A Teleoanticipatory Approach to the Deceptive Modulation of Treadmill Walking Speed using Immersive Virtual Reality: A Double-Blinded, Crossover Study

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Abstract

Background: The influence of exercise deception and immersive virtual reality on ratings of perceived exertion and heart rate during exercise have been studied in isolation, but rarely in tandem. Given that there is evidence to suggest that both factors can affect perceived exertion and heart rate during exercise, addressing the gap in knowledge pertaining to such influences is imperative.

Objective: This study investigated the influence of speed deception on heart rate and ratings of perceived exertion (RPE) during immersive virtual reality (IVR) while walking on a treadmill.

Methods: Using a double-blinded, crossover research design, sixteen college-aged adults (eight females) were randomly assigned a testing order for a total of six, ten-minute trials of treadmill walking; three trials conducted with IVR on one day and three non-IVR trials (i.e. control) on another day at 3.3, 3.5, and 3.7 mph. A 24 hour washout period was given in between the first and second day of testing. Participants were told that all trials occurred at 3.5 mph. Borg RPE scores were assessed after each trial while HR was monitored throughout.

Results: The IVR trials produced lower mean RPE scores in comparison to the non-IVR trials during 3.5 and 3.7 mph ($p = 0.002$, 95% CI: (0.6, 1.8); $p = 0.002$, 95% CI (1.2, 2.7), respectively). The IVR trials also yielded a lower mean HR compared to the non-IVR trials at the highest speed of 3.7 mph ($p = 0.049$, 95% CI: (2.0, 12.7)). Within group differences for the non-IVR group were identified in RPE for the 3.3 and 3.5 mph trials compared to those at 3.7 mph ($p = 0.002$, 95% CI: (-1.4, -0.5); $p = 0.002$, 95% CI: (-1.4, -0.5), respectively). No differences were detected within the IVR group.

Conclusions: These findings suggest that using deception via an immersive virtual reality exergaming experience may affect attenuated participant perceived effort and heart rate response without the user noticing the effect.

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without the user noticing the effect.

Keywords: Immersive Virtual Reality; Deception; RPE; Treadmill

Introduction

Awareness of the physical demands of exercise will often determine the strategies used to successfully complete it. Based on a combination of prior experience, ratings of perceived exertion (RPE), biomechanical and cardio-metabolic feedback while performing the exercise, participants will engage in a self-pacing strategy known as teleoanticipation [1]. By incorporating feedback and feed-forward mechanisms that encompass a variety of physiological systems, the brain will engage in selective neuromuscular regulation to efficiently and effectively complete the exercise [2]. However, predetermining an endpoint for the exercise is necessary to ensure optimal performance under the teleoanticipatory model [3]. In the absence of an endpoint, physiological resources will be conserved to account for extended or intensified exercise [4, 5]. Conversely, knowledge of when an endpoint is approaching will allow this conservation to subside while subsequently increasing the work rate [6].

An individual's RPE, which primarily drives teleoanticipation, is commonly measured using the Borg RPE scale [7]. The Borg RPE scale ranges from '6' to '20,' with each score designed to correspond to a tenfold increase in heart rate (e.g., 8 equals 80 beats/min) [8]. In previous research, RPE scores have been used to drive accurate, individualized exercise prescriptions [9]. Although RPE scores are subjective, there is a general consensus that these are largely attributed to the intensity of the exercise being performed [10]. This trend has been demonstrated to be consistent with running and resistance training, as a higher RPE has been associated with higher intensity exercise [11].

