How Real Is Unreal?

Virtual Reality and the Impact of Visual Imagery on the Experience of Exercise-Induced Pain

Maria Matsangidou[1(✉)], Chee Siang Ang[1], Alexis R. Mauger[2], Boris Otkhmezuri[1], and Luma Tabbaa[1]

[1] Intelligent Interactions Research Group, Department of Engineering and Digital Arts, University of Kent, Canterbury, UK
{M.Matsangidou, C.S.Ang, bo201, L.A.M.N.Tabbaa}@kent.ac.uk

[2] Endurance Research Group, School of Sport and Exercise Sciences, University of Kent, Chatham, UK
L.Mauger@kent.ac.uk

Abstract. As a consequence of prolonged muscle contraction, acute pain arises during exercise due to a build-up of noxious biochemicals in and around the muscle. Specific visual cues, e.g., the size of the object in weight lifting exercises, may reduce acute pain experienced during exercise. In this study, we examined how Virtual Reality (VR) can facilitate this "material-weight illusion", influencing perception of task difficulty, which may reduce perceived pain. We found that when vision understated the real weight, the time to exhaustion was 2 min longer. Furthermore, participants' heart rate was significantly lower by 5-7 bpm in the understated session. We concluded that visual-proprioceptive information modulated 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. This result could inform the design of VR aimed at increasing the level of physical activity and thus a healthier lifestyle.

Keywords: Pain · Exercise · Virtual reality · Material-Weight illusions · Body representation

1 Introduction

Exercise is essential in helping to maintain and improve a healthy way of living, but intense or prolonged exercise can cause a degree of discomfort and pain. The International Association for the Study of Pain (IASP) [1] defines pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage", which suggests that pain has both a nociceptive 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.

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Pain has an important role in protecting the body from damaging stimuli through avoidance behavior, and so pain during exercise may influence decision making that either results in the individual reducing the exercise intensity (so that pain is reduced), or withdrawing from the exercise entirely [2]. In either scenario, this could have negative consequences for the individual's physical activity level and/or training stimulus. If pain perception could be offset during exercise, this could result in individuals having an increased willingness to either increase their exercise intensity or continue exercise for a longer period of time. This would potentially result in an increased level of physical activity and thus a healthier lifestyle.

A number of studies have used brain-imaging approaches to examine if pain expectations are associated with concomitant changes in nociceptive circuitry. Some studies have looked into the relationship between expectations and pain experience. Interestingly, it has been found that expectations about a painful stimulus can profoundly influence the brain and pain perception [3]. 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 or moderate perception of the nociceptive stimulus [3–5].

It has been shown that individuals initially apply force to lift an object based on the visual material properties, e.g., the size [6, 7]. 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 [8] which are termed "material-weight illusions" (MWI) [9] and may be also responsible for providing expectations of task difficulty and consequently the expected pain perception arising from the subsequent muscle force requirement. Therefore, moderating the expectation (by deception of object size) of the difficulty of an exercise task may affect the subsequent pain perception caused by it.

1.1 Virtual Reality and Pain Management

VR is a technology that allows users to experience a computer-simulated reality based on visual cues, enhanced with auditory, tactile and olfactory interactions. The system provides the user with an overall illusion of different senses and creates an immersive experience [10]. Indeed, a range of studies have explored clinical uses of VR, including pain management, physical rehabilitation and psychotherapy [11–13]. In recent years, low cost consumer-facing immersive VR systems have become widely available (e.g., Google Cardboard, Gear VR, Oculus Rift[1]). These affordable immersive VR technologies provide us with feasible solutions, which could be used in a range of real world settings, including homes, sport centers, hospitals, etc. [14].

Whilst a variety of pharmacological analgesics and psychological methods have been used as medical treatments for pain among patients. Research in the past decades has suggested that VR technology could provide an alternative solution to pain

[1] https://store.google.com/product/google_carboard, www.samsung.com/global/galaxt/wearables/gear-vr, www.oculus.com.

management [10–13]. For instance, VR can allow a patient to concentrate on the virtual experience, thus distracting him/herself from the perception of nociceptive signals, and pain [15].

These studies suggest that distraction strategy using VR is a common and successful treatment of pain, with most predominantly focused on pain from burn injury (and thermal stimuli-induced pain) and the analgesic effect of distraction via VR [16–20]. However, more recent studies using an Altered Visual Feedback strategy (AVF) suggests an alternative approach to pain management, which may be more appropriate for pain caused by physical movement [21–23].

1.2 Virtual Reality and Altered Visual Feedback Strategy

Previous studies have used VR and AVF to treat kinesiophobia - a fear of movement. It more frequently occurs in patients with chronic pain and can lead to a reduction in physical activity. In a study by Bolete et al. [21], a virtual basketball arena was used to help people overcome kinesiophobia. The participants were located in the centre of the virtual arena and performed a virtual basketball catching task based on their body rotation. The participants stood still on the ground and small manipulations were applied to the visual feedback to alter the way the neck, back and hip contributed to the catching rotation. It was shown that VR enabled the participants to increase their range of motion.

In addition, altered visual cues were also used to examine pain caused by neck movement [23]. In this study, patients with chronic neck pain were asked to rotate their heads. However, the visual feedback of the rotation via VR was manipulated to overstate or understate the real rotation by 20% more or less of the actual movement. The results revealed that altered visual feedback might increase or decrease the pain perception based on the visual proprioceptive feedback. These results [21, 23] showed that AVF increased movement amplitudes in participants with chronic back/neck pain.

