The effects of a virtual stimulus on the 20-minute time-trial performance of trained, male cyclists

Nicole Evans

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Department of Health, Sport and Exercise Sciences

School of Health Sciences

Waterford Institute of Technology

Statement of originality and ownership of work

Department of Health, Sport and Exercise and Science
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I confirm that all the work submitted in this project is my own work, not copied from any other person's work (published or unpublished) and that it has not previously been submitted for assessment on any other course, in any other institution.

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Abstract

Overview

The objectives of this study were to examine the effects of Zwift, a virtual reality (VR) training software for cycling on the twenty-minute time-trial (TT) performance of trained, male cyclists. At present, no research has been carried out on the effects of VR on the performance of trained cyclists.

The four research questions underpinning this study consist of:

1.Will the virtual stimulus affect the athlete's mean power, maximal power or power variability index when compared to completing an indoor twenty-minute time trial without an additional stimulus or feedback?

2. Will the virtual stimulus affect the athlete's rate of perceived exertion (RPE) when compared to completing an indoor twenty-minute time trial without an additional stimulus or feedback?

3. Will the virtual stimulus affect the athlete's heart rate and blood lactate levels when compared to completing an indoor twenty-minute time trial without an additional stimulus or feedback?

4. Is there a relationship between level of immersion, presence and performance increases experienced during the VR trials?

Study Design

Seven trained males (n=7) participated in the study. The participants were competitive, road cyclists currently ranked category one or two according to Cycling Ireland's rider ranking criteria. A randomised control trial design was implemented for this study. The VR group (n=4) and the control (n=3) both completed two, twenty-minute TT's spaced one week apart. The first set of TTs were to establish base line figures to compare the control and VR-stimulus trials against. The VR stimulus was introduced during the second TT for the VR group.

Results

The results of this study indicated a significant increase in the five-minute RPE reading in the VR group. The R-value also indicated a strong linear relationship between sense of

presence within the virtual environment and mean power increase for the VR group. No other significant differences were found between the VR group and Control group on comparison of TT1 and TT2.

Conclusions

The potential effects of the VR software were decreased as the participants progressed from an external, dissociative attentional style to an internal, associative attentional style as the intensity and physical demands of exercise increased with the progression of the TT. More research is needed to assess the potential of the VR stimulus stimulating a greater effect while cycling at a moderate or low intensity.

1. Introduction

The focus of this study is to research the effects of a virtual stimulus on the twenty-minute time trial (TT) performance of trained cyclists. Virtual reality (VR) software or immersive multi-media consists of an artificially simulated environment that a user can interact with in a realistic manner (Carlin et al., 1996). VR cycling software is becoming increasingly popular; it provides users with an alternative to standard stationary trainer workouts and an ability to take part in training and competition with other users indoors when training outside may not be appropriate (Batista et al., 2008). A benefit of VR is that allows users to virtually complete a segment of road or track anywhere in the world from their own home. This is a useful training tool when preparing for international competitions to mimic race conditions in training (Lev & Katz, 2007).

Zwift is an online gaming platform for cyclists which allows users to compete against other online users in a virtual setting. Triplett's (1898) coaction effect revealed that a performance increase appears with the presence of others completing the same task. Similarly, Dashiell (1935) found that subjects performed better with an audience than when completing a task alone. Drawing on both theories, the introduction of a virtual audience and other users completing the same task will stimulate a similar performance increase that occurred in both studies if a high level of presence can be achieved within the virtual environment. Sense of presence has been shown to limit the effectiveness of a VR software and therefore limits the potential benefits of using VR software as a mechanism to improve cycling performance (Nichols et al., 2000).

VR has been effective in reducing the perceived pain and physical discomfort of burn patients undergoing rehabilitation as an aid for dissociation (Hoffman et al., 2001). Physical discomfort experienced during maximal intensity exercise is a limiter to cycling time-trial (TT) performance (Whitehead et al., 2017). Through dissociation, VR will have the same effect of reducing perceived physical discomfort and pain in cycling as it has with patients undergoing rehabilitation sessions thus allowing the user to cycle for a longer duration or at a higher intensity. However, at present no research has been conducted which assesses the ability of VR software to influence the cycling performance of trained cyclists through the reduction of perceived discomfort and pain or other associated factors.

2. Psychological effects associated with the use of virtual reality

2.1 Nonpharmacological pain relief

VR has been shown to be an effective method of reducing pain in burn patients undergoing rehabilitation sessions and its analgesic effects have not been shown to decrease with exposure (Hoffman et al., 2000; Hoffman et al., 2001). The International Association for the Study of Pain's (IASP) (1994) definitions were used to define pain, pain tolerance and pain threshold for this study. The IASP (1994) defines pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage" and believe it is subjective to the person experiencing this pain. Drawing on this definition, Borg's (1998) rate of perceived exertion scale was used to measure the pain an individual was experiencing during this study as it is believed that perceived exercise induced pain will increase with perceived exertion. IASP (1994) define pain threshold as the least level of pain that an individual can recognise and pain tolerance as the highest level of pain that an individual is prepared to experience. These will be important factors for determining whether the virtual stimulus in this study affected the pain levels of the individuals tested when compared to the no-stimulus TT.

2.*2 Dissociation*

It is understood that athletes use dissociation as a psychological method to help and distract from pain and discomfort when exercising and the potential monotony of long training sessions (Schomer, 1987). This differs from the clinical definition of dissociation as athletes are capable of ceasing the dissociative state at will (Masters and Ogles, 1998). Aardema et al. (2010) found that participants that tested as having high levels of immersive tendencies were more likely to experience a higher level of dissociative symptoms when using VR software than users that tested lower in these areas. Schomer (1987) found that associative thinking increased the perceived rate of exertion in marathon runners while contrastingly dissociative thinking has been shown to increase time to exhaustion while exercising at a maximal intensity. Therefore, this allows the participant to increase their pain tolerance to a higher level than when they are using an internal focus (Gill and Strom, 1985). Rutter et al. (2009) found that VR as a method of distraction led to significant increases in pain tolerance and pain threshold levels amongst participants. Significant decreases in duration of time spent thinking about pain and a decrease of the intensity of the pain were also experienced. Similarly, Hoffman et al. (2001) and Rutter et al. (2009) found that the effectiveness of VR as a method dissociation and pain reduction did not decrease with exposure. This is vital to the use of VR as a method of improving cycling performance as it allows the athletes to continually experience a constant performance effect.

Hutchinson and Tenenbaum (2007) discovered that as exercise intensity increases to near maximal workloads, it becomes almost impossible to maintain a dissociative focus. This is caused by overwhelming physiological sensations of pain and discomfort which dominate attentional focus and lead to an internal associative focus. This limits the effectiveness of VR software at decreasing RPE when exercising at maximal workloads. However, external stimuli of music and video together has been shown to elicit decreases in RPE and allow a participant to remain in a dissociative state for longer when exercising at maximal intensities by further reducing the level of external stimulation the user is experiencing than when using video alone (Razon et al., 2009; Chow & Etnier, 2017). VR as a method of distraction and dissociation affects the pain perception of individuals by introducing competition for attentional focus and by reducing the level of external stimulation the user is experiencing associated with the painful stimulus and real-world environment (Wismeijer & Vingerhoets, 2005).