Utilizing deception to manipulate an exercise experience has become increasingly common. Whether through the incorporation of a digital competitor [12] or hypnotic manipulation [13], deception has demonstrated the potential to change how people perceive exercise. Recently, visual hill gradients observed through virtual reality while cycling have been shown to alter perceptions of effort and breathlessness [14]. In this particular study conducted by Finnegan et al., participants who observed a steeper hill gradient experienced a higher level of breathlessness and cycled with more power despite the resistance of the cycle ergometer remaining consistent throughout. However, a systematic review conducted by Jones et al. found that while a majority of research has investigated manipulations of the exercise endpoint, there is little research available examining the effects of exercise intensity deception [15]. Only two studies were identified within this review that evaluated the effects of pre-exercise intensity deception, both of which yielded no significant differences in selected outcome measures (RPE and heart rate, respectively) [16, 17]. However, Jones et al. contend that the methodologies used in these investigations varied greatly, such as the way in which participants were deceived and differences in training experience of the participants. As a result, further study is required to ascertain if there is a relationship between the deception of exercise intensity and exercise variables.

Virtual reality (VR) has emerged as a viable tool for exercise studies involving deception. VR allows individuals to engage with simulated content in virtual environments outside of the real world [18]. More recently, as VR technology has improved, immersive virtual reality (IVR) has been developed to enhance the experience. IVR, unlike its predecessor, incorporates unique sensorimotor elements (i.e., visual, auditory, and/or tactile stimuli) that alter a user's experience to make them feel as if what they are perceiving is their actual surroundings [19]. In comparison to traditional VR environments, IVR environments have been found to produce a higher sense of presence and immersion [20].

Furthermore, IVR has the unique potential to produce "place illusion," which refers to the sensation of "being there" in the surroundings [21]. Early study employing IVR during exercise has yielded encouraging implications, as it was discovered to yield lower RPE levels while improving satisfaction during biking [22, 23]. These findings, while salient, highlight the need for more study employing deception tactics with IVR to determine if they extend to other training modalities such as a treadmill.

To our knowledge, there are no studies that have investigated the efficacy of IVR in conjunction with deception strategies during treadmill exercise. This study investigated the performance of participants exposed to speed deception on heart rate and ratings of perceived exertion (RPE) during immersive virtual reality while walking on a treadmill. We hypothesized that participants in the IVR condition would report lower RPE scores and equally yield lower heart rates (HR) in comparison to the non-IVR condition.

METHODS

Participants

Sixteen college-aged healthy volunteers (eight females) were recruited from the University of California, Los Angeles (UCLA) campus. Exclusion criteria included the presence of any disorders that would preclude moderate-to-high intensity exercise participation and testing. All participants provided written informed consent at the beginning of the study. This research was approved by the UCLA Institutional Review Board and carried out in accordance with the ethical standards of the Helsinki Declaration.

Study Design

Using a double-blinded, crossover research design, participants were tested during two separate days, each consisting of three, 10-minute treadmill walking trials separated by a 3-minute rest period, with a 24-hour washout period in between each day. All participants were randomly assigned to a participant number produced from a random number generator, which was operated by an investigator independent from recruitment and testing. Each participant number corresponded to a randomized sequence of testing for the two different days. The order for the speeds of the treadmill (3.3 mph, 3.5 mph, and 3.7 mph) were randomized, as well as the order for the IVR or non-IVR trials (i.e., IVR trials occurred on either the first day or second day of testing). The non-IVR trials used the identical treadmill albeit with no head-mounted display (HMD). Participants were told (and deceived) that all trials occurred at 3.5 mph for blinding purposes. All testing was administered by trained research personnel under the supervision of the lab director in the UC Fit-Digital Health Exercise Physiology Research Laboratory at UCLA during the early spring of 2023 for a one month period. Study participants were asked to refrain from completing moderate-vigorous physical activity at least 24 hours prior to beginning the study until its conclusion. For baseline measures, body mass was measured on a calibrated medical scale (accuracy ± 0.1kg), and height was determined using a precision stadiometer (Seca, Hanover, MD, USA; accuracy ± 0.01 m). Body fat percentage was measured using a validated octipolar, multi-frequency, multi-segmental bioelectrical impedance analyzer (InBody Co., Seoul, Korea Republic) [24]. The instrument measured resistance and reactance using proprietary algorithms. To ensure accuracy, participants adhered to standard pre-measurement BIA guidelines recommended by the American Society of Exercise Physiologists [25].