However, there were some limitations in these studies [21, 23]. First, the visual feedback manipulation of both studies was small (e.g., up to 20%). There is a need to conduct experiments which manipulate the visual feedback of the participant (e.g., 50%), in order to be able to identify clearly the effect of AVF strategy. In addition, both studies examined if the participants overcame kinesiophobia and rotated their neck, back and hip a bit more because of the visual manipulation. However, whilst an improved range of movement may benefit some patients in terms of engaging in physical activity, it does not necessarily mean they could exercise for longer and therefore acquire a greater training stimulus. As a result, there is a need to conduct an experiment to address the effect of AVF on how well a participant can tolerate a given level of exercise intensity. By asking participants to perform a static exercise task with and without employing AVF strategy, we are able to more accurately explore how AVF may moderate the naturally occurring pain during exercise. In pilot testing conducted in our laboratory, we established that the appearance of a 20% smaller/larger weight was difficult to distinguish, whereas a 50% difference in the visual appearance of a weight created a more obvious distinction between the conditions.

In conclusion, although positive results were found in using VR and AVF to manage kinesiophobia and chronic pain, little has been done to study the use of VR for reducing the naturally occurring pain experienced during strenuous exercise. In this study, we aim to investigate how VR and AVF strategy may affect the perception of exercise-induced pain (EIP) among healthy people. In particular, using a low-cost VR technology, we aim to examine how our material expectations influence our perception of task difficulty and our exercise performance. We also aim to investigate how visual cues may influence the level of pain and discomfort caused by an exhaustive muscle contraction. To examine this, we changed people's expectations of exercise by deceiving them about the size of a weight lifted using VR visual stimulation. In particular, we test the following hypotheses:

H1: *Altered Visual Feedback strategy in Virtual Reality will influence perception of task difficulty during exercise.*

H2: *Altered Visual Feedback strategy in Virtual Reality will influence endurance performance during exercise.*

H3: *Altered Visual Feedback strategy in Virtual Reality will affect pain experienced during exercise.*

2 Materials and Methods

2.1 Participants

Thirty healthy participants (males = 16 and females = 14), aged between 24 to 45 years (M = 35.60, SD = 7.05) participated in this the study. Participants' 1RM (one repetition maximum, i.e. the heaviest weight they could lift) for 180 degrees of dominant arm elbow flexion ranged from 4 to 25 kg (M = 13.92, SD = 5.77). 56% of the participants did not do any resistance exercise training and 33% did not do any aerobic training during the week. Overall, they had a weakly mean workout time of 4 h. All participants had normal or corrected to normal vision and no disability in their hand, arm, shoulder, neck, back or another area that could affect their performance of the exercise task. All participants had no history of any cardiovascular, mental or brain disorders or were taking any chronic medications that affect the central nervous system.

2.2 Ethics

The study was approved by University of Kent SSES Research Ethics & Advisory Group (ref. Prop. 112_2015_2016). All participants signed a consent form prior to the study and the study was performed in accordance with the Declaration of Helsinki.

2.3 Procedure

The experiment required the participant to pay four separate visits to the laboratory. The first visit involved the calculation of the 1RM and the VR familiarization session, whilst the second, third and fourth visit involved a Control and two VR intervention sessions.

Phase 1. On the first day of the experiment, we calculated the 1RM of each participant. The participants stood with their back straight against a wall, with their elbow and wrist joint at a 180º angle. Participants were asked to bicep curl a dumbbell weight through a full range of motion (180º-full flexion-180º) (Fig. 1). Then, weights were added to the dumbbell until the participant could no longer perform a bicep curl through the full range of motion. The heaviest weight the participant was able to lift was set as their 1RM. From the 1RM, a weight of 20% was calculated and set as their baseline weight:

$$Baseline\,Weight\,(kg) = \frac{lRM * 20}{100}$$

The participants then rested for 10 min and moved on to the VR familiarization.

During VR familiarization, the participants sat 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. With their elbow at an angle of 90º flexion, and their wrist joint 20 cm above the table surface, the participants were instructed to hold their Baseline Weight in an isometric contraction for as long as they could (Fig. 1). A Samsung Galaxy Gear (see footnote 1) head mounted VR was placed on the participants' head, where they saw their virtual body sitting on a virtual chair in a neutral room. In the virtual room, there was a virtual table with a yoga mat on it, imitating the real environment. The participant's hand held the weight in the 90º position in VR (Fig. 2). No other elements were added to the virtual room since different environmental factors may distract the participant. The VR was connected with a Microsoft band, so as to record the movement of the participant's hand. Once the participant were familiarized with the Virtual Environment (VE), we then placed the dumbbell in the participant's hand and asked him/her to lift it and keep his/her hand in the isometric position. The participants did not see the real weight before VR experience.

