. Also, it was found that a natural open field world can help people secluded in an institution (e.g. in a hospital or in prison) to relax (Ulrich, 1979, 1981, 1983, 1984, 1991, 1992 and 2002). On the other hand, icy fetchers might be more appropriate for pain caused by burn injuries, since SnowWorld was found to be particularly effective for patients with burn pain (Hoffman et al., 2004 and 2007).

9.2 Limitations

This thesis aimed to identify whether and in what way VR and/or intervention strategies may affect the perception of Exercise Pain. Due to the limited research in this area and the complex nature of the experience of pain. This thesis had to explore several factors to be able to provide answers to some key questions of paramount importance.

In this respect, there are limitations which can be used as food for thought for further investigation in this area of study. Key examples of such limitations are the following:

1. When investigating the effectiveness of AVF strategy on the experience of Exercise Pain, the study involved a gym population selected from a sports centre, as opposed to studies 4 and 5, where the population included both athletes and non-athletes. It can therefore be asserted that the significantly lower HR reported on the athletic participants was due to this difference in the constitution of the population. Future studies should therefore examine whether Distraction and Altered Distraction might also reveal lower HR if they were applied to athletes.

2. Participants in studies 2, 4 and 5 were not equally selected from both genders. Females were significantly more than males. Therefore, future studies should include more males so as to have an equal sampling.

9.3 Implications and Future Work

A key motivation for this thesis was the potential use of the VR application for pain management during exercise. Four out of five studies were carried out in a controlled environment (laboratory) and showed that VR can help to offset pain perception and task difficulty. The positive outcomes of VR were also detected in study 4, which was run at a sports center. Therefore, an implication arising from these studies is that VR exercise training can have positive results in sports centers as well as in home-based settings.

It is worth mentioning that VR's analgesic effectiveness is not affected by participants' awareness of the visual feedback modification (study 4); thus, the personalised use of the VR technology will still produce positive outcomes in home-based training sessions.

Given the continuous advances in the usability of VR technologies and accompanying interactive devices and based on the results of this thesis, it is now conceivable to use affordable VR technology and low-cost interactivity devices, since it was found to reduce significantly the naturally occurring pain and effort associated with single limb exercise. Following this reasoning, VR exercise could be carried out at home with minimal supervision.

In two out of five studies, participants had limited engagement in regular, structured resistance or aerobic exercise (only 30%) and low interest in exercise. However, positive attitudes were reported toward the VR exercise. Participants reported that they could imagine motivating themselves to use the VR application to exercise at least for 10 minutes on a daily basis. Therefore, another implication of this thesis is that VR can motivate positively individuals who are reluctant to exercise, and this could potentially result in an increased level of physical activity and thus a healthier lifestyle.

We should not overlook the fact that perceived pain and exertion have been considered to be an obstacle for athletes and professionals during exhaustive trainings. The results of the five studies are promising in this respect; perceived pain and exertion can be reduced and this can increase the duration of exercise. This suggests that VR technologies can be used more widely by athletes and professionals to offset pain and exertion. In such a case, athletes and professionals will increase their durability during training and, by extension, will improve their performance. In addition, VR exercise accompanies interactive devices, which have the potential to monitor the user’s physiological signals and levels of performance during VR exercise.

The positive implications of this thesis should not be restricted to healthy population and athletes; they can well be extended to patients suffering from heart diseases and stroke patients suffering from arm motor impairments. In fact, results suggest that VR technology can play a significant role in pain perception during endurance performance. In particular, it is shown that the positive outcomes of VR can help to offset HR increase. This is important, as it is known that HR increases during exercise. However, there is a healthy range of bmp, which should be close to resting HR mean in order to be considered as efficient and healthy. The findings revealed that VR can help the individual maintain HR means closer to the resting ones. Based on these findings, it can be inferred that VR technology allows the individual to continue exercising for a longer period of time without burdening the heart. This calls for further research on individuals with heart diseases, who could benefit from engaging in exercise but at the same time be protected from the risk of reporting an increased HR that can cause a heart failure.