IVR Intervention

The IVR intervention made use of an innovative software application (Octonic VR, New York, NY, USA) developed to enable a variety of viewing experiences while walking on a treadmill. On a HMD (Meta Quest 2, Menlo Park, CA, USA), a standardized, pre-selected immersive environment portraying an island in the sky (i.e., "Sky Island") was projected. As participants walked on the treadmill, in-app music played as their view dynamically changed in response to their pace and direction of gaze. The visual input while wearing the HMD entirely concealed the participants' immediate surroundings, as is customary with IVR. However, a mixed reality feature unique to this program permitted a real-world visual perspective of the treadmill overlayed by the IVR environment to ensure safety while walking.

Figure 1. Snapshot view of *Sky Island* (Octonic VR app) environment from the head-mounted display (HMD) during the immersive virtual reality intervention while walking on a treadmill.

Equipment

Participants completed both IVR and non-IVR trials on a treadmill (REDLIRO, USA) while donning a forearm-worn optical heart rate monitor (Rhythm+TM 2.0, Scosche Industries, Oxnard, California). HR data was collected and graphically displayed using a fitness app (iCardio®, Cupertino, CA, USA) monitored by research administrators.

Figure 2. Left Panel - Experimental setup during the IVR intervention mirroring participant’s HMD to a display for researchers; Right Panel - Perspective from the participants HMD showing the treadmill speeds settings and overlays in the IVR environment.

Experimental Procedures

Two independent research administrators assessed each participant individually during the 6 trials. A designated study administrator read a standardized set of instructions prior to the start of the first experiment. Participants were instructed that they would be performing three trials, separated by three-minute rest periods, while always walking at 3.5 mph on a treadmill on two different days (six trials total). One day of testing included three trials while wearing the IVR HMD, whereas the second day included three trials sans IVR. After each 10-minute session, participants were asked to rate their perceived exertion (RPE) using the Borg RPE Scale, with a score ranging from 6 to 20. Furthermore, individuals' heart rates were monitored throughout every trial. After completion of the first day of testing, a 24-hour washout period was given prior to the subsequent trials.

Deception occurred in several ways, the first of which was the treadmill's speed. Participants were instructed that all treadmill trials would be completed at 3.5 mph. However, each day of testing included two deceptive speed conditions (3.3 and 3.7 mph) in addition to the 'true' 3.5 mph speed condition. The ‘manual’ option in the app menu was chosen so that the HMD did not affect the treadmill speed. A separate research administrator modified the in-app display beforehand so that participants always saw a speed of 3.5 mph regardless of the deceptive pace they were actually accomplishing. The same research administrator altered the speeds for each participant, whereas the other research administrator was blinded to the speeds.

Participants were also given false information in regard to the IVR trials. In order to ‘deceive’ the participants from the true aim of the study, they were informed that there was a component of the IVR background that was changing in between trials. No further details were provided, and research administrators were not permitted to answer any questions pertaining to the background. After the completion of the second day of testing, participants were asked if they noticed any differences between the first and second days of testing. Responses were recorded and transcribed.

Statistical Analysis

Descriptive statistics are presented as mean and standard deviation (SD). A 3 x 2 repeated-measures analysis of variance (ANOVA) was utilized: independent variables were treadmill speed (3 levels) and presence of immersive virtual reality (IVF) (2 levels) while dependent variables were RPE and HR. Effect sizes of main effects and interactions were measured by partial eta squared (η^2). These calculations were followed up by paired t-tests using the Benjamini-Hochberg procedure to maintain the familywise error rate. Effect sizes were measured by Cohen's *d*. Statistical significance was determined by $\alpha = 0.05$ and all tests were two-tailed. All data were exported to IBM SPSS Statistics for Windows, version 22 (IBM Corp., Armonk, N.Y., USA) for analysis.