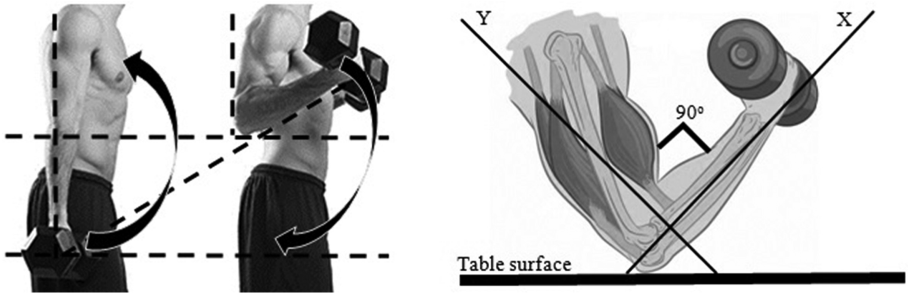

Fig. 1. To the left: Bicep curl 180º-full flexion-180º. To the right: Bicep curl Isometric Position.

Apparatus. The VR system was developed using Unity3D 5 to work with Samsung Gear VR and Samsung Galaxy S6 phone. The 3D models (human upper body, the virtual room and barbells) (Fig. 2) were created in Maya version 2016. The system we developed allows the researchers to customize the VR scenarios, including the gender of the human body, dominant hand, skin colors, colors of the t-shirt, and the weights of the barbells. In order to create a sense of embodiment, we used Microsoft Band's

Fig. 2. Human 3D model – user's perception.

gyroscope[2] to animate the virtual arm, reflecting the movement of participant's arm (rotation X and Y).

During the VR familiarization exercise, the following data were collected:

- Heart Rate (HR), was recorded continuously with a telemetric device (Polar Electro, N2965, Finland). Heart Rate is a continuous physiological signal, which allows us to record physiological changes and correlations between exercise intensity. It is an objective measurement, recommended to ensure an inclusive approach whilst conducting clinical pain experiments [24, 25].
- Time to Exhaustion (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 induced pain task [26–28]. A time to exhaustion task, together with parallel measures of exercise-induced pain (EIP) has been previously used to assess the effect of EIP of exercise performance [29].
- Pain Intensity (PIR), was assessed during the exercise task using the 1-10 Cook Scale [30]. Participants' perceived pain was reported for every minute during the exercise task.
- Rating of Perceived Exertion (RPE), was assessed during the exercise task using the 6-20 Scale [31]. Participants' perception of effort (defined as the sensation of how hard they are driving their arm in order to maintain the muscle contraction) was recorded for every minute elapsed during the exercise task.

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

After the familiarization session, a questionnaire was given to the participants in order to rate their sense of Presence in the VR (e.g. in the computer generated world, I had the sense of "being there"), the sense of Hand Ownership (e.g. I had the feeling that the hand in the VR glasses is my hand; It felt like I was looking directly at my hand rather than at a fake hand; It felt like the hand I was looking at was my hand), their Comfort (e.g. how comfortable did you find the set up (lift the weight) through the VR glasses) and Motivation (e.g. could you imagine motivating yourself to use the VR glasses to exercise everyday for 10 min). Participants rated their statements on a 7-point Likert scale anchored "Not at all" and "Very much".

Phase 2. In the second, third and fourth day, the participant 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 familiarization session. However, in the two other sessions, we modified the VR visual feedback, unbeknownst to the participants. Specifically, the visual weight as presented in the VR, understated or overstated the real weight by 50% more or less than the control session (Fig. 3). 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 reduce the changes of the order of the sessions adversely influencing the results. At the end of the experiment, we asked if the participant was able to identify a difference between the three sessions, and if they were what the difference was.

Fig. 3. The depicted images represent the three sessions in this order: Understated – Control – Overstated.

The same data (pain related and VR related measurements) were collected during all the sessions.

3 Results

3.1 Pain Measurements

Heart Rate (HR). To investigate whether there was a difference between the participants overall mean HR in the three sessions, an ANOVA with repeated measures followed by Bonferroni post hoc test was conducted. The analysis revealed a significant difference between HR during the three sessions ($F = 14.73$, $df = 2, 58$, $p < .001$). Post hoc tests using the Bonferroni correction revealed that there was a significant

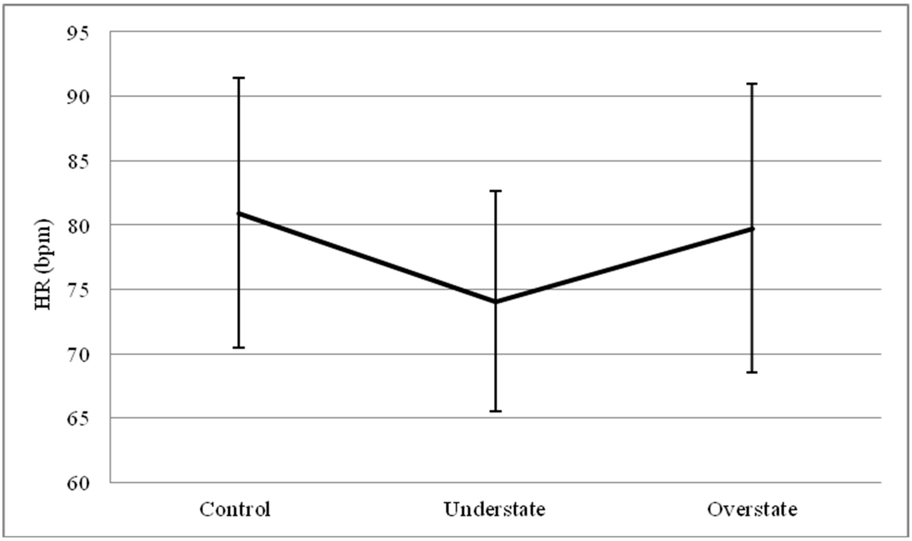

Fig. 4. Mean HR during the three sessions.

difference between the mean HR in the Understate session (M = 74.07, SD = 8.58), and the Control session (M = 80.93, SD = 10.50). There was also a significant difference between the Understate (M = 74.07, SD = 8.58) and the Overstate session (M = 79.73, SD = 11.21) (Fig. 4).