Apart from patients suffering from heart diseases, the above findings can be applied to stroke patients with arm motor impairments, which need exercise and physiotherapy. Research has shown that a key factor for an effective exercise rehabilitation of stroke patients is the duration and intensity of the exercise performance (Langhorne, Coupar & Pollock, 2009). The studies carried out in this research demonstrated that VR and psychological intervention strategies can influence positively PIR and RPE, meaning that the user is able to continue exercising in high intensity for a longer period of time. This potentially results in patients being able to increase the duration and intensity of treatment to promote motor recovery after stroke.

Likewise, VR exercise technology can be applied for clinical populations at home. A good idea would be to incorporate social interactions into the virtual environment, since in many cases patients become homebound for a long period of time and hence lack social interactions. Therefore, future VR exercise applications could allow patients to carry out daily exercise along with other people and interact with them virtually.

Another aspect that calls for further investigation is the sustainability of VR in the long term. Although participants in all five studies reported that they were willing to use the VR application on a regular basis for limb exercise, further research is needed to establish the sustainability of this motivation over a longer period of time. Previous studies, as well as the five studies described in this thesis, mostly cover short-term effects. Only one study (Bahat et al., 2015) has compared the effect of VR over short- and long-term periods. The 2015 study revealed that, in the long run, VR is no better than standard interventions. Therefore, whether VR could have long-lasting beneficial effects on pain management remains to be established.

An area which needs to be investigated further relates to the observation that a virtual representation of the part in pain (e.g., virtual hand) can reduce perceived pain. Future studies must compare a digital–VR hand to a mixed relativity hand (virtual and augmented reality) in order to identify the most efficient way to represent affected body parts in VR. In addition, future experiments should examine whether the perceived immersion of the user could be further improved by enhancing the sense of embodiment, via connecting the VR with portable, advanced and low-cost sensors (e.g., BITalino – Electromyography (EMG) Sensor). This affordable technology can connect accurately the user's hand and fingers movement with the VE. More precise sensing technologies may increase the sense of presence and hand ownership and this may potentially result in even higher levels of immersion.

The work done in this thesis provides a basis for future research related to pain management and Virtual Reality. More importantly, it provides VR designers with innovative ideas to create more engaging virtual environments not only for healthy people engaging in regular exercise, but also for patients who avoid participating fully in physical therapies due to procedural pain.

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Appendix

Appendix 1: Virtual Reality (VR) Questionnaires

Presence.

1. Please rate your sense of being in the scenario, on the following scale from 1 to 7, where 7 represents your normal experience of being in a place. *I had a sense of "being there" in the Virtual Environment*: 1. Not at all ... 7. Very much.

   1 2 3 4 5 6 7

   Not at all Very much

2. To what extent were there times during the experience when the scenario was the reality for you? *There were times during the experience when the Virtual Environment was the reality for me*... 1. At no time ... 7. Almost all the time.

   1 2 3 4 5 6 7

   At no time Almost all the time

3. When you think back about your experience, do you think of the Virtual Environment more as images that you saw, or more as somewhere that you visited? *The scenario seems to me to be more like*... 1. Images that I saw ... 7. Somewhere that I visited.

   1 2 3 4 5 6 7

   Images that I saw Somewhere that I visited

4. During the time of the experience, which was strongest on the whole, your sense of being in the Virtual Environment, or of being elsewhere? *I had a stronger sense of*... 1. Being elsewhere ... 7. Being in the Virtual Environment.

   1 2 3 4 5 6 7

Being elsewhere	Being in the Virtual Environment

5. Consider your memory of being in the Virtual Environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By ‘structure of the memory’ consider things like the extent to which you have a visual memory of the virtual environment , whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements. *I think of the scenario as a place in a way similar to other places that I've been today...* 1. Not at all ... 7. Very much so.

1	2	3	4	5	6	7
Not at all						Very much

6. During the time of the experience, did you often think to yourself that you were actually in the Virtual Environment? *During the experience, I often thought that I was really standing in the* Virtual Environment... 1. Not very often ... 7. Very much so.

1	2	3	4	5	6	7
Not very often						Very much

Hand ownership.