RESULTS

Demographics

All sixteen participants (mean age = 20.5 ± 1.2 years old) successfully completed the study. Mean height, weight, and body fat collectively for all participants was 171 ± 14 cm, 69 ± 15 kg, and 19 ± 7.5 %, respectively.

	Non-IVR			IVR		
Deceptive Treadmill Speed (mph)	**3.3**	**3.5**	**3.7**	**3.3**	**3.5**	**3.7**

HR (±SD) (bpm)	111 (13)	110 (16)	115 (16)	107 (14)	105 (10)	107 (10)
Borg RPE (±SD)	8.5 (1.5)	8.6 (1.1)	9.0 (1.3)	7.5 (0.5)	7.4 (0.5)	7.6 (0.6)

Table 1. Mean heart rate (±SD) and Borg RPE scores (±SD) corresponding to deceptive treadmill speed in the non-immersive virtual reality (IVR) and IVR trials

RPE Scores

Although there was no significant difference in RPE between the 3.3 and 3.5 mph trials within the non-IVR group, these scores were lower compared to those associated with the 3.7 mph trials (p = 0.002, 95% CI: (-1.4, -0.5); p = 0.002, 95% CI: (-1.4, -0.5), respectively). No significant differences in RPE were observed within the IVR group. During the 3.5 and 3.7 mph trials, the IVR group reported lower RPE scores in comparison to the non-IVR group (p = 0.002, 95% CI: (0.6, 1.8); p = 0.002, 95% CI (1.2, 2.7), respectively) (Table 1).

Heart Rate

In the non-IVR group, there was a significantly higher HR in the 3.7 mph trials compared to the 3.5 mph trials (p = 0.027, 95% CI: (-6.8, -1.8)). No significant differences in HR were observed within the IVR group. Between groups, only the 3.7 mph trials yielded a lower HR in the IVR group compared to the non-IVR group (p = 0.049, 95% CI: (2.0, 12.7)) (Table 1).

Post-IVR Session Subjective Responses

Through an in-person post study interview, all but one of the sixteen participants reported “feeling no differences in treadmill speed while wearing the HMD” between trials. However, 75% (12 participants) reported feeling “a different treadmill speed” between trials while not donning the HMD. Moreover, participants commonly reported that “time went by faster” during the IVR trials, which were also deemed to be “more stimulating” and “more enjoyable.”

Discussion

IVR exercise has been linked to a variety of benefits. IVR exercise has been associated with reductions in fatigue, stress and depression, as well as increases in tranquility and quality of life [26]. In addition, the capacity of IVR exergaming to be physically demanding while enjoyable allows it to be an effective and engaging form of exercise [27]. These advantages, when combined with generally high satisfaction and usage scores, have revealed the potential for IVR to vastly improve health and well-being [28]. Despite these advantages, there is a scarcity of studies testing the efficacy of deception via IVR exercise across different modalities. To the best of our knowledge, this study is the first of its kind to examine the effects of IVR in conjunction with treadmill speed deception.

The results of the present study support the first of our hypotheses, as the mean RPE scores corresponding to the IVR trials were significantly lower than those from the non-IVR trials at 3.5 and 3.7 mph (7.4 and 7.6 versus 8.6 and 9.5; $p < 0.002$, respectively). This finding is consistent with a deceptive study using a training bike conducted by Löchtefeld et al., which found that the manipulation of visual and haptic cues could allow for an increase in the user’s speed by 15.2% without the user’s awareness [29]. Similarly, in regards to resistance training, both a 5% and 10% deceptive increase in loading while leg pressing have been shown to elicit nearly identical strength measures without negatively affecting physical self-efficacy [30]. In contrast to our results, however, Leininger et al. found no difference in RPE between exergaming and matched-intensity treadmill walking [31]. An important distinction between both studies is the use of immersive VR versus twodimensional, VR-only. Being engaged in an IVR environment may heighten dissociation and/or distract the user from the perceived effort of the exercise.