3. Sense of presence and the effectiveness of virtual environments

3.1 Sense of presence

Presence can be defined as the subjective experience of feeling like you are in an environment, even if you are physically situated in a different environment (Witmer & Singer, 1998). The ability for a user to experience presence within an environment is an important factor in determining the quality and effectiveness of a VR software (Slater et al., 1996). There is currently no standard measurement for determining sense of presence within a virtual environment. Nichols et al. (2000) and Held and Durlach (1992) suggested that sense of presence could be determined by the participant acting reflexively to a stimulus within the virtual environment, such as ducking in response to a simulated projectile moving towards them. In the context of this study sense of presence could be determined by the reaction of a participant to other riders and environmental changes. If a participant accelerates in response to a visual of a rider in front of them or in response to a simulated decline it is understood that their level of presence within the environment is reasonably high.

The higher the level of presence achieved, the more likely a participant is to behave in real world way within a virtual environment (Kober & Neuper, 2013). A widely used measurement of presence for VR are self-reported questionnaires. Witmer and Singer (1998) developed a presence questionnaire based on four underlying factors of presence: Control Factors, Sensory Factors, Distraction Factors and Realism Factors. It is believed that these factors interact with each other and directly influence presence by their effect on involvement, immersion or both within the virtual environment (Witmer & Singer, 1998). Contrastingly, Slater (1999) believed three factors underpinned the experience of presence: the sense of being in the virtual environment, the extent to which the virtual environment becomes the dominant environment experienced by the user and the level to which the virtual environment is remembered as a place. This research lead to the development of the Slater-Usoh-Steed questionnaire which also measures experience of presence (Usoh et al., 2000). The Slater-Usoh-Steed questionnaire is significantly briefer than Witmer and Singer’s (1998) presence questionnaire with seven and thirty-two questions respectively. The Slater-Usoh-Steed questionnaire also gathers both qualitative and quantitative information from the participant which may provide a more conclusive description of the participants level of presence experienced than Witmer and Singer’s questionnaire which is solely quantitative. Both questionnaires are reasonable measures of presence within a virtual environment and the appropriateness of each may vary depending on the nature of the research and the researcher’s definition of presence and its underlying factors. Usoh et al. (2000) found that utilising presence questionnaires to assess experiences is only an effective measure if the virtual environment is consistent for each participant. Their ability to examine and compare experiences in varying environments is doubtful.

The level of presence a user can experience has been shown to be affected by both external factors as well individual internal factors and personality traits (Riva et al., 2003). External factors which influence presence are technology related factors. These factors include screen size, VR viewing device, display, technical faults, lag and stereoscopy (Kober and Neuper, 2012). Exercise and exercising at varying intensities has also been shown to effect presence in virtual environments (Vogt et al., 2015; Huang et al., 2008). Personality factors influencing presence relate to imagination, absorption, immersive tendencies, locus of control and the Big Five personality traits: Agreeableness, Conscientiousness, Openness, Extraversion and Neuroticism (Kober and Neuper, 2012). Alsina-Jurnet and Gutiérrez-Maldonado (2010) discovered that users of VR with high spatial intelligence and an introverted personality type are more likely to experience higher levels of presence within virtual environments. Witmer and Singer (1998) developed an immersive tendencies questionnaire to assess the susceptibility of a user to experience presence within a virtual environment. Users that test as having higher immersive tendencies are more likely to become immersed in the virtual environment and therefore will experience a higher level of presence. In the context of this study, the relationship between athletes with higher immersive tendencies and their sense of presence within the virtual environment will be further examined.

There is an optimal level of VR exposure in eliciting high levels of sense of presence. Higher levels of VR exposure especially when combined with the sensory demands of exercising can induce feelings of motion sickness in some individuals. Witmer and Singer (1998) showed that participants that displayed symptoms of motion sickness while exercising under VR conditions also reported feeling a lower sense of presence. Vogt et al. (2015) found that exercising moderately under high VR exposure conditions such as that produced by an immersion square system led to increased discomfort and a decrease in motivation relevant to the increasing levels of VR exposure. These factors occurred due to the cortical arousal stimulated in the high VR exposure research group, producing motion-sickness like symptoms. Due to these symptoms users sense of presence within the virtual environment was reduced as they switched to an internal, associative attentional focus.

3.2 Motivation, adherence and enjoyment

Mestre et al. (2011) found that while VR visual imagery stimulated dissociation in participants while exercising, the addition of music to the visual stimulus was required to maintain the participants long-term motivation and adherence to the task. Similarly, Jones et al. (2014) showed that exercising under music and video conditions increased exercise enjoyment in comparison to exercising with video or without any additional stimulus. VR games have been shown to positively influence exercise enjoyment levels and subsequently increase exercise motivation for both children and adults (Finkenstein & Suma, 2011; Finkenstein et al., 2013).

It is understood that most people find natural environments preferable and more restorative than urban environments (Wilkie and Stavridou, 2013). Zwift aims to replicate the more enjoyable outdoor conditions and its restorative nature indoors, leading to greater exercise enjoyment and satisfaction. Higher levels of exercise enjoyment experienced while using VR software promotes exercise adherence (Rhodes et al., 2009). Exercise adherence is especially promoted in virtual environments that involve competition (Finkenstein et al., 2013).

4. The effects of virtual reality on athletic performance

4.1 Virtual training partners

Triplett's (1898) revealed that participant's performance levels increase when another individual is present and completing a similar task. This coaction effect would lead to significant long-term improvements in the performance of an athlete due to increased physiological adaptions generated by performing more effectively during each training session. Similarly, Dashiell's (1935) theory of social facilitation found that subjects performed better with an audience than when completing a task alone when performing automated tasks such as in the case of elite sport. VR allows elite athletes to replicate these two conditions to further enhance their training. This is especially useful in individual sports such as cycling when a significant proportion of training is completed alone. This is further supported by research which demonstrates that participants experienced a significant performance increase in cycling TTs when a virtual rider was present (Jones et al, 2016). Jones et al. (2016) discovered that participants cycled faster when cycling against a virtual rider which represented 102% of their baseline cycling speed.

4.2 Reducing performance-induced anxiety

Visualisation is an effective tool used in sports psychology to assist an athlete in preparing for competition. Sorrentino et al. (2015) studied the effects of using VR software in visualisation training in Olympic athletes by virtually replicating their competition environment. The athletes reported that the VR software was a useful tool to assist them in visualising their performance and that it significantly lowered their competition related anxiety levels. Relaxing virtual environments have been shown to reduce anxiety by allowing participants to experience a calming environment which is more vivid and life-like than they can create using their own imagination (Gorini & Riva, 2008). This research indicates that VR could be used as a tool for managing pre-competition anxiety and arousal levels in athletes.

5. Summary and rationale

A significant number of factors influence the effectiveness of VR on stimulating a performance effect during exercise. These factors include immersive tendencies, sense of presence, VR exposure, exercise intensity, exercise duration, motion sickness, attentional focus, external set-up and software quality. VR software is likely to be more effective in populations with high immersive tendencies due to its relationship with sense of presence. VR is an effective tool in promoting exercise adherence and contributing to increased exercise motivation and enjoyment for both trained and untrained populations. It also offers benefits to populations under-going painful physical therapy or rehabilitation sessions due to its ability to create a dissociative, external attentional focus. There are many potential benefits for implementing VR software into training sessions for competitive athletes. These benefits include reducing pre-competition anxiety, assisting with visualisation, generating performance increases and lowering RPE and physical discomfort during high and moderate exercise intensities.