1. During the time of the experience, did you often had the feeling that the hand in the VR glasses was your hand?

1	2	3	4	5	6	7
At no time						Almost all the time

2. During the time of the experience, did you often had the feeling that you were looking directly at your hand rather than at a fake hand?

1 2 3 4 5 6 7

Fake Hand My Hand

3. During the time of the experience, did you often had the feeling that the hand you were looking at was your hand?

1 2 3 4 5 6 7

At no time Almost all the time

Prior knowledge of this VR system.

1. Had you used in the past VR Technology?

1 2 3 4 5 6 7

Not at all Very much

Ratings of Comfort.

1. How comfortable did you find the set up (lift the weight) through the VR glasses

1 2 3 4 5 6 7

Not at all Very much

Ratings on Motivation.

1. Could you imagine motivating yourself to use the VR glasses to exercise every day for 10 minutes?

1 2 3 4 5 6 7

Not at all Very much

Identification of Visual Feedback.

1. Did you notice anything different between the sessions?

   ☐ No

   ☐ Yes

Appendix 2: Private Body Consciousness Questionnaires

Instructions for Private Body Consciousness Scale:

Answer the following questions about yourself by circling the number that indicates how characteristic each statement is of you, using the following scale.

(0) Extremely uncharacteristic

(1) Uncharacteristic

(2) Neutral

(3) Characteristic

(4) Extremely characteristic

Private Body Consciousness scale:

1. I am sensitive to internal bodily tensions.

   0 1 2 3 4

2. I know immediately when my mouth or throat gets dry.

   0 1 2 3 4

3. I can often feel my heart beating.

   0 1 2 3 4

4. I am quick to sense the hunger contractions of my stomach.

   0 1 2 3 4

5. I'm very aware of changes in my body temperature.

   0 1 2 3 4

Appendix 3: Pain Measurements Scales.

Appendix 3.1: Pain Intensity.

Pain intensity during the exercise task will be assessed using the 1-10 Cook Scale (Cook et al., 1997). Participants perceived pain will be recorded for every minute elapsed of the exercise task.

Instructions for exercise pain reports:

The scale before you contains the numbers 0-10. You should use this scale to assess the perceptions of pain which arise as a result of exercising. This should be the pain which is produced by muscle burn and ache as a result of repeated or prolonged muscular contraction, and <u>not</u> pain resulting from the injury. Do not underestimate or overestimate the degree of hurt you feel, just try to estimate it as honestly and objectively as possible. The numbers on the scale represent a range of pain intensity from ‘very faint pain (number ½) to ‘extremely intense pain-almost unbearable’ (number 10). When you feel no pain from muscle burn/ache, you should respond with the number zero. When pain becomes just noticeable, you should respond with the number ½. If you feel extremely strong pain which is almost unbearable, you should respond with the number 10. You can also respond with numbers greater than 10. If the pain is greater than 10, respond with the number that represents the pain intensity you feel in relation to 10. In other words, if the pain is twice as great then respond with the number 20. Repeatedly during the test, you will need to rate the feelings of exercise pain arising from muscle pain/ache. When you rate these pain sensations, be sure to rate only the specific pain sensations from exercise pain and not from other pain you may be feeling (e.g. blisters). Do not use your ratings as an expression of fatigue (i.e. inability of the muscle to produce force) or exertion (i.e. how hard it is for you to drive your arm), although increased pain may compromise your willingness to produce muscular force.

Pain Intensity Scale:

0	**No pain at all**
½	**Very faint pain**

1	**Weak pain**
2	**Mild pain**
3	**Moderate pain**
4	**Somewhat strong pain**
5	**Strong pain**
6	
7	**Very strong pain**
8	
9	
10	**Extremely intense pain (almost unbearable)**
•	**Unbearable pain**

Appendix 3.2: Rating of Perceived Exertion (RPE).

Ratings of Perceived Exertion during the exercise task will be assessed using the 6-20 Scale. Participants perceived pain perception of effort defined as the sensation of how hard they are driving their arm in order to maintain the muscle contraction, will be recorded for every minute elapsed of the exercise task.