The second of our hypotheses was partially supported. Only the HR response during the trials at 3.7 mph was lower in the IVR group than the non-IVR group (107 bpm versus 115 bpm; $p < 0.049$, respectively). Little research has assessed heart rate trends in protocols that integrate deception and exergaming together, but there is a limited amount of each in isolation. In an IVR exergaming study with geriatric participants, mean HR measurements increased for three out of four individuals between two different training sessions [32]. Furthermore, a comparison between four exergames found that 75% of the exergames produced a lower perceived exertion than actual exertion based on their average heart-rate as a percentage of their maximum heart-rate (66%, 78%, and 55% of maximum heart rate, respectively) [33]. Conversely, in a deceptive treadmill and cycling study, lower heart rate measurements were observed during the condition in which the endpoint was not specified compared to when an endpoint was predetermined [34]. Further research is warranted to evaluate trends in HR during deceptive training in order to provide informed exercise recommendations, such as appropriate training HR zones, for IVR exergaming users.

The findings of the present study may be attributed to several different factors; first, the preservation of teleoanticipation. Previous research has shown that manipulating the endpoint can negatively affect exercise performance by disrupting the anticipatory setting of the pace [35]. Teleoanticipatory pacing strategies are crucial to delay fatigue and optimize performance [36]. The protocol used in this study did not modify the duration of the exercise nor deceive the participants of the endpoint. Hence, participants should have been able to fully complete the exercise without calculated or spontaneous adjustments affecting the use of physiological resources.

Furthermore, the differences in RPE and heart rate between the two conditions may have been a result of the IVR intervention. A commonly reported benefit of IVR is the ability to empower one to escape negative emotions, stresses, and affairs [37]. IVR has even been shown to reduce discomfort and minimize pain to a degree comparable to clinical analgesic treatments [38]. However, the environment in which the user is immersed in also matters. Simulated urban environments have been reported to produce feelings of increased fatigue and decreased levels of self-esteem, whereas nature-based environments have yielded decreased levels of negative emotions (i.e. fatigue, tension, depression, etc.) [39]. In the present study, the selected environment incorporated several different natural elements (e.g., waterfalls, rocks, beaches, unique cloud formations, etc.) into view. It is possible that this environment allowed participants to divert their attention away from daily stressors and the exercise they were performing. Consequently, as we showed, a faster deceptive speed would not be noticed by the user or reflected by their HR response (i.e., autonomic nervous system). Rutkowski et al. recently demonstrated a similar phenomenon through heart rate variability analysis wherein lower heart rate responses during IVR were attributed to reductions in stress levels [40]. They noted the “calming environment” altered autonomic nervous system activity, which was responsible for the observed heart rate behavior with virtual reality immersion.

Practical Recommendations

The implications of these results should serve as a guide for IVR exergaming as it continues to evolve. The lower HR and RPE scores corresponding to exercising with IVR may suggest that it has the potential to lower the perceived difficulty of exercise, which may be particularly beneficial for sedentary individuals. Furthermore, the lower HR and RPE scores produced in the 3.7 mph trials may suggest that IVR may have utility as a ‘deceptive’ exercise intervention. None of the participants reported a conscious awareness of the 5.7% increase in speed, nor was it reflected in their RPE. These results may suggest that participants can perform exercise at a greater intensity while using IVR. Further research is warranted to determine if prolonged IVR training in different simulated environments can yield similar results. Moreover, a threshold for how much intensity (i.e., speed) can be increased before a participant notices should also be studied.

Limitations

This study is not without its limitations. This study could have benefited from a larger sample size to add statistical power. To this end, the sample was almost entirely composed of fit, college-aged individuals. A more diverse sample would have been ideal to improve generalizability. Additionally, due to the design of the protocol, the findings of the present study may be limited to short-term effects of IVR. Future research should be conducted to examine if these effects would be consistent over a prolonged period of time.

Conclusion

The findings of this study suggest that using deception via an immersive virtual reality exergaming experience affects attenuated participant perceived effort and heart rate response without the user noticing the effect.