5.1 Rationale for research

At present, no could be found that assessed the effects of VR exposure on the performance of trained cyclists. Further research is also required to establish the most effective level of VR exposure to elicit increases in exercise performance and lower perceived exertion and discomfort. Greater clarification is needed on the effectiveness of VR as a tool for dissociation during maximal intensity exercise. Another area that requires further exploration is the effects of sense of presence in trained athletes when completing their origin sport within a virtual environment and how this relates to their immersive tendencies and performance.

The aim of this research study is to seek greater understanding as to whether moderate VR exposure could increase or decrease the TT performance of trained cyclists when compared to cycling indoors without any additional stimulus at a maximal intensity. This research also aims to further examine the relationship between level of immersion, sense of presence and performance. This research will assess the effectiveness of increasingly popular VR training software for home cycling, Zwift, on the maximal cycling performance of trained cyclists.

5.2 Research questions

The four main research questions underpinning this study are:

1. Will the virtual stimulus affect the athlete's mean power, maximal power or power variability index when compared to completing an indoor twenty-minute time trial without an additional stimulus or feedback?

2. Will the virtual stimulus affect the athlete's rate of perceived exertion when compared to completing an indoor twenty-minute time trial without an additional stimulus or feedback?

3. Will the virtual stimulus affect the athlete's heart rate and blood lactate levels when compared to completing an indoor twenty-minute time trial without an additional stimulus or feedback?

4. Is there a relationship between level of immersion, presence and a performance increases experienced during the VR trials?

6. Methodology

6.1 Conceptual framework

Seven trained cyclists (n=7) participated in the study. The participants were all male with a mean age (years) of 33.29 ± 7.06 years (VR=34.75 ± 6.7 years; Control=31.33 ± 8.5 years). The participant's mean weight (kg) was 80 ± 5.89kg (VR=81.43 ± 5.2kg; Control=78.1 ± 7.35kg). The participants consisted of competitive, road cyclists. Participants were chosen that met the following selection criteria: (i) The participants were male, (ii) They were cycling competitively for at least two years, (iii) They are currently ranked as a category one or two road cyclist and have been for a minimum of one year as per Cycling Ireland's point's criteria, (iv) They had not previously been exposed to any VR software such as Zwift or Trainer Road, (v) They showed no contraindications to exercise (Thomas et al., 1992).

These criteria were selected to identify a sample of trained, male cyclists that are healthy and have not previously been exposed to VR cycling software. Male subjects were solely chosen due to convenience. Previous research has indicated that task repetition may influence phase duration in the case of VR software and therefore participants were chosen that had not been previously exposed to any VR cycling software to ensure that familiarity with the course chosen for the TT did not influence their results (Mestre et al., 2011). The above data was collected through an online questionnaire to identify suitable participants for the study (Appendix B.) The questionnaire required participants to detail their cycling discipline, training history, level of interaction with VR cycling software, current road licence category along with their Cycling Ireland licence number so it could be verified and their familiarity with twenty-minute maximal efforts. The questionnaire was distributed to three local cycling clubs and displayed on online forums for competitive, Irish road cyclists. Twenty-four subjects completed the online questionnaire and from this eighteen fit the selection criteria and were chosen for testing. The physical activity readiness questionnaire was completed by each participant prior to the first TT taking place to ensure it was safe for the participant to complete high intensity exercise. Sixteen of the participants that were selected from the questionnaire completed the initial baseline time-trial (TT1). Of the sixteen participants that completed TT1, seven participants completed both TT1 and TT2 (n=7). Following TT1 the participants were sorted into two groups by random selection. The two groups were the VR group (n=4) and the Control group (n=3).

A randomised control trial design was implemented for this study to reduce bias within the two groups. The VR group and the Control both completed two, twenty-minute TTs spaced one week apart. TT1 was used to establish base line figures to compare the second Control and VR TT's (TT2) against. The participants were instructed to abstain from strenuous exercise and alcohol thirty-six hours prior to the TTs taking place and to abstain from caffeine or other stimulants six hours before all TTs. The participant's weight was taken before the beginning of the TT1. Prior to the baseline testing all participants completed the immersive tendencies questionnaire to assess their ability to become immersed in virtual environments (Witmer and Singer, 1998; Appendix C).

All participants were given ten-minutes to complete a self-selected warm-up on the smart-trainer. Following the warm-up, the participants stopped pedalling for thirty-seconds before beginning the TT. During this time their bike computers were removed so they did not receive performance related feedback during the TT. The Control group completed two, twenty-minute TTs which they were instructed to perform at the maximum intensity that they could hold for twenty minutes. Similarly, the VR group completed two twenty-minute TTs before which they were told to perform them at the maximal intensity they could sustain for twenty-minutes. During TT2 the conditions of TT1 were replicated for the Control. The VR stimulus was introduced for the duration of TT2 in the VR group, all other factors were the same as TT1. The participants received no numerical feedback during either of the TTs. Both groups were freely able to alter the resistance at any time during the TTs by changing gears on their bicycles. Following TT2, the VR group completed the Presence Questionnaire to assess their experience of the virtual environment (Witmer and Singer, 1998; Appendix D.).

The participant's road bicycles were configured on a Wahoo-Kickr Direct Drive Smart-Trainer 1.68m behind three display screens (Figure 1.) which would be used to display the VR software during the VR group's TT2. The VR software used was Zwift, a programme which allows users to virtually ride both re-created and synthetic routes around the world with other users showing up as computer generated cyclists on the display screens. The user can interact with other riders in a realistic manner and ride in a group or by themselves. The software will re-create inclines and declines by automatically adjusting the resistance on the Wahoo Kickr Smart-Trainer, however this feature was disabled for the twenty-minute TT. The software uses a looped, non-lyrical background music and common audio which would be present outdoors such as bird calls. The software displays an athlete's live power, speed, cadence, distance covered, duration, heart rate and their power output relative to their body weight as well as that of other riders in their area. These variables were covered on the screen for TT2. This was to ensure that the athlete received no numerical feedback throughout the duration of the TT other than the visual cues from the VR software itself, such as passing other users on the course. The course selected for the TT was the "London Loop". It is a fifteen-kilometre circuit with an elevation difference of one hundred and fifty-two metres (Figure 1.).

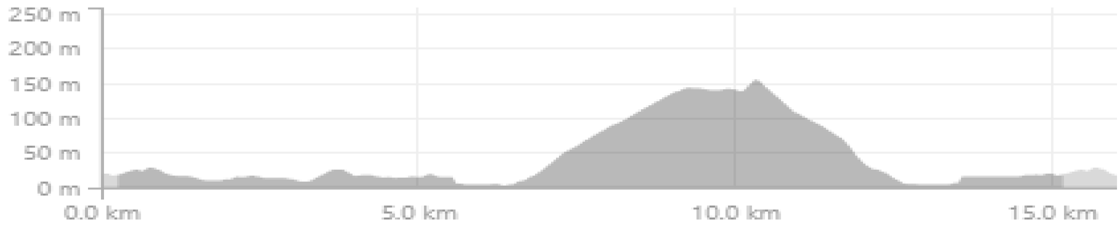

Figure 1. Profile of the "London Loop" circuit used during the VR group's TT2.

6.2 Research variables

The research variables that were assessed during this study consisted of: 1) Power, 2) Power Variability, 3) Heart Rate, 4) Blood Lactate, 5) Rate of Perceived Exertion, 6) Sense of Presence, 7) Immersive Tendencies.