Additional analysis was conducted to investigate whether there was a difference between the participants HR in the three sessions based on the ISO time (ISOtime = 3 min), which is the shortest time to exhaustion across all subjects in all conditions.

The analysis showed a significant difference for the HR during the three sessions at the first three minutes (ISO time) ($F = 15.37$, $df = 2, 58$, $p < .001$). Post-hoc paired comparisons with Bonferroni corrections indicated that the mean HR in the understate session (M = 72.29, SD = 3.04) was significantly lower in comparison to control (M = 79.34, SD = 2.00) and overstate (M = 77.97, SD = 2.22) sessions.

There was also a significant difference for the HR and the ISOtime ($F = 15.89$, $df = 1.47, 42.70$, $p < .001$ with Greenhouse-Geisser correction). Post hoc tests using the Bonferroni correction revealed that there was a significant difference between the first (M = 75.24, SD = 11.81), and the third (M = 77.84, SD = 10.61) minute. There was also a significant difference between the second (M = 76.51, SD = 10.87) and the third (M = 77.84, SD = 10.61) minute.

Time to Exhaustion (TTE). To investigate whether there was a difference between the 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 ($F = 23.50$, $df = 1.60, 46.33$, $p = .000$ with Greenhouse-Geisser correction). Post-hoc paired comparisons with Bonferroni corrections indicated that the mean TTE in the understate 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 understate session, the minimum time to exhaustion a participant lasted was 3.29 min and the maximum was 13.21 min. The minimum time to exhaustion for the control session was 2.59 min and the maximum was 8.11 min, similarly, during the overstate session the minimum time to exhaustion was 3.03 min and the maximum was 7.50 min.

Pain Intensity (PIR). To investigate whether there was a difference between the Pain Intensity reported by the participants in the three sessions for the 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 Pain Intensity during the three sessions for the first three minutes (F = 9.45, df = 2.65, 76.73, p = .000 with Greenhouse-Geisser correction). Post-hoc paired comparisons with Bonferroni corrections indicated that the mean Pain Intensity in the understate session at each minute (Mmin1 = .65, SD = .93), (Mmin2 = 1.78, SD = 1.84), (Mmin3 = 3.30, SD = 2.18) was significantly lower than the control (Mmin1 = 1.23, SD = .88), (Mmin2 = 2.93, SD = 1.70), (Mmin3 = 4.92, SD = 2.30) and the overstate conditions (Mmin1 = 1.48, SD = 0.98), (Mmin2 = 3.40, SD = 1.49), (Mmin3 = 5.48, SD = 2.17) sessions (Fig. 5).

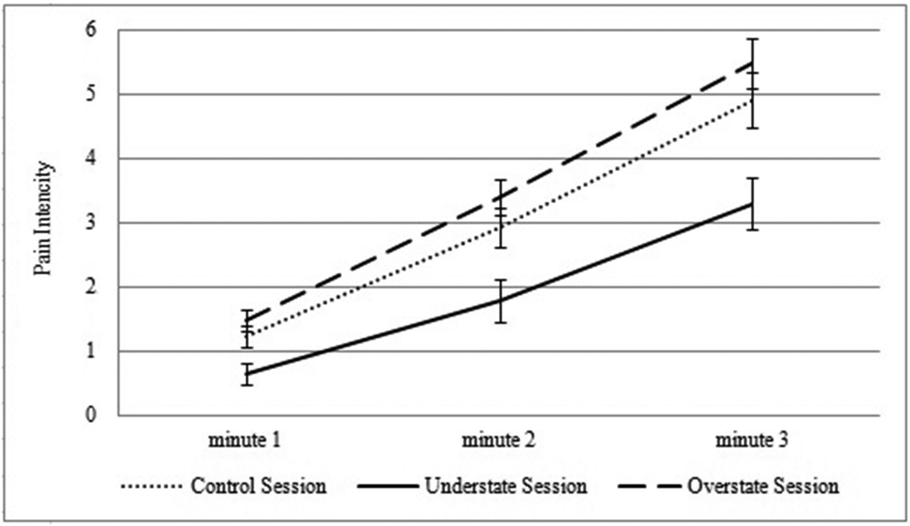

Fig. 5. Mean Pain Intensity rates for three sessions, for each ISO minute.