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Conflicts of Interest

We declare no conflicts of interest and received no funding for this study. Octonic had no role in the study design, data collection, analysis, interpretation, or writing of the manuscript.

Author Contributions

The study was conceived and designed by T.Y., T.K.S., C.A.M., T.L.N., and B.A.D. T.Y., T.K.S., C.A.M., T.L.N., A.E.B., R.J.L., T.H.N., D.M.B., and J.P.F. performed data collection. T.Y., T.K.S., C.A.M., T.L.N., A.E.B., R.J.L., T.H.N., D.M.B., J.P.F., M.S.M., E.V.N. and B.A.D. completed data analysis. T.Y. and T.K.S. interpreted data and composed the manuscript while M.S.M., E.V.N., and B.A.D. made crucial edits. All authors have read and agreed to the published version of the manuscript.

References

1. Wittekind, A.L., Micklewright, D., Beneke, R. (2011). Teleoanticipation in all-out short-duration cycling. *Br J Sports Med*, *45*(2):114-9. doi:10.1136/bjsm.2009.061580
2. Edwards, A.M., Bentley, M.B., Mann, M.E., Seaholme, T.S. (2011). Self-pacing in interval training: A teleoanticipatory approach. *Psychophysiology*, *48*(1):136-41. doi:10.1111/j.1469-8986.2010.01034.x
3. Lambert, E.V., St Clair Gibson, A., Noakes, T.D. (2005). Complex systems model of fatigue: integrative homoeostatic control of peripheral physiological systems during exercise in humans. *British Journal of Sports Medicine*, *39*(1):52-62. doi:10.1136/bjsm.2003.011247
4. Baden, D.A., McLean, T.L., Tucker, R., Noakes, T.D., St Clair Gibson, A. (2005). Effect of anticipation during unknown or unexpected exercise duration on rating of perceived exertion, affect, and physiological function. *Br J Sports Med*, *39*(10):742-6. doi:10.1136/bjsm.2004.016980
5. Coquart, J.B., Garcin, M. (2008). Knowledge of the endpoint: effect on perceptual values. *Int J Sports Med*, *29*(12):976-9. doi:10.1055/s-2008-1038741