6.3 Data collection methods

Power (w) and heart-rate (bpm) were measured using the Wahoo-Kickr Direct Drive Smart-Trainer and Garmin heart rate monitor respectively. Blood lactate (mmol/L) was measured using a Lactate Plus at five-minute intervals throughout TT1 and TT2. Blood samples for lactate calculations were taken from each participant's right index finger, which was thoroughly cleaned and dried before the extraction of each blood sample. Rate of perceived exertion was measured at five-minute intervals during TT1 and TT2 using a standard Borg RPE Scale (Borg, 1998). Witmer and Singer's (1998) immersive tendencies questionnaire was used to assess the participants tendency to experience presence within a virtual environment. Witmer and Singer's (1998) presence questionnaire was completed by the VR group post TT2 to assess their level of presence while using the VR software.

6.4 Data analysis

The mean power output (w) of the control and VR trials were graphed and compared against original baseline testing values. A T-Test was carried out to determine if a significant difference was present between TT1 and TT2 figures for both the VR and Control group. Analysis was carried out on each group independently and in respect of each other. The correlation coefficient was calculated for the relationship between immersive tendencies and sense of presence and the relationship between sense of presence and the mean power output (w) difference between TT1 and TT2 in the VR group.

6.5 Ethical considerations

Prior to beginning the study ethical approval was provided by the Department of Sport and Exercise Science (DSES) in Waterford Institute of Technology. The performance testing requires the participants to cycle at maximal intensity. High intensity exercise is high risk in participants with health conditions such as heart disease, hypertension, abnormal cholesterol levels and in sedentary populations. The risks associated with high intensity exercise were minimised by selecting a trained population that regularly perform at high to maximal intensities. Participants were required to complete a physical activity readiness questionnaire prior to participating in the study (Thomas et al., 1992). Any participants that presented contraindications to exercise were excluded from the study due to the risk it presented to their health and well-being. Participants were also informed of the health risks associated with completing high intensity exercise prior to beginning the study. Participants were required to complete an informed consent form prior to beginning the study (Appendix A.).

Sensitive information was obtained from participants prior to beginning the study. To protect the confidentiality of the participants all information was stored on an encrypted file on a password protected computer. No personal information was stored on cloud-based storage devices due to the possibility of the leaking or hacking of information. After the testing period was completed all non-essential information obtained from participants was destroyed. Participants completed this research study on an entirely voluntary basis and were free to withdraw from the study at any stage with no negative consequences.

Figure 2. Equipment set up for the VR trials showing multi-screen display of Zwift, Wahoo-Kickr Direct Drive smart-trainer (bottom left) and bike set-up (left).

7. Results

7.1 Introduction

The participants (n=7) were all male with a mean age of 33.29 ± 7.06 years (VR=34.75 ± 6.7 years; Control=31.33 ± 8.5 years). The participants mean weight was 80 ± 5.89kg (VR=81.43 ± 5.2kg; Control=78.1 ± 7.35kg). The results of this study indicated a significant increase in the five-minute RPE reading in the VR group from TT1 to TT2 (P=0.04) (13.25 ± 1.26 vs 15.75 ± 1.5 for TT2; Table 5). The R-value also indicated a strong, positive, linear relationship between sense of presence within the virtual environment and mean power increase (w) for the VR group in comparison of the participant's mean power output in TT1 and TT2 (r=1.0; Figure 5.). No other significant differences were found between the VR group and Control group in comparison of TT1 and TT2.

A T-Test was carried out to assess if significant differences between the VR and Control group were present at the time of the baseline testing and no significant differences between the groups were found (P=0.48, T=2.18). There was no significant difference between the temperature (c°) in the testing laboratory in TT1 and TT2 (P=0.42, T=2.18).

7.2 Power and power variability

A T-Test was carried out to assess the significance of the differences which occurred in the mean power output (w), max power production (w) and power variability index (PVI) of the VR and Control groups in TT1 to TT2. No significant difference was found in the mean power output (w) in the VR group from TT1 to TT2 (P=0.15) (324.75 ± 16.34 vs 342.25 ± 13.57 respectively; Figure 3., Table 1.). Similarly, no significant difference occurred in the mean power output (w) of the Control group (P=0.96) (293 ± 34.7 vs 294.33 ± 28.73 for TT1 and TT2 respectively; Figure 3; Table 2). No significant change occurred in the max power production (w) of either group (P=0.61 and 0.65, respectively; Table 1. and Table 2.). Neither group experienced a significant difference in their power variability index (P=0.35, P=0.23 for the VR and Control groups, respectively; Table 1. and Table 2.).

Table 1. Difference between the mean power output (w), max power output (w) and power variability index (PVI) of the VR group (n=4) in TT1 and TT2

	VR TT1	VR TT2	Percentage change (%)	P Score	T Score
Mean power (w)	324.75 ± 16.34	342.25 ± 13.57	5.39	0.15	2.45
Max power (w)	523.75 ± 109.38	574.5 ± 155.77	9.69	0.61	2.45
PVI	1.12 ± 0.23	1.0 ± 0.01	-10.49	0.35	2.45

Table 2. Difference between the mean power output (w), max power output (w) and power variability index (PVI) of the Control group (n=3) in TT1 and TT2.

	Control TT1	Control TT2	Percentage change (%)	P Score	T Score
Mean power (w)	293 ± 34.7	294.33 ± 28.73	0.46	0.96	2.78

Max power (w)	647.67 ± 160.75	591 ± 124.43	-8.75	0.65	2.78
PVI	1.01 ± 0.01	1.01 ± 0.01	-0.66	0.23	2.78

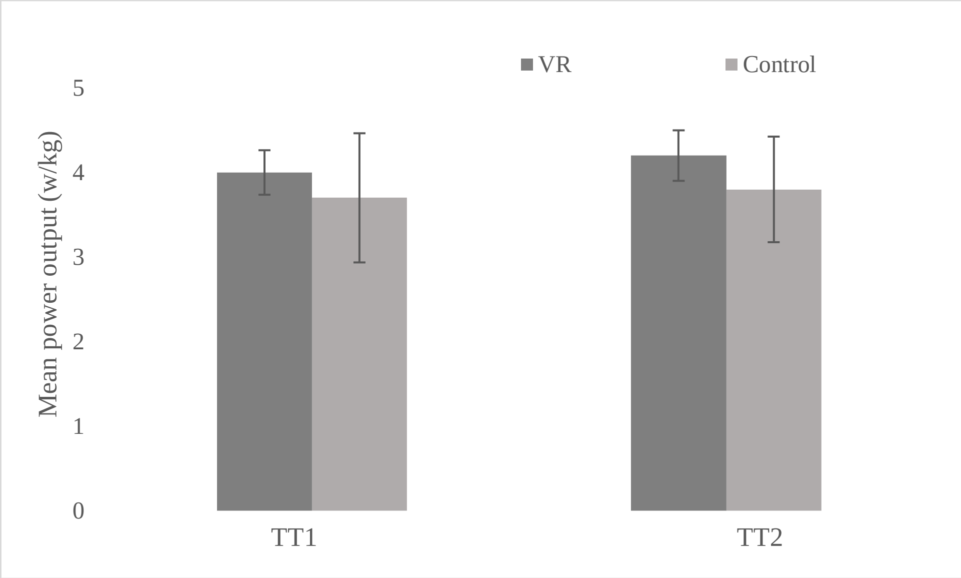

Figure 3. Mean power output (w) for the VR and Control groups during TT1 (left) and TT2 (right). No significant differences were observed in the mean power output (w) of the VR group or Control group in comparison to TT1 and TT2 (P=0.15 and P=0.96, respectively)