Instructions for exercise Perceived Exertion:

During this test we want you to rate your perception of effort defined as the sensation of how hard you are driving your arm in order to lift the weight. Look at the scale before you; we want you to use this scale from 6 to 20, where 6 means “no exertion at all” and 20 means “maximal exertion”. To help you choose a number that corresponds to how you feel within this range, consider the following. When you do not have the sensation of driving your arm, choose number 6 (“no exertion at all”) - e.g. at rest with no contraction. When you have the sensation of driving your arm “hard”, choose number 15. Number 20 (“Maximal exertion”) corresponds to the feeling of effort when you are exercising maximally (i.e. as hard as you can for that given moment). Try to appraise your perception of effort as honestly as possible, without thinking what the actual physical load is. Don’t underestimate your perception of effort but do not overestimate it either. It’s your own feeling of effort that’s important, not how it compares to other people. What other people think is not important either. Look at the scale and the expressions and then give a number.

Perceived Exertion Scale:

6	**No exertion at all**
7	
	Extremely light
8	
9	**Very light**
10	

11	**Light**
12	
13	**Somewhat hard**
14	
15	**Hard (heavy)**
16	
17	**Very hard**
18	
19	**Extremely hard**
20	**Maximal exertion**

Appendix 3.3: Participant Health Questionnaire.

Participant Number Code:………………….

Please ensure you have completed and signed the Informed Consent Form to show that you have read and completed this Health Questionnaire

Please answer these questions truthfully and completely. The sole purpose of this questionnaire is to ensure that you are in a fit and healthy state to complete the exercise test.

ANY INFORMATION CONTAINED HEREIN WILL BE TREATED AS CONFIDENTIAL.

SECTION 1: GENERAL HEALTH QUESTIONS

Please read the 10 questions below carefully and answer each one honestly: check YES or NO.

	YES	**NO**
1. Has your doctor ever said that you have a heart condition or high blood pressure?	☐	☐
2. Do you feel pain in your chest at rest, during your daily activities of living, or when you do physical activity?	☐	☐
3. Do you lose balance because of dizziness or have you lost consciousness in the last 12 months? (Please answer NO if your dizziness was associated with over-breathing including vigorous exercise).	☐	☐
4. Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?	☐	☐

If yes, please list condition(s) here:		
5. Are you currently taking prescribed medications for a chronic medical condition?	☐	☐
If yes, please list condition(s) and medications here:		
6. Do you currently have (or have you had within the past 12 months) a bone, joint or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer NO if you had a problem in the past but it *does not limit your ability* to be physically active.	☐	☐
If yes, please list condition(s) here:		
7. Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐
8. Have you ever been diagnosed with Vision problems?	☐	☐
If yes, please list condition(s) here:		
9. Do you, or any in your immediate family, has a history of brain or mental disorders?	☐	☐

10. Are you currently taking any medication that may affect the central nervous system?	☐	☐

If you answered NO to all of the questions above, you are cleared to take part in the exercise test

SECTION 2: CHRONIC MEDICAL CONDITIONS

Please read the questions below carefully and answer each one honestly: check YES or NO.

		YES	**NO**
1.	**Do you have arthritis, osteoporosis, or back problems?** If YES answer questions 1a-1c. If NO go to Question 2.	☐	☐
1a.	Do you have difficulty Controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebrae (e.g. spondylolisthesis), and/or spondylosis/pars defect (a crack in the bony ring on the back of the spinal column)?	☐	☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	☐	☐
2.	**Do you have cancer of any kind?**	☐	☐

	If YES answer questions 2a-2b. If NO, go to Question 3.		
2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head and neck?	☐	☐
2b.	Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?	☐	☐
3.	**Do you have heart disease or cardiovascular disease? This includes coronary artery disease, high blood pressure, heart failure, diagnosed abnormality or heart rhythm.** If YES answer questions 3a-3e. If NO go to Question 4.	☐	☐
3a.	Do you have difficulty Controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
3b.	Do you have an irregular heartbeat that requires medical management? (e.g. atrial fibrillation, premature ventricular contraction)	☐	☐
3c.	Do you have chronic heart failure?	☐	☐
3d.	Do you have a resting blood pressure equal to or greater than 160/90mmHg with or without medication? Answer YES if you do not know your resting blood pressure.	☐	☐