6. Tucker, R. (2009). The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. *Br J Sports Med*, *43*(6):392-400. doi:10.1136/bjsm.2008.050799
7. Day, M.L., Mcguigan, M.R., Brice, G., Foster, C. (2004). Monitoring Exercise Intensity During Resistance Training Using the Session RPE Scale. *The Journal of Strength & Conditioning Research*, *18*(2):353-8. doi:10.1519/R-13113.1
8. Williams, N. (2017). The Borg Rating of Perceived Exertion (RPE) scale. *Occupational Medicine*, *67*(5):404-5. doi:10.1093/occmed/kqx063
9. Glass, S.C., Knowlton, R.G., Becque, M.D. (1992). Accuracy of RPE from graded exercise to establish exercise training intensity. *Med Sci Sports Exerc*, *24*(11):1303-7.
10. Lagally, K.M., Robertson, R.J., Gallagher, K.I., Gearhart, R., Goss, F.L. (2002). Ratings of perceived exertion during low- and high-intensity resistance exercise by young adults. *Percept Mot Skills*, *94*: 723-31. doi:10.2466/pms.2002.94.3.723
11. Ceci, R., Hassmen, P. (1991). Self-monitored exercise at three different RPE intensities in treadmill vs field running. *Med Sci Sports Exerc*, *23*(6):732-8.
12. Corbett, J., Barwood, M.J., Ouzounoglou, A., Thelwell, R., Dicks, M. (2012). Influence of Competition on Performance and Pacing during Cycling Exercise. *Medicine & Science in Sports & Exercise*, *44*(3):509-15. doi:10.1249/MSS.0b013e31823378b1
13. Williamson, J.W., McColl, R., Mathews, D., Mitchell, J.H., Raven, P.B., Morgan, W.P. (2001). Hypnotic manipulation of effort sense during dynamic exercise: cardiovascular responses and brain activation. *J Appl Physiol*, *90*(4):1392-9. doi:10.1152/jappl.2001.90.4.1392
14. Finnegan, S.L., Dearlove, D.J., Morris, P., Freeman, D., Sergeant, M., Taylor, S., Pattinson, K.T.S. (2023). Breathlessness in a virtual world: An experimental paradigm testing how discrepancy between VR visual gradients and pedal resistance during stationary cycling affects breathlessness perception. *PLoS One*, *18*(4):e0270721. doi:10.1371/journal.pone.0270721
15. Jones, H.S., Williams, E.L., Bridge, C.A., Marchant, D., Midgley, A.W., Micklewright, D., McNaughton, L.R. (2013). Physiological and Psychological Effects of Deception on Pacing Strategy and Performance: A Review. *Sports Medicine*, *43*(12):1243-57. doi:10.1007/s40279-013-0094-1
16. Pires, F.O., Hammond, J. (2012). Manipulation effects of prior exercise intensity feedback by the Borg scale during open-loop cycling. *British Journal of Sports Medicine*, *46*(1):18-22. doi:10.1136/bjsm.2010.079053
17. Hampson, D.B., St Clair Gibson, A., Lambert, M.I., Dugas, J.P., Lambert, E.V., Noakes, T.D. (2004). Deception and Perceived Exertion during High-Intensity Running Bouts. *Perceptual and Motor Skills*, *98*(3):1027-38. doi:10.2466/pms.98.3.1027-1038
18. Han, D.I.D., Bergs, Y., Moorhouse, N. (2022). Virtual reality consumer experience escapes: preparing for the metaverse. *Virtual Reality*, *26*(4):1443-58. doi:10.1007/s10055-022-00641-7
19. Slater, M., Sanchez-Vives, M.V. (2016). Enhancing Our Lives with Immersive Virtual Reality. *Frontiers in Robotics and AI*, *3*, Article 74. doi:10.3389/frobt.2016.00074
20. North, M.M., North, S.M. (2016). A Comparative Study of Sense of Presence of Traditional Virtual Reality and Immersive Environments. *Australasian Journal of Information Systems*, *20*(0). doi:10.3127/ajis.v20i0.1168
21. Slater, M., Pérez Marcos, D., Ehrsson, H., Sanchez-Vives, M.V. (2009). Inducing illusory ownership of a virtual body. *Frontiers in Neuroscience*, *3*(2), 214-220. doi:10.3389/neuro.01.029.2009
22. Zang, N., Pope, Z., Gao, Z. (2017). Acute Effect of Virtual Reality Exercise Bike Games on College Students' Physiological and Psychological Outcomes. *Cyberpsychology, Behavior, and Social Networking*, *20*(7):453-7. doi:10.1089/cyber.2017.0042
23. Mestre, D.R., Ewald, M., Maiano, C. (2011). Virtual reality and exercise: behavioral and psychological effects of visual feedback. *Annual Review of Cybertherapy and Telemedicine 2011*, 122-7.