7.3 Blood lactate and heart rate

A T-Test was carried out to assess the significance of the differences which occurred in blood lactate (mmol/L) and the mean and maximal heart rate (bpm) of the VR and Control groups in TT1 and TT2. There was no significant difference in the lactate levels (mmol/L) of the VR group at the five-minute, ten-minute, fifteen-minute and twenty-minute readings in TT1 and TT2 (P=0.98, P=1.0, P=0.62 and P=0.25 respectively; Table 3.). Similarly, no significant change occurred in the lactate levels (mmol/L) of the control group in TT1 and TT2 (P=0.68, P=0.98, P=0.62 and P=0.73 respectively; Table 4). No significant difference was found in the VR participants mean heart rate (bpm) in TT2 in comparison to TT1 (P=0.69, 168.75 ± 5.62 vs 170 ± 1.83 for TT2; Table 3.). No significant difference in the maximal heart rate (bpm) reached during TT2 occurred in the VR group in comparison to TT1 (P=0.46, 181 ± 5.23 vs 186.25 ± 12.18 for TT2; Table 3.) No significant difference was found in either the mean heart rate (bpm) or maximal heart rate (bpm) of the Control group in comparison of TT1 and TT2 (P=0.94, 162.33 ±

10.26 vs 163 ± 10.54 for TT2 and P= 0.96, 174 ± 17.09 vs 173.33 ± 17.24 for TT2 respectively; Table 4.).

Table 3. Difference between the blood lactate (mmol/L), mean heart rate (bpm) and max heart rate (bpm) of the VR group (n=4) in TT1 and TT2.

	VR TT1	**VR TT2**	**Percentage change (%)**	**P Score**	**T Score**
Blood lactate (mmol/L) (5min)	9.0 ± 0.55	8.98 ± 2.37	-0.28	0.98	2.45
Blood lactate (mmol/L) (10min)	10.02 ± 3.56	10.03 ± 1.19	0	1.0	2.45
Blood lactate (mmol/L) (15min)	10.28 ± 2.55	10.98 ± 0.83	6.81	0.62	2.45
Blood lactate (mmol/L) (20min)	11.28 ± 3.11	13.40 ± 1.12	18.85	0.25	2.45
Mean HR (bpm)	168.75 ± 5.62	170 ± 1.83	0.74	0.69	2.45
Max HR (bpm)	181 ± 5.23	186.25 ± 12.18	2.90	0.46	2.45

Table 4. Difference between the blood lactate (mmol/L), mean heart rate (bpm) and max heart rate (bpm) of the Control group (n=3) in TT1 and TT2.

	Control TT1	Control TT2	Percentage change (%)	P Score	T Score
Blood lactate (mmol/L) (5min)	8.63 ± 2.57	9.3 ± 0.6	7.72	0.68	2.78
Blood lactate (mmol/L) (10min)	10.67 ± 5.21	10.6 ± 2.42	4.26	0.90	2.78
Blood lactate (mmol/L) (15min)	9.73 ± 5.36	11.73 ± 3.72	20.55	0.62	2.78
Blood lactate (mmol/L) (20min)	13.13 ± 2.32	13.8 ± 2	5.08	0.73	2.78
Mean HR (bpm)	162.33 ± 10.26	163 ± 10.54	0.41	0.94	2.78
Max HR (bpm)	174 ± 17.09	173.33 ± 17.24	-0.38	0.96	2.78

7.4 Rate of perceived exertion

A T-Test was carried out to assess the statistical significance of the differences which occurred in the five-minute, ten-minute, fifteen-minute, twenty-minute and mean RPE readings of the VR and Control groups in TT1 and TT2. A significant difference occurred in RPE at the five-minute reading for the VR group during TT2 in comparison to TT1 (P=0.04, 13.25 ± 1.26 vs 15.75 ± 1.5 for TT2; Table 5.). No significant differences occurred in RPE in the ten-minute, fifteen-minute or twenty-minute readings for the VR group in TT2 in comparison to TT1 (P=0.75, 0.70, 1.0 respectively; Table 5.). Subsequently no significant difference occurred in the mean RPE for the VR group (P=0.33; Table 5.). No significant difference was found in the RPE of the control group at any reading in TT2 in comparison to TT1 (P=0.78, P=1.0, P=1.0 and P=0.37, respectively; Table 6.). Subsequently, no significant difference was found in the mean RPE of the Control group (P=0.64; Table 6.).

Table 5. Difference between the rate of perceived exertion (RPE) of the VR group (n=4) in TT1 and TT2.

	VR TT1	VR TT2	Percentage change (%)	P Score	T Score
RPE (5min)	13.25 ± 1.26	15.75 ± 1.5	18.87	0.04*	2.45
RPE (10min)	17 ± 0.82	17.25 ± 1.26	1.47	0.75	2.45
RPE (15min)	18 ± 0.82	18.25 ± 0.96	1.39	0.70	2.45
RPE (20min)	19.25 ± 0.58	19.5 ± 0.58	0	1.0	2.45
Mean RPE	16.94 ± 2.52	17.69 ± 1.74	4.43	0.33	2.04

Table 6. Difference between the rate of perceived exertion (RPE) of the Control group (n=3) in TT1 and TT2.

	Control TT1	Control TT2	Percentage change (%)	P Score	T Score
RPE (5min)	16.33 ± 1.54	16.67 ± 1.53	2.04	0.78	2.78
RPE (10min)	16.67 ± 1.53	17.33 ± 1.53	0	1.0	2.78
RPE (15min)	17.67 ± 1.15	17.67 ± 1.53	0	1.0	2.78
RPE (20min)	19.67 ± 0.58	20 ± 0	5.26	0.37	2.78
Mean RPE	17.58 ± 1.68	17.92 ± 1.73	0.95	0.64	2.07

7.5 Immersive tendencies and sense of presence

The R-value indicates a moderate, negative linear relationship between immersive tendencies and VR participants experiencing a higher sense of presence within the virtual environment in TT2 (r=0.48). The R-value indicates a strong linear relationship between sense of presence within the virtual environment and mean power output (w) for the VR group in TT2 (r=1.0).

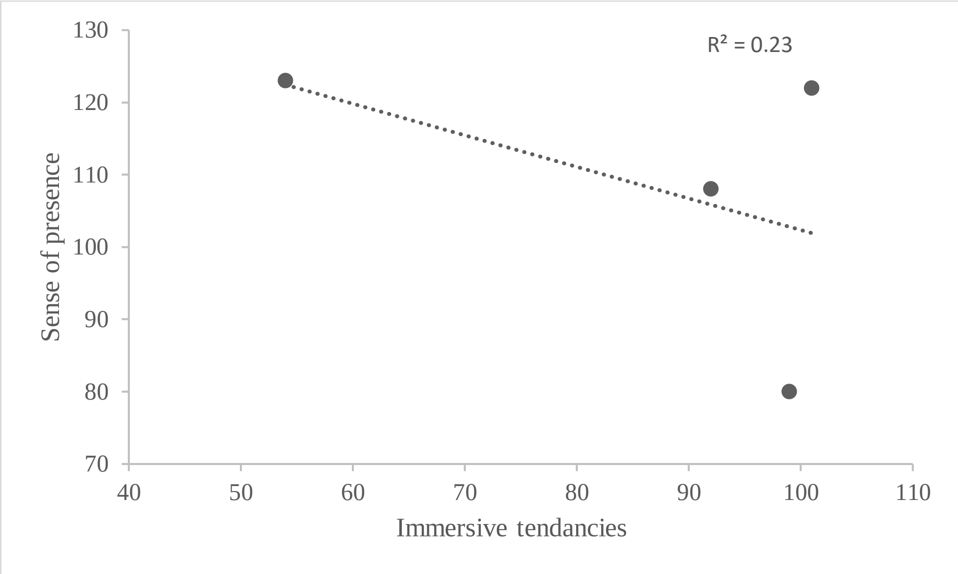

Figure 4. The relationship between immersive tendencies and sense of presence within the virtual environment in the VR group in TT2 (r^2=0.23, r=-0.48).