3e.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in a regular physical activity in the last 2 months?	☐	☐
4.	**Do you have any metabolic conditions? This includes Type 1 Diabetes, Type 2 Diabetes, and Pre-Diabetes.** If YES answer questions 4a-4c. If NO, go to Question 5.	☐	☐
4a.	Is your blood sugar often above 13mmol/L? (Answer YES if you are not sure).	☐	☐
4b.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, OR the sensation in your toes and feet?	☐	☐
4c.	Do you have other metabolic conditions (such as thyroid disorders, current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	☐	☐
5.	**Do you have any mental health problems or learning difficulties?** This includes Alzheimer's, dementia, depression, anxiety disorder, eating disorder, psychotic disorder, intellectual disability and down syndrome. If YES answer questions 5a-5b. If NO go to Question 6.	☐	☐
5a.	Do you have difficulty Controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐

5b.	Do you also have back problems affecting nerves or muscles?	☐	☐
6.	**Do you have a respiratory disease?** This includes chronic obstructive pulmonary disease, asthma, pulmonary high blood pressure. If YES answer questions 6a-6d. If NO, go to Question 7.	☐	☐
6a.	Do you have difficulty Controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
6b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	☐	☐
6c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, labored breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	☐	☐
6d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	☐	☐
7.	**Do you have a spinal cord injury?** This includes tetraplegia and paraplegia. If YES answer questions 7a-7c. If NO, go to Question 8.	☐	☐
7a.	Do you have difficulty Controlling your condition with medications or other physician-prescribed therapies? (Answer	☐	☐

	NO if you are not currently taking any medications or other treatments).		
7b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	☐	☐
7c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as autonomic dysreflexia)?	☐	☐
8.	Have you had a stroke? This includes transient ischemic attack (TIA) or cerebrovascular event. If YES answer questions 8a-8c. If NO go to Question 9.	☐	☐
8a.	Do you have difficulty Controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
8b.	Do you have any impairment in walking or mobility?	☐	☐
8c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	☐	☐
9.	Do you have any other medical condition which is not listed above or do you have two or more medical conditions? If you have other medical conditions, answer questions 9a-9c. If NO go to Question 10.	☐	☐

9a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?	☐	☐
9b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, and kidney problems)?	☐	☐
9c.	Do you currently live with two or more medical conditions?	☐	☐
	Please list your medical condition(s) and any related medications here:		
10.	**Have you had a viral infection in the last 2 weeks (cough, cold, sore throat, etc.)?** If YES please provide details below:	☐	☐
11.	**Is there any other reason why you cannot take part in this exercise test?** If YES please provide details below:	☐	☐
12.	**Please provide brief details of your current weekly levels of physical activity (sport, physical fitness or conditioning activities), using the following classification for exertion level:** **L = light (slightly breathless)** **M = moderate (breathless)** **V = vigorous (very breathless)**		

	Activity **Duration (mins.)** **Level (L/M/V)** **Monday** **Tuesday** **Wednesday** **Thursday** **Friday** **Saturday** **Sunday**

Please see below for recommendations for your current medical condition and sign this document:

✓ **If you answered NO to all of the follow-up questions about your medical condition, you are cleared to take part in the exercise test.**

✗ **If you answered YES to one or more of the follow-up questions about your medical condition it is strongly advised that you should seek further advice from a medical professional before taking part in the exercise test.**

This health questionnaire is based around the PAR-Q+, which was developed by the Canadian Society for Exercise Physiology www.csep.ca

Appendix 4: CV and Publication List

WORK EXPERIENCE

Oct 15– present *Graduate Teaching Assistant*

University of Kent, Kent/Canterbury (United Kingdom) at School of Engineering and Digital Arts (EDA)