24. Dolezal, B.A., Lau, M.J., Abrazado, M., Storer, T.W., Cooper, C.B. (2013). Validity of two commercial grade bioelectrical impedance analyzers for measurement of body fat percentage. *Journal of Exercise Physiology Online*, 16:74.
25. Heyward, V. (2001). ASEP methods recommendation: Body composition assessment. *J Exerc Physiol*, 4.
26. Qian, J., McDonough, D.J., Gao, Z. (2020). The Effectiveness of Virtual Reality Exercise on Individual's Physiological, Psychological and Rehabilitative Outcomes: A Systematic Review. *International Journal of Environmental Research and Public Health*, *17*(11):4133. doi: 10.3390/ijerph17114133
27. Yoo, S., Kay, J. (2016). VRun: running-in-place virtual reality exergame. Proceedings of the 28th Australian Conference on Computer-Human Interaction; Launceston, Tasmania, Australia: *Association for Computing Machinery*, 562–6. doi:10.1145/3010915.3010987
28. Xu, W., Liang, H.N., Baghaei, N., Ma, X., Yu, K., Meng, X., Wen, S. (2021). Effects of an Immersive Virtual Reality Exergame on University Students' Anxiety, Depression, and Perceived Stress: Pilot Feasibility and Usability Study. *JMIR Serious Games*, 9(4):e29330. doi:10.2196/29330
29. Löchtefeld, M., Krüger, A., Gellersen, H. (2016). DeceptiBike: Assessing the Perception of Speed Deception in a Virtual Reality Training Bike System. *Proceedings of the 9th Nordic Conference on Human-Computer Interaction; Gothenburg, Sweden: Association for Computing Machinery*; Article 40. doi:10.1145/2971485.2971513
30. Piper, T., Radlo, S., Gerhardt, K., Brooks, D., Schnaiter, J. (2023). The Effects of Deception on Maximal Strength, Goals, and Physical Self-Efficacy. *International Journal of Strength and Conditioning*, *3*(1). doi:10.47206/ijsc.v3i1.124
31. Leininger, L., Coles, M.G., Gilbert, J.N. (2010). Comparing enjoyment and perceived exertion between equivalent bouts of physically interactive video gaming and treadmill walking. *Health Fitness J*, 3:12-8. doi:10.14288/hfjc.v3i1.49
32. Campo-Prieto, P., Rodríguez-Fuentes, G., Cancela-Carral, J.M. (2021). Immersive Virtual Reality Exergame Promotes the Practice of Physical Activity in Older People: An Opportunity during COVID-19. *Multimodal Technologies and Interaction*, *5*(9):52. doi:10.3390/mti5090052
33. Yoo, S., Ackad, C., Heywood, T., Kay, J. (2017). Evaluating the Actual and Perceived Exertion Provided by Virtual Reality Games. Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems; Denver, Colorado, USA: *Association for Computing Machinery*, 3050–7. doi:10.1145/3027063.3053203
34. Eston, R., Stansfield, R., Westoby, P., Parfitt, G. (2012). Effect of deception and expected exercise duration on psychological and physiological variables during treadmill running and cycling. *Psychophysiology*, *49*(4):462-9. doi:10.1111/j.1469-8986.2011.01330.x
35. Ansley, L., Robson, P.J., St Clair Gibson, A., Noakes, T.D. (2004). Anticipatory pacing strategies during supramaximal exercise lasting longer than 30 s. *Med Sci Sports Exerc*, *36*(2):309-14. doi:10.1249/01.MSS.0000113474.31529.C6
36. Stone, M.R., Thomas, K., Wilkinson, M., Jones, A.M., St Clair Gibson, A., Thompson, K.G. (2012). Effects of deception on exercise performance: implications for determinants of fatigue in humans. *Med Sci Sports Exerc*, *44*(3):534-41. doi:10.1249/MSS.0b013e318232cf77
37. Melancon, J. (2011). Consumer profiles in reality vs fantasy-based virtual worlds: implications for brand entry. *Journal of Research in Interactive Marketing*, *5*(4):298-312. doi:10.1108/17505931111191500
38. Gromala, D., Tong, X., Choo, A., Karamnejad, M., Shaw, C.D. (2015). The Virtual Meditative Walk: Virtual Reality Therapy for Chronic Pain Management. Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems; Seoul, Republic of Korea: *Association for Computing Machinery*:521–4.
39. Yu, C-P., Lee, H-Y., Luo, X-Y. (2018). The effect of virtual reality forest and urban environments on physiological and psychological responses. *Urban Forestry & Urban Greening*, *35*:106-14.

doi:10.1016/j.ufug.2018.08.013
40. Rutkowski, S., Szary, P., Sacha, J., Casaburi, R. (2021). Immersive Virtual Reality Influences Physiologic Responses to Submaximal Exercise: A Randomized, Crossover Trial. *Front Physiol*, *12*, 702266. doi:10.3389/fphys.2021.702266