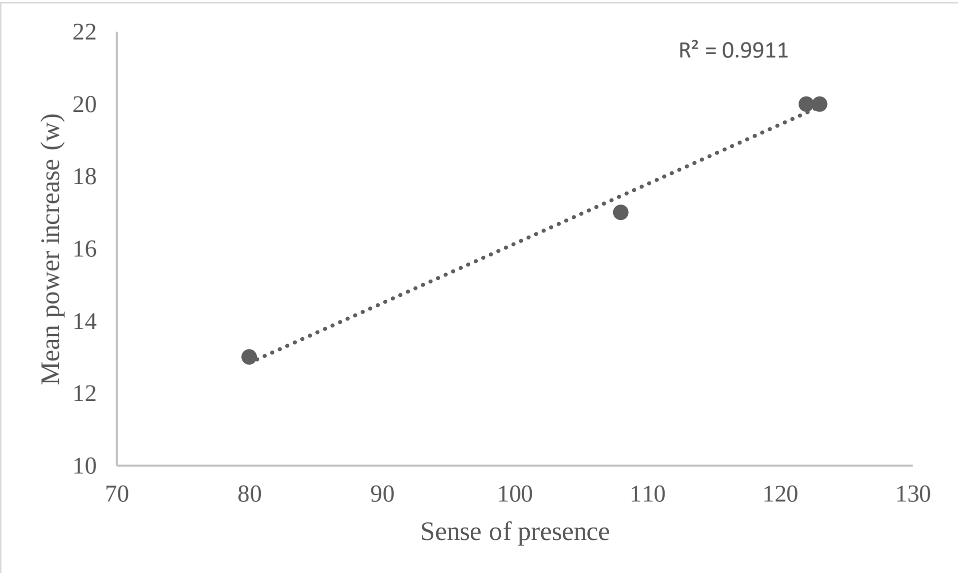

Figure 5. The relationship between sense of presence within the virtual environment and mean power increase (w) in the VR group in TT2 (r^2=0.99, r=1.0).

8. Discussion

8.1 Research aim

The aim of this research was to seek greater understanding as to whether moderate VR exposure could affect the maximal twenty-minute TT performance of trained cyclists when compared to cycling indoors without any additional stimulus at maximal intensity. A secondary aim included further examination of the relationship between level of immersion, sense of presence and exercise performance within virtual environments. The rationale for this research was that at present, no research could be found which has assessed the effects of VR exposure on the TT performance of trained cyclists. Further research was required to determine the relationship between sense of presence in trained athletes when competing in their origin sport within a virtual environment and how this relates to their immersive tendencies.

8.2 Summary of results

The results of this study indicated a significant increase in the five-minute RPE reading in the VR group from TT1 to TT2 ($P=0.04$) (13.25 ± 1.26 vs 15.75 ± 1.5 for TT2; Table 5). The R-value also indicated a strong linear relationship between sense of presence within the virtual environment and mean power increase (w) for the VR group in comparison of the participants mean power output in TT1 and TT2 ($r^2=0.99$; Figure 5.). No significant differences were found between the VR group and Control group in comparison of TT1 and TT2.

8.3 Power output and power variability

The VR and Control group both experienced a non-significant increase in their mean power output (w) during TT2 in comparison to TT1 of 5.39% ($P=0.15$) and 0.46% ($P=0.96$), respectively (Table 1 and Table 2). Vogt et al. (2015) and Huang et al. (2008) showed that the level of presence achieved within a virtual environment can be affected by exercise and exercise intensity. It is possible that the exercise intensity (maximal 20-minute TT) was too high to allow the VR group to experience a level of presence high enough to elicit a significant increase in their mean power production (w). This is in line with the research presented by Hutchinson and Tenebaum (2007) which discovered that as exercise intensity increases to near maximal workloads, it becomes almost impossible for the participant to maintain a dissociative attentional focus. This is due to physiological sensations of pain which cause a switch to an internal associative focus. This switch may have limited any effect the VR software could have had on the mean power production of the participants for the remainder of the TT as it was no longer the participants attentional focus. Nichols et al. (2000) showed that presence in the virtual environment limits the effectiveness of the VR software, therefore, if presence is low due to an internal associative attentional focus, the potential benefits of using VR software as a mechanism to increase the mean power output of athletes is reduced.

The VR group experienced a non-significant increase in their maximal power output (w) during TT2 in comparison to TT1 (P= 0.61) (523.75 ± 109.38 and 574.5 ± 155.77 respectively; Table 1). In contrast, the Control group experienced a non-significant decrease in their maximal power output (w) during TT2 in comparison to TT1 (P=0.65) (647.67 ± 160.75 and 591 ± 124.43; Figure 2.). Due to the participants highly trained status, significant differences in their maximal power output (w) were likely not present due to their ability to self- regulate their power output to a more consistent and efficient wattage for the duration of the TT. A more significant difference may have been observed in an untrained population. This may be due to an inefficiency at pacing a twenty-minute, maximal effort and therefore may have been more influenced by environmental factors within the VR software.

Neither the VR or Control group experienced a significant difference in their PVI during TT2 in comparison to TT1 (P=0.35 and P=0.23 respectively; Table 1 and Table 2). PVI was used as a measure of responsiveness to the virtual environment. This can be contributed in the same vein as to as to why no significant difference occurred in relation to the participant's maximal power output (w). The participants were highly trained and have a high capability of managing their PVI to increase cycling efficiency. Greater differences in PVI are likely to occur in untrained or moderately trained populations that are less efficient in managing their power variability and pacing. Held and Durlach (1992) suggested that presence could be determined by the participant acting reflexively to a stimulus within the virtual environment and therefore PVI would increase or decrease dependent on how much the participants reacted to stimuli within the virtual environment such as ascents, descents and other riders. However, the results of this study indicate that power variability index is a poor method of determining presence within the virtual environment in highly trained populations.

8.4 Immersive tendencies and sense of presence

A moderate, negative linear relationship was discovered between immersive tendencies and VR participants experiencing a higher sense of presence within the virtual environment in TT2 (r=-0.48). This contrasts with research conducted by Witmer and Singer (1998) which concluded that users who test higher for immersive tendencies are more likely to become immersed in the virtual environment and thus experience higher levels of presence. A stronger relationship between the variables may occur if exercise intensity was reduced to moderate or low levels which would allow a greater external attentional focus, thus allowing for increased levels of presence within the virtual environment.