1) Assistant Lecturer: EL538/Interaction Design
2) GTA: EL338/Visual Culture; EL539/Professional Practice; EL636/Final Year; EL790: Year In Industry

Oct 15– present *Researcher*

1) University of Kent, Intelligent Interactions Lab, Canterbury CT2 7NZ, UK, Virtual Reality for Pain Management.
2) St Andrew's Northampton, Cliftonville, Northampton, NN1 5DG, UK, Virtual Reality for Patients with Severe Dementia

Jan 14– present *Visiting Researcher*

University of Cyprus, Experimental Psychology Lab, Kallipoleos 75, Nicosia, CY

1) BioPac (ECG, EMG, EDA): Virtual Reality for Pain Management during Resisters Exercise

Jan 14– present *Affiliated Researcher*

Cyprus University of Technology, The Cyprus Interaction Lab, Le Corbusier, Limassol, CY

1) Crowdsourcing: Trait Empathy and Ethnic Background in a Visual Emotion Recognition Task

2) Grand: € 1.000000 – NOTRE: Horizon 2020 Twinning programme – TWINN – 2015, Involved in write-up and submission

3) MSc Interaction Design, Involved in the establishment process of the MSc; Website administration, https://www.idmaster.eu/

4) Summer School organization, with Tallinn University, on Research Methods in HCI

Jan 13–Jul 13 *Graduate Teaching Assistant*

University of Cyprus, Department of Psychology, Kallipoleos 75, Nicosia, CY, Assistant Lecturer: PSY 217/Family Psychology

Jan 13–Dec 13 *Administration of the Psychology Department website*

University of Cyprus, Department of Psychology, Kallipoleos 75, Nicosia, CY

Jan 12–Jan 13 *Researcher*

Cyprus University of Technology, Department of Communication and Internet studies, Limassol (Cyprus) Limassol, CY

1) Data collection and analysis

2) Responsible for the design and implementation of voting consultation on electronic platform: www.choose4greece.com / www.choose4cyprus.com

May 12–Dec 12 *Volunteer*

1st Cyprus Presidency of the Council of the EU 2012

May 11– Jul 11 *User Experience Researcher (Internship)*

Evresis CRM/Loyalty Marketing Specialists, Nicosia (Cyprus)

EDUCATION

Sep15– present *Doctor of Philosophy (Ph.D.) in Digital Arts*

University of Kent, School of Engineering and Digital Arts (EDA)

Kent VC scholarship, £56,244 (£14,553 plus tuition fees £4195 per year).

Thesis topic: The Impact of Virtual Reality on the Experience of Exercise Pain

Sep12– May 14 *MA Social and Developmental Psychology*

University of Cyprus, School of Psychology, Grade: 9.28/10 (Excellent)

1st prize award, €750 - Faculty of Social Sciences and Education

Thesis topic: Predictors and consequences of violence in romantic relationships among young adults, Thesis Grade: Excellent

Sep12– May 14 *MA Communication and New Journalism*

Open University of Cyprus, School of Humanities and Social Sciences, Grade: 8/10 (Very Good)

Thesis topic: Dating Violence among Young Adults: The Role of Social Media, Thesis Grade: 9/10 (Excellent)

The thesis has been selected as required reading for the Social Computing module of the M.Sc. in Social Information Systems.

Sep 08– May 12 *BS.c. Communication and Internet studies: Information Society*

Cyprus University of Technology, Department of Communication and Internet Studies, Grade: 7.84 (Very Good)

Thesis topic: A socio-psychological empirical approach to love in Cyprus, Thesis Grade: 10/10 (Excellent)

The thesis has been selected as guidelines material for thesis writing of the BS.c. Communication and Internet studies.