Rating of Perceived Exertion (RPE). To investigate whether there was a difference between the Rating of Perceived Exertion (RPE) reported by the participants in the three sessions for ISO time (ISOtime = 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 = 4.56,

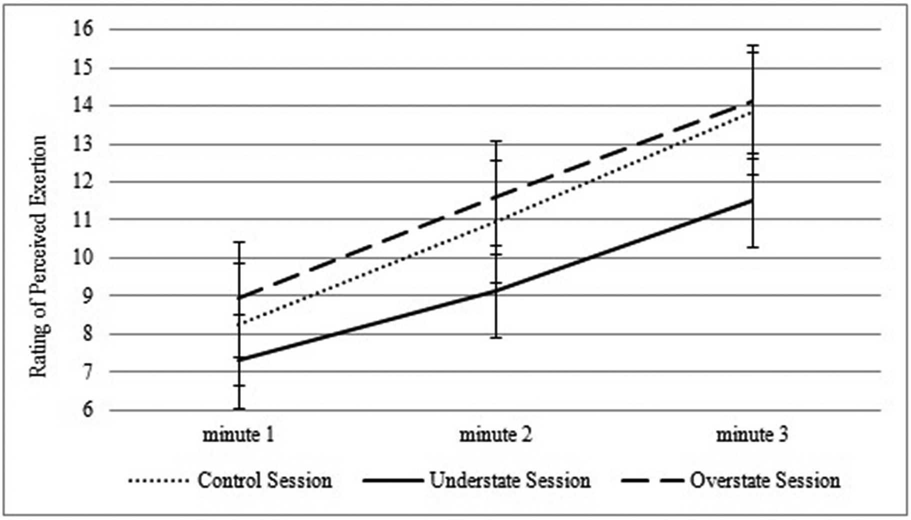

Fig. 6. Mean number of Rating of Perceived Exertion for three sessions, for each ISO minute.

df = 4, 116, p < .005). Post-hoc paired comparisons with Bonferroni corrections indicated that the mean RPE in the understate session at each minute point was (Mmin1 = 7.30, SD = 1.70), (Mmin2 = 9.13, SD = 2.66), (Mmin3 = 11.53, SD = 2.76) significantly lower than the control (Mmin1 = 8.27, SD = 1.66), (Mmin2 = 10.97, SD = 2.40), (Mmin3 = 13.83, SD = 2.63) and the overstated (Mmin1 = 8.93, SD = 1.93), (Mmin2 = 11.60, SD = 2.51), (Mmin3 = 14.13, SD = 2.66) session (Fig. 6).

3.2 Virtual Reality (VR)

Overall, our participants reported high rates of Immersion (> 3.5). Based on their rating, our VR application produced a high degree of Presence, Hand Ownership and Comfort. In addition, most participants reported that the VR application motivated them positively.

Presence. In both phases, participants reported high levels of presence. However, participants reported slightly higher levels of presence during phase 1 (M = 5.27, SD = 1.57) than phase 2 (M = 5.20, SD = 1.67).

Hand Ownership. In both phases, participants reported moderate to high levels of hand ownership. However, participants reported slightly higher levels of hand ownership during phase 2 (M = 4.22, SD = 1.61) than during phase 1 (M = 4.13, SD = 1.12).

Ratings of Comfort. In both phases, participants reported high levels of comfort. However, participants reported slightly higher levels of comfort during phase 2 (M = 6.13, SD = 1.96) than during phase 1 (M = 5.80, SD = 1.58).

Ratings on Motivation. Finally, in both phases, participants reported high levels of motivation. However, participants reported slightly higher levels of motivation during phase 2 ($M = 5.30$, $SD = 1.93$) than during phase 1 ($M = 5.13$, $SD = 2.11$).

Awareness of Visual Feedback Modification. Six out of 30 participants reported that they were aware of the visual feedback modification (e.g. they knew the physical weight was the same in all three conditions in phase 2), which was a significant part of our sample ($t\ (29) = 24.23$, $p < 0.001$). A paired sample t test was used to compare the difference between TTE of individuals who identified the modification and individuals who failed to identified it. Our results showed significant differences on TTE between the individuals who identified the visual feedback modification and the one who didn't. Specifically, significant results were reported during understate ($t\ (28) = 1.39$, $p < 0.05$), control ($t\ (28) = 1.39$, $p < 0.005$) and overstate ($t\ (28) = 1.35$, $p < 0.005$) sessions (Table 1).

Table 1. Mean RPE for the three sessions, based on the identification of the visual feedback modification.

	Mean time (min): Control session	Mean time (min): Understate session	Mean time (min): Overstate session
Identified the visual feedback modification	06:59	09:23	07:07
Didn't identified the visual feedback modification	05:28	07:21	05:27

4 Discussion and Future Research

4.1 Discussion

The use of VR technology to influence individual perception is a relatively new approach to acute pain management. In our study, we found that VR through Altered Visual Feedback strategy (AVF) interventions appeared to be very effective for this sample of 24 to 45 year old adults of both genders.

H2 is accepted since the results demonstrated a significant increase in Time to Exhaustion (TTE) during the VR understate session in contrast to the control and overstate sessions. Overall our participants lasted approximately two minutes longer during the understate session in contrast to the control and overstate sessions. Interestingly, during the understate session the maximum time to exhaustion was 13.21 min which is in great contrast to the control and the overstate sessions, with an approximately five minute difference. Previous research found that mental and material representations could shape the neural processes that result in an actual painful sensory experience [3–5]. Therefore, in our study, we moderated the expectation of the participant by understating the visual feedback by 50%. This moderation might have affected the subsequent pain perception caused by the exercise task. As a result, the participant perceived less pain and therefore exercised for longer.