A strong, positive linear relationship was discovered between sense of presence within the virtual environment and mean power increase (w) in TT2 for the VR group (r=1.0). The ability for a user to experience presence within an environment is an important factor in determining the quality and effectiveness of a VR software (Slater et al., 1996). The results of this study suggest that as presence increases so does the mean power output (w) of the participant. By increasing the level of VR exposure to higher levels, for example by using a VR headset to display the software, it is possible the participants would subsequently experience higher levels of presence and thus larger improvements in their mean power output (w). The ability to increase presence by the introduction of higher levels of VR exposure during exercise is limited by cortical arousal stimulation which produces motion like symptoms that lead to increased discomfort, motivation and ultimately reduced presence due to its competition for attentional focus (Witmer & Singer, 1998; Vogt et al., 2015).

8.5 Blood lactate and heart rate

No significant differences occurred in the blood lactate (mmol/L) and the mean or maximal heart rate (bpm) of the VR and Control groups in comparison of TT1 with TT2 (Table 3. and Table 4., respectively). No current research suggests that VR has the potential to affect the blood lactate (mmol/L) levels or the mean or maximal heart rate (bpm) of users. However, these variables were assessed as biological markers of exertion. RPE was seen to decrease and mean power (w) was seen to increase with the use of VR software in previous research and therefore it is relevant to also assess the effects of VR on biological markers to gain a greater understanding of its effects on trained athletes (Huang et al., 2008; Jones et al., 2016).

8.6 Rate of perceived exertion

The results of this study indicated a significant increase in the five-minute RPE reading in the VR group from TT1 to TT2 (P=0.04) (13.25 ± 1.26 vs 15.75 ± 1.5 for TT2; Table 5). No other significant differences occurred in relation to RPE in the VR or Control group. It is likely that other RPE readings throughout the TT did not yield significant differences in RPE as the VR participant's attentional focus had shifted away from the software to an internal associative focus. Hutchinson and Tenenbaum (2007) discovered that as exercise intensity increases to near maximal workloads, it becomes almost impossible to maintain a dissociative focus while Triplett (1898) discovered that participants were likely to experience an increase in performance when another individual is present and completing a similar task. Therefore, it is possible that the VR stimulus motivated the VR participants to exercise harder during the first five-minutes of TT2. During this stage participants were still able to maintain a dissociative focus by directing their attention and gaze towards the VR software which promoted increased performance levels due to its ability to facilitate dissociative states and its inclusion of other competitors completing similar tasks. As sensations of pain and discomfort increased past the five-minute stage of TT2 participants were no longer able to maintain a dissociative focus and their attentional focus switched to an internal, associative focus. Therefore, the VR stimulus effect at this stage in reducing or increasing RPE may have been impaired as the VR software was no longer the participant's attentional focus.

Rutter at al. (2009) found that VR as a method of distraction led to significant increases in pain tolerance and pain threshold levels amongst participants. Significant decreases in duration of time spent thinking about pain and decreases in the intensity of the pain were also experienced in participants. However, in the Rutter at al. (2009) study, participants were not completing maximal exercise, and this may have allowed for decreased sensory demands competing for the attentional focus of the participant and thus allowing them to direct greater attentional focus to the VR software. Similarly, Huang et al. (2008) found a significant decrease in RPE during the initial six-minutes of exercising with a VR head mounted display. This contrasts the results of this study which showed a significant increase in RPE during the initial five-minutes of exercising with the VR stimulus however, the time frame for which the VR caused a significant difference in RPE in both studies are similar. This further suggests that a VR stimulus is only effective during the initial stages of maximal exercise while there is less competition with physiological pain and discomfort for attentional focus.

Interestingly, the VR participants experienced a significant increase in their RPE at the five-minute reading (P=0.04) but no significant differences occurred in their blood lactate (mmol/L) at that reading (P=0.98; Table 3.) or their mean and maximal heart rates (bpm) (P=0.69 and P=0.46, respectively; Table 3.). It is possible that RPE was increased due to an increase in the sensory demands placed on the participants. In addition to the physical pain and discomfort they were experiencing they also had engaging visuals and sounds within the virtual environment in competition with physiological sensations for their attentional focus. This may have led to an increase in cortical arousal which manifested itself into higher feelings of perceived exertion despite minimal change in physiological markers of exertion (Witmer & Singer, 1998; Vogt et al., 2015).

8.7 Limitations of the study

As this study focused on a highly trained population of male cyclists the results may not be applicable to untrained or general populations and further research is needed to clarify the effects of the VR stimulus on these populations. Another limitation of this study was its relatively small sample size (n=7). Participants withdrawing from the study before it's completion was a contributing factor to this limitation and it proved difficult to source participants which met the selection criteria as the testing coincided with the beginning of the competitive season for Irish cyclists. Many suitable participants expressed they felt completing the testing had the potential to harm their competitive performance. A potential limitation of this study is the use of the presence questionnaire to assess presence within the virtual environment immediately after completion of TT2. The questionnaire is extensive, and participants expressed that they found it somewhat difficult to concentrate and complete the questionnaire post TT2. This may contribute to inaccuracies within the information collected on presence.

8.8 Conclusion

This study presented two main significant findings, that the use of VR cycling software increases the perceived exertion of trained cyclists during the initial stages of a twenty-minute TT preformed indoors on a stationary trainer. The other significant finding was a strong, positive, linear relationship between sense of presence within the virtual environment and mean power increase (w). The potential effects of the VR software were decreased as the participants progressed from an external, dissociative attentional style to an internal, associative attentional style as the intensity and physical demands of exercise increased with the progression of the TT. Although no other significant differences were observed, this is an area which warrants more research in terms of a different population, different VR training software or by addressing study limitations such as introducing a larger sample size. VR training software for cyclists such as Zwift are becoming increasingly popular and their potential effects relative to performance should be further examined to provide coaches and athletes with a broader understanding of their physiological and psychological effects.

8.9 Recommendations for future research and practical applications

The use of VR cycling software such as Zwift may be more suited to studies which seek to examine exercise adherence and motivation. VR subjects expressed that they found the VR software to be enjoyable during the initial stages of TT2 when it was still their attentional focus. This is encouraging for research examining the motivational or adherence effects of the software on exercise. Zwift's performance related effects appear to be more suited to shorter cycling bouts (<five-minutes) at maximal intensity than the twenty-minute TT's performed in this study. For maximal cycling efforts with a duration of less than five-minutes RPE and other performance related factors may increase. Alternatively, reducing the exercise intensity to low or moderate levels may promote significantly different results as the participants will be able to maintain an external attentional focus on the VR software. The introduction of gaze tracking would be useful to assess the attentional focus of the participant on the VR software throughout exercise.

VR software may have a larger influence on the performance related factors of untrained or moderately trained populations in factors such as power variability, mean and maximal power output and mean and maximal heart rate. Highly trained cyclists are likely to be extremely familiar with self-regulating performance variables, pacing and the feelings of discomfort they experience when working at their maximal twenty-minute capacity.

Therefore, less variation is likely to occur than in untrained populations where VR may elicit a greater impact on their performance.

Although this research does not indicate any significant benefits of using Zwift cycling software during maximal intensity exercise, no significant results were found to support the software reducing performance. Therefore, Zwift may still offer a more enjoyable, indoor training environment for competitive cyclists. VR software has been shown to be an effective tool in reducing pre-competition anxiety and therefore it may be useful to cyclists to use Zwift in their competition preparation to allow them to virtually ride competition courses and assess their performance against competitors and other cyclists (Gorini & Riva, 2008; Sorrentino et al., 2015). Its use as a tool to aid exercise enjoyment and performance should not be avoided despite that in this study, the VR software did not elicit significant performance enhancing effects.