Sep 05– May 08 *Secondary Education*

Apolitirion Pancyprian Lyceum Larnaca, Grade: 19.62 / 20 (Distinctions)

CERTIFICATES

Jul 15 *Research Methods in HCI*

Summer School: Cyprus University of Technology and Tallinn University, Limassol (Cyprus), Student and Involved in the Organizing Committee

Jul 12 *Special Courses on the Methodology of Research: Quantitative and Qualitative analysis*

Summer School: University of Aegean, Mytilene (Greece)

Oct 08– Nov 08 *Cinema Screenwriting Workshop*

Cultural Services of the Ministry of Education & Culture and Media Desk Cyprus (Horeftika Vimata Association), Nicosia (Cyprus)

HONORS AND AWARDS

2015: Kent VC scholarship: £56,244 – School of Engineering and Digital Arts –

2014: 1st prize award: €750 – Faculty of Social Sciences and Education. University of Cyprus.

2014: Distinction – Social and Developmental Psychology. Department of Psychology - University of Cyprus.

2009: Second Debut Award: €2.500 – Publication of Poetry Collection.

2005 – 2008: Distinction – Pancyprian Lyceum Larnaca.

2005: Poetry praise – National and Kapodistrian University of Athens and Ionian University.

2004: Distinction – Evryviadeio Gymnasium Larnaca.

2002: 3rd Place – Lions International Peace Poster Contest

SELECTIVE PUBLICATIONS

JOURNALS

Published:

Matsangidou, M., Otterbacher, J., Ang, C. S., & Zaphiris, P. (2018). Can the crowd tell how I feel? Trait empathy and ethnic background in a visual pain judgment task. *Universal Access in the Information Society*, 1-13.

Matsangidou, M., Ang, C. S., & Sakel, M. (2017). Clinical utility of virtual reality in pain management: a comprehensive research review. *British Journal of Neuroscience Nursing*, *13*(3), 133-143.

Matsangidou, M., & Otterbacher, J. (2018). Can Posting be a Catalyst for Dating Violence? Social Media Behaviors and Physical Interactions. *Violence and Gender.*

Matsangidou, M., Ang, C. S., Avraamides, M., Mauger, A. R., & Intarasirisawat, J., Otkhmezuri, B. (2018). Is Your Virtual Self as Sensational as Your Real? Virtual Reality: The Effect of Body Consciousness on the Experience of Exercise Sensations. *Psychology of Sport & Exercise.*

Matsangidou, M., Ang, C. S., Mauger, A. R., Otkhmezuri, B., & Tabbaa, L. (2017, September). How Real Is Unreal? Virtual Reality and the Impact of Visual Imagery on the Experience of Exercise-Induced Pain. In *IFIP Conference on Human-Computer Interaction* (pp. 273-288). Springer, Cham.

Under Review:

Matsangidou, M., Ang, C. S., & Mauger, A. R. (Under Review). Establishing a link between Virtual Reality, Heart Rate and Pain Perception. *Journal of PAIN.*

Otkhmezuri, B., Boffo, M., Siriaraya, P., **Matsangidou, M.,** Wiers, R. W., Mackintosh, B., Ang, C. S., Salemink, E. (Under Review). Believing is Seeing: Boosting the Interpretation Bias Modification effects on anxiety by using a mobile Virtual Reality tool. B*ehaviour Research and Therapy*.

Rose, V., Stewart, I., Jenkins, K., Ang, C.S. & **Matsangidou, M.** (Under Review). A Systematic Literature review exploring the feasibility of Virtual Reality interventions with individuals living with Dementia. *Conference on Artificial Reality and Telexistence and the 23rd Eurographics Symposium on Virtual Environments (ICATEGVE 2018).*

Rose, V., Stewart, I., Jenkins, K., Tabbaa, L., Ang, C.S. & **Matsangidou, M.** (Under Review). Bringing the Outside In: The Feasibility of Virtual Reality with Individuals Living with Dementia in a Locked Psychiatric Hospital. *The Gerontologist.*

BOOKS

Matsangidou, M. (2009). Poetry Collection: The ample sea (Η Ευρύχωρος Θάλασσα). Cyprus: *Αφή Publisher.* - The book receives the Second Debut Award in Cyprus.

Matsangidou, M. (2013). Greet the rising sun: We are talking about Greece. Athens*: Μεταμεσονύκτιες εκδόσεις.*

Matsangidou, M. (2014). Manifesto. Athens: *Μεταμεσονύκτιες εκδόσεις.*