The effectiveness of VR and AVF was further highlighted by the lower HR during the understate session. Our findings suggested that there was a significant difference, which indicates that during the whole understate session the participants' heart rate was significantly lower by 5-7 bpm, than during the control and overstate session. As explained above, HR is an objective measurement of a continuous physiological signal, which has been used in the assessment of clinical pain experiments [2, 25]. HR allows us to record physiological changes and correlations between exercise intensity. With this in mind and based on evidence that individuals initially apply force to lift an object based on the visual material properties [6, 7], we believe that the perception of exercise difficulty during the understate session was modulated by the visual material properties. Therefore, the mental representation of Pain Intensity might shape the physiological response, by decreasing the participant's HR, likely in an anticipatory manner.

H3 is accepted since the findings are further supported by the fact that VR AVF led to a significant decrease in participant rates of Pain Intensity. Interestingly, during the understate session, the mean Pain Intensity reported by our in the first minute was approximately 50% lower than the mean Pain Intensity during the control and overstate sessions. Even though during the following minutes, there was a modest decrease between the differences of Pain Intensity rates in the three sessions, there were still significant differences. In addition to previous studies [23], our findings suggest that the participant not only lasted longer during the understate session but also felt and reported lower rates of pain during the understate session.

Similarly, *H1* is accepted since there was a significant decrease in participants' rating of perceived exertion (RPE) during the understate session in regards to the control and overstate sessions. Participants' sensation of how hard they were driving their arm in order to maintain the muscle contraction was considerably lower during the understate session.

A particularly promising result was that even though some of our participants were able to identify feedback modification, there was still a positive effect of the VR AVF on the participants. During the understate sessions, the participants who knew that the visual feedback modified still lasted approximately two minutes longer than the control and the overstate sessions. This result highlights the effectiveness of VR AVF and the potential applications it has for use in home based training sessions.

These results support the assumption made in [14] that low-cost VR HMD with AVF strategy has the potential to be used in exercises to reduce pain. Although the current study was carried out with healthy participants, a fruitful future research direction will be to explore its use in pain management in healthcare settings. Due to the low cost nature, it is practical to carry out this type of intervention at home. We therefore further hypothesize that this will lead to the improvement of health care and pain management, since individuals will be able to manage pain and improve their physical activity on a daily basis.

The overall findings of this study are consistent with other studies in the literature [21, 23], which suggest that VR AVF is an effective tool for pain management and rehabilitation. However, the magnitude of effects in the current study exceeds those of other studies. To the best of our knowledge, this study is the only one of its kind to find significant improvements due to VR AVF in all of the aforementioned indices of the pain experience within a single sample.

The results of this study provide further evidence that AVF technique with VR technology can play a significant role in the improvement of pain management. In particular, our findings show the positive consequences of being able to offset pain perception during exercise. Overall, our results suggest that VR AVF can increase TTE and decrease HR, Pain Intensity and RPE. This results in individuals having an increased willingness to continue exercise for a longer period of time. Therefore, VR has to potential to reduce EIP, and thus presents opportunities to use VR to increase physical activity. In addition, our participants reported high rates of motivation and willingness to carry on with more exercise sessions with the VR headset.

4.2 Future Research and Conclusions

A key motivation for the current study is the potential use of the VR application in home based training sessions in order to improve frequency of physical activity and minimize the perceived pain and/or exertion. Therefore, there is need for future research of home VR training in order to examine the long-term effectiveness, user experience and motivation of the VR AVF. In addition, there is a need to examine its effectiveness in an uncontrolled home based environment.

Overall, our study showed that our VR application supports VR's analgesic effectiveness, even when the participant was aware of the visual feedback modification. However, there is a need for further research to ensure that the effect can still be observed in home based training sessions. Our study also revealed high rates of motivation for using the VR application, although further research is needed to investigate the sustainability of user's motivation over a longer period of time.

In addition, the present results support the notion that minimizing the virtual weight presented through the VR systems will help maximize the duration of the training sessions and minimize the pain. Additional work in the field should examine how changes in the actual weight when the visual feedback is kept constant will affect participants performance and pain perception. Also, more work is needed to explore other elements and features that might enhance and maximize the VR AVF pain management effect in medium to long-term use. We believe that future research could focus on the following areas:

Natural Environments: A pleasant nature scene may decrease pain perception and stress by causing positive emotional responses. There is some evidence to suggest that viewing nature can aid recovery from stress and that blood pressure tends to decline within a few minutes of viewing unspectacular nature [32–36]. Therefore, we suggest enhancing the positive effect of AVF with elements that contain natural environments and pleasant natural sounds (e.g., birds singing).

Single Game Distraction: The effectiveness of VR distraction as a strategy is well established in the literature [16–20, 26–28]. Therefore, we suggest enhancing the AVF with a simple game distraction task. For example, in the existing neutral virtual room with the understate weight condition, a jumping ball can be added and the participant will be required to count the number of jumps. Based on distraction mechanism and selective attention theory [37], we hypothesize that this might enhance the induced analgesia.

Advance Ice-features Distraction: Several studies that went beyond the line of single distraction strategy incorporated ice-features in the Virtual Environment (VE) (e.g., Icy 3D Canyon, SnowWorld) [17–19, 38, 39]. As a result, these VRs with Snow-VE provided an illusion of a "cooling" effect by having the participants look at the snowy environment. This VE provides the user with a complimentary useful feature on distraction strategy, as it is creating a "virtual cooling sensation". Functional magnetic resonance imaging (fMRI) demonstrated a great reduction in participants' pain-related brain activity, while they were using SnowWorld game during thermal experiment [40, 41]. We believe that ice-features could be useful prior to exercise in the heat, as pre-cooling in advance of the exercise would be of benefit to the exercise performance and capacity.