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Appendix A

Information Sheet and Informed Consent Form

Introduction

You have been invited to take part in a study which will require you to complete two, 20minute, high intensity cycling Time-Trials on a stationary trainer under different conditions. If you agree to take part in the study, it will involve you attending two, hour long testing sessions over the course of two weeks. The purpose of this study is to provide athletes and professionals with information which may affect Time-Trial performance in trained cyclists.

Why have you been invited to take part?

You have been invited to take part in this study as you are a trained, male cyclist that is currently ranked Category 1/2 as per Cycling Ireland's road ranking criteria.

Does the study provide anonymity?

Yes, the collection procedures chosen for the study provide anonymity and confidentiality to all participants that take part. All non-essential information such as your contact details will be destroyed/deleted once the testing sessions are completed.

Do you have to take part in this study?

No, your participation in the study is entirely voluntary. If you do not wish to take part or you wish to withdraw at any time during the study, you are not required to give a reason and you will not be contacted again. However, if you withdraw before the study is completed you will not receive a copy of your results post-testing.

Does this study have any risks?

The study will require you to perform two, high intensity cycling time trials which may carry certain health risks for people with contraindications to exercise. However, for the healthy, trained population the study carries very little risk.

Consent of Participant

By signing this document, you agree that you are fully informed of the risks associated with participating in this study and give your consent to participate in the described testing.

Signature of Participant: Date:

Appendix B

Participant recruitment survey

Question 1.

Please fill in your contact details below. You will be contacted with further information regarding the study via email so please ensure that your email address is correct. All information (including your name) will remain confidential.

Name

Email address

Phone number

Question 2.

Please insert your age into the text box below.

Question 3.

Please insert your Cycling Ireland Licence Number in the text box below.

Question 4.

How long have you been ranked as a Cat 1/Cat 2 cyclist?

Question 5.

How often do you use virtual cycling software? Examples of virtual cycling software include TrainerRoad or Zwift.

Question 6.

How often do you complete a 20-minute functional threshold power (FTP) test, 20-minute time-trial or maximal 20-minute cycling effort?

Question 7.

Do you have any known health conditions that would prevent you from safely participating in high intensity exercise?

Appendix C

Immersive tendencies questionnaire (Witmer & Singer, 1998).

Characterize your experience in the environment, by marking an "X" in the appropriate box of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

1. **Do you easily become deeply involved in movies or tv dramas?**

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

2. **Do you ever become so involved in a television program or book that people have problems getting your attention?**

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

3. **How mentally alert do you feel at the present time?**

|________|________|________|________|________|________|________|

NOT ALERT MODERATELY ALERT FULLY ALERT **4. Do you ever become so involved in a movie that you are not aware of things happening around you?**

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

5. **How frequently do you find yourself closely identifying with the characters in a story line?**

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

6. **Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?**

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

7. How physically fit do you feel today?

|________|________|________|________|________|________|________|

NOT FIT MODERATELY FIT EXTREMELY FIT

8. How good are you at blocking out external distractions when you are involved in something?

|________|________|________|________|________|________|________|

NOT VERY GOOD SOMEWHAT GOOD VERY GOOD

9. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

10. Do you ever become so involved in a daydream that you are not aware of things happening around you?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

11. Do you ever have dreams that are so real that you feel disoriented when you awake?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

12. When playing sports, do you become so involved in the game that you lose track of time?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

13. How well do you concentrate on enjoyable activities?

|________|________|________|________|________|________|________|

NOT AT ALL MODERATELY WELL VERY WELL

14. How often do you play arcade or video games? (OFTEN should be taken to mean every day or every two days, on average.)

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

15. Have you ever gotten excited during a chase or fight scene on TV or in the movies?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

16. Have you ever gotten scared by something happening on a TV show or in a movie?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

17. Have you ever remained apprehensive or fearful long after watching a scary movie?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

18. Do you ever become so involved in doing something that you lose all track of time?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

Appendix D

Presence Questionnaire (Witmer & Singer, 1998).

Characterize your experience in the environment, by marking an "X" in the appropriate box of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

WITH REGARD TO THE EXPERIENCED ENVIRONMENT

1. How much were you able to control events?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

2. How responsive was the environment to actions that you initiated (or performed)?

|________|________|________|________|________|________|________|

NOT MODERATELY COMPLETELY

RESPONSIVE RESPONSIVE RESPONSIVE

3. How natural did your interactions with the environment seem?

|________|________|________|________|________|________|________|

EXTREMELY BORDERLINE COMPLETELY

ARTIFICIAL NATURAL

4. How much did the visual aspects of the environment involve you?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

5. How natural was the mechanism which controlled movement through the environment?

|________|________|________|________|________|________|________|

EXTREMELY BORDERLINE COMPLETELY

ARTIFICIAL NATURAL

6. How compelling was your sense of objects moving through space?

|________|________|________|________|________|________|________|

NOT AT ALL MODERATELY VERY

COMPELLING COMPELLING

7. How much did your experiences in the virtual environment seem consistent with your real-world experiences?

|________|________|________|________|________|________|________|

NOT MODERATELY VERY

CONSISTENT CONSISTENT CONSISTENT

8. Were you able to anticipate what would happen next in response to the actions that you performed?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

9. How completely were you able to actively survey or search the environment using vision?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

10. How compelling was your sense of moving around inside the virtual environment?

|________|________|________|________|________|________|________|

NOT MODERATELY VERY

COMPELLING COMPELLING COMPELLING

11. How closely were you able to examine objects?

|________|________|________|________|________|________|________|

NOT AT ALL PRETTY VERY

CLOSELY CLOSELY

12. How well could you examine objects from multiple viewpoints?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT EXTENSIVELY

13. How involved were you in the virtual environment experience?

|________|________|________|________|________|________|________|

NOT MILDLY COMPLETELY

INVOLVED INVOLVED ENGROSSED

14. How much delay did you experience between your actions and expected outcomes?

|________|________|________|________|________|________|________|

NO DELAYS MODERATE LONG

DELAYS DELAYS

15. How quickly did you adjust to the virtual environment experience?

|________|________|________|________|________|________|________|

NOT AT ALL SLOWLY LESS THAN

ONE MINUTE

16. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

|________|________|________|________|________|________|________|

NOT REASONABLY VERY

PROFICIENT PROFICIENT PROFICIENT

17. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

|________|________|________|________|________|________|________|

NOT AT ALL INTERFERED PREVENTED

SOMEWHAT TASK PERFORMANCE

18. How much did the control devices interfere with the performance of assigned tasks or with other activities?

|________|________|________|________|________|________|________|

NOT AT ALL INTERFERED INTERFERED

SOMEWHAT GREATLY

19. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

IF THE VIRTUAL ENVIRONMENT INCLUDED SOUNDS:

20. How much did the auditory aspects of the environment involve you?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

21. How well could you identify sounds?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

22. How well could you localize sounds?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

IF THE VIRTUAL ENVIRONMENT INCLUDED HAPTIC (SENSE OF TOUCH):

23. How well could you actively survey or search the virtual environment using touch?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

24. How well could you move or manipulate objects in the virtual environment?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT EXTENSIVELY