Social interaction: As aforementioned, the VR has the potential to produce applications for clinical populations at home. In many cases, due to their conditions, patients become homebound for a long period of time and hence lack social interactions. Therefore, we believe that it may be beneficial to have a VR that will allow the patient to carry out daily exercises along with other people and interact with them virtually.

In conclusion, our study provided promising results in the use of a low cost VR system as an effective solution for reducing perceived pain in resistance exercise among a healthy population. This opens up research possibilities to investigate other VR design strategies, which will ultimately allow people to use the technology reliably at home. Crucially, we would like to extend this work to include patient groups who could benefit from engaging in an effective VR-based rehabilitation in the home environment.

References

1. Merskey, H., Bogduk, N.: Classification of Chronic Pain, IASP Task Force on Taxonomy. International Association for the Study of Pain Press, Seattle (1994), www.iasp-painorg
2. Mauger, A.R.: Factors affecting the regulation of pacing: current perspectives. Open Access J. Sports Med. **5**, 209–214 (2014)
3. Atlas, L.Y., Wager, T.D.: How expectations shape pain. Neurosci. Lett. **520**(2), 140–148 (2012)
4. Atlas, L.Y., Bolger, N., Lindquist, M.A., Wager, T.D.: Brain mediators of predictive cue effects on perceived pain. J. Neurosci. **30**(39), 12964–12977 (2010)
5. Koyama, T., McHaffie, J.G., Laurienti, P.J., Coghill, R.C.: The subjective experience of pain: where expectations become reality. Proc. Natl. Acad. Sci. U.S.A. **102**(36), 12950–12955 (2005)
6. Adelson, E.H.: On seeing stuff: the perception of materials by humans and machines. In: Photonics West 2001-Electronic Imaging, pp. 1–12. International Society for Optics and Photonics, June 2001
7. Johansson, R.S., Westling, G.: Coordinated isometric muscle commands adequately and erroneously programmed for the weight during lifting task with precision grip. Exp. Brain Res. **71**(1), 59–71 (1988)
8. Gordon, A.M., Westling, G., Cole, K.J., Johansson, R.S.: Memory representations underlying motor commands used during manipulation of common and novel objects. J. Neurophysiol. **69**(6), 1789–1796 (1993)

9. Seashore, C.E.: Some psychological statistics. 2. The material-weight illusion. Univ. Iowa Stud. Psychol. **2**, 36–46 (1899)
10. Li, A., Montaño, Z., Chen, V.J., Gold, J.I.: Virtual reality and pain management: current trends and future directions. Pain Manage. **1**(2), 147–157 (2011)
11. Morris, L.D., Louw, Q.A., Grimmer-Somers, K.: The effectiveness of virtual reality on reducing pain and anxiety in burn injury patients: a systematic review. Clin. J. Pain **25**(9), 815–826 (2009)
12. Riva, G.: Virtual reality in psychotherapy: review. Cyberpsychology & Behav. **8**(3), 220–230 (2005)
13. Rothbaum, B.O., Hodges, L., Kooper, R.: Virtual reality exposure therapy. J. Psychother. Pract. Res. (1997)
14. Matsangidou, M., Ang, C.S., Sakel, M.: Clinical utility of virtual reality in pain management: a comprehensive research review from 2009 to 2016. Br. J. Neurosci. Nurs. (2017)
15. Hoffman, H.G., Seibel, E.J., Richards, T.L., Furness, T.A., Patterson, D.R., Sharar, S.R.: Virtual reality helmet display quality influences the magnitude of virtual reality analgesia. J. Pain **7**(11), 843–850 (2006)
16. Czub, M., Piskorz, J.: How body movement influences virtual reality analgesia? In: 2014 International Conference on Interactive Technologies and Games (iTAG), pp. 13–19 (2014). ieeexplore.ieee.org
17. Hoffman, H.G., Meyer III, W.J., Ramirez, M., Roberts, L., Seibel, E.J., Atzori, B., Patterson, D.R.: Feasibility of articulated arm mounted oculus rift virtual reality goggles for adjunctive pain control during occupational therapy in pediatric burn patients. Cyberpsychology Behav. Soc. Networking **17**(6), 397–401 (2014)
18. Maani, C.V., Hoffman, H.G., Morrow, M., Maiers, A., Gaylord, K., McGhee, L.L., DeSocio, P.A.: Virtual reality pain control during burn wound debridement of combat-related burn injuries using robot-like arm mounted VR goggles. J. Trauma **71**(1), 125–130 (2011)
19. Markus, L.A., Willems, K.E., Maruna, C.C., Schmitz, C.L., Pellino, T.A., Wish, J.R., Schurr, M.J.: Virtual reality: feasibility of implementation in a regional burn center. Burns: J. Int. Soc. Burn Injuries **35**(7), 967–969 (2009)
20. Wender, R., Hoffman, H.G., Hunner, H.H., Seibel, E.J., Patterson, D.R., Sharar, S.R.: Interactivity influences the magnitude of virtual reality analgesia. J. Cyber Ther. Rehabil. **2** (1), 27–33 (2009)
21. Bolte, B., de Lussanet, M., Lappe, M.: Virtual reality system for the enhancement of mobility in patients with chronic back pain. In: Proceedings of the 10th International Conference Disability, Virtual Reality & Associated Technologies (2014)
22. Chen, K.B., Ponto, K., Sesto, M.E., Radwin, R.G.: Influence of altered visual feedback on neck movement for a virtual reality rehabilitative system. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 58(1), pp. 693–697. SAGE Publications, September 2014
23. Harvie, D.S., Broecker, M., Smith, R.T., Meulders, A., Madden, V.J., Moseley, G.L.: Bogus visual feedback alters onset of movement-evoked pain in people with neck pain. Psychol. Sci. **26**(4), 385–392 (2015)
24. McGrath, P.J., Walco, G.A., Turk, D.C., Dworkin, R.H., Brown, M.T., Davidson, K., Hertz, S.H.: Core outcome domains and measures for pediatric acute and chronic/recurrent pain clinical trials: PedIMMPACT recommendations. J. Pain **9**(9), 771–783 (2008)
25. von Baeyer, C.L., Spagrud, L.J.: Systematic review of observational (behavioral) measures of pain for children and adolescents aged 3 to 18 years. Pain **127**(1), 140–150 (2007)

26. Dahlquist, L.M., Herbert, L.J., Weiss, K.E., Jimeno, M.: Virtual-reality distraction and cold-pressor pain tolerance: does avatar point of view matter? Cyberpsychology Behav. Soc. Networking **13**(5), 587–591 (2010)
27. Dahlquist, L.M., Weiss, K.E., Clendaniel, L.D., Law, E.F., Ackerman, C.S., McKenna, K. D.: Effects of videogame distraction using a virtual reality type head-mounted display helmet on cold pressor pain in children. J. Pediatr. Psychol. **34**(5), 574–584 (2009)
28. Sil, S., Dahlquist, L.M., Thompson, C., Hahn, A., Herbert, L., Wohlheiter, K., Horn, S.: The effects of coping style on virtual reality enhanced videogame distraction in children undergoing cold pressor pain. J. Behav. Med. **37**(1), 156–165 (2014)
29. Astokorki, A.H., Mauger, A.R.: Tolerance of exercise-induced pain at a fixed rating of perceived exertion predicts time trial cycling performance. Scand. J. Med. Sci. Sports (2016), doi:10.1111/sms.12659
30. Cook, D.B., O'Connor, P.J., Eubanks, S.A., Smith, J.C., Lee, M.I.N.G.: Naturally occurring muscle pain during exercise: assessment and experimental evidence. Med. Sci. Sports Exerc. **29**(8), 999–1012 (1997)
31. Borg, G.: Borg's perceived exertion and pain scales. Hum. Kinet. (1998)
32. Altman, I., Wohlwill, J.F. (eds.): Behavior and the Natural Environment, vol. 6. Springer Science & Business Media (2012)
33. Maller, C., Townsend, M., Pryor, A., Brown, P., St Leger, L.: Healthy nature healthy people: 'contact with nature' as an upstream health promotion intervention for populations. Health Promot. Int. **21**(1), 45–54 (2006)
34. Pretty, J., Peacock, J., Sellens, M., Griffin, M.: The mental and physical health outcomes of green exercise. Int. J. Environ. Health Res. **15**(5), 319–337 (2005)
35. Ulrich, R.S.: Effects of interior design on wellness: theory and recent scientific research. J. Health Care Inter. Des. **3**(1), 97–109 (1991)
36. Ulrich, R.S., Simons, R.F., Losito, B.D., Fiorito, E., Miles, M.A., Zelson, M.: Stress recovery during exposure to natural and urban environments. J. Environ. Psychol. **11**(3), 201–230 (1991)
37. Chabris, C.F., Simons, D.J.: The Invisible Gorilla: Thinking Clearly in a World of Illusions. HarperCollinsPublishers (2010)
38. Carrougher, G.J., Hoffman, H.G., Nakamura, D., Lezotte, D., Soltani, M., Leahy, L., Patterson, D.R.: The effect of virtual reality on pain and range of motion in adults with burn injuries. J. Burn Care Res. Official Publ. Am. Burn Assoc. **30**(5), 785–791 (2009)
39. Schmitt, Y.S., Hoffman, H.G., Blough, D.K., Patterson, D.R., Jensen, M.P., Soltani, M., Sharar, S.R.: A randomized, controlled trial of immersive virtual reality analgesia, during physical therapy for pediatric burns. Burns: J. Int. Soc. Burn Injuries **37**(1), 61–68 (2011)
40. Hoffman, H.G., Richards, T.L., Coda, B., Bills, A.R., Blough, D., Richards, A.L., Sharar, S. R.: Modulation of thermal pain-related brain activity with virtual reality: evidence from fMRI. NeuroReport **15**(8), 1245–1248 (2004)
41. Hoffman, H.G., Richards, T.L., Van Oostrom, T., Coda, B.A., Jensen, M.P., Blough, D.K., Sharar, S.R.: The analgesic effects of opioids and immersive virtual reality distraction: evidence from subjective and functional brain imaging assessments. Anesth. Analg. **105**(6), 1776–1783 (2007)