Study title: Effects of virtual reality on cardiorespiratory fitness test results

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Protocol Title:
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Participants

A power analysis using G*Power version 3.1 will be conducted to determine sample size adequacy. We anticipate a moderate-large effect (d = 0.7) of VR on physiological outcomes based on past studies using similar designs (Rutkowski et al., 2021). With an alpha level of .05 and a power level of .80, an estimated 19 participants will be needed to observe a significant effect on $\dot{V}O_{2peak}$.

To account for participant dropout and missing data, we will recruit an additional 5 participants for a total of 24 participants. The primary means of participant recruitment will be the posting of approved informational flyers throughout the Forrest Hills, Summerville, and Health Science campuses of Augusta University. A secondary means of recruitment will be word-of-mouth. Approved study fliers will also be shared with other instructors at the affiliated institution so that they may announce the study opportunity to their students and share the flier on learning management systems.

Healthy men and (non-pregnant) women 18 years and older will be recruited to take part in this study. Prospective participants will be operationally defined as "healthy" according to results of the 7-item Physical Activity Readiness Questionnaire [PAR-Q; Warburton et al. (2019)]. Answering "yes" to any of the risk assessment questions will result in exclusion from study participation.

Research design

A repeated-measures crossover design will be used in which healthy participants complete a familiarization session and two experimental trials. Experimental days consisted of a maximal graded exercise test with (VR) and without (Control) the use of the immersive VR program separated by at least 1 week. The order of the conditions on the experimental trial days will be counterbalanced and randomized. Cardiometabolic data and psychological responses will be collected during the exercise tests to address the aims of the study. This study will be approved by the associated Institutional Review Board (project 2130870). Written informed consent for each participant will be obtained prior to their participation.

Instruments

A stadiometer and scale (Continental Scale Corp., Bridgeview, IL, USA) were used to measure height and weight of participants. Body composition will be assessed using the InBody 570 bioelectrical impedance analysis device (InBody Co., Ltd, Seoul, South Korea). Participants removed socks and shoes before stepping onto the device. Body composition analysis will be performed according to manufacturer specifications. HR will be measured using a Polar H10 monitor (PolarElectro, Kempele, Finland), a valid and reliable instrument for measuring HR with strong agreement with the electrocardiogram (Schaffarczyk et al., 2022). The H10 monitor is worn on an adjustable belt secured at the xiphoid process over the skin as specified by the manufacturer.

All exercise will be completed on a Velotron cycle ergometer (SRAM, Chicago, IL) which will be paired with software for the investigator to control the intensity (CompuTrainer Inc., Seattle, WA). Expired gases were analyzed in a metabolic cart calibrated on the day of testing to manufacturer specifications (Parvo Medics TrueOne 2400, Marray, UT) via gas collection apparatus (Hans Rudolph Inc., Shawnee, KS). The Meta Quest 2 virtual reality headset (Meta Platforms, Inc., Menlo Park, CA, USA) will be used to run and display the virtual reality video during the VR condition GXT. The video will be a clip from www.YouTube.com which will be

modified using video editing software Adobe Premiere Pro (Adobe Inc., San Jose, CA) to increase speed at each stage of the exercise test to align optical flow with work rate.
The Preferences for and Tolerance of the Intensity of exercise Questionnaire (PRETIE-Q) (Ekkekakis, Hall, & Petruzzello, 2005; Santos & Teixeira, 2023) will be used to assess individual preference for different exercise intensities, information which will be to be used as a covariate when analyzing maximal exercise test outcomes (Hutchinson et al., 2018). Participants completed the questionnaire digitally via the program Qualtrics on a laboratory computer or personal cell phone.

Ratings of perceived exertion (RPE) were collected using the category-ratio 10-point scale. Affective valence will be assessed with the Feeling Scale. Both of these scales were delivered visually on the VR field of view when measurements were to be taken so that participants would be able to see the scale and associated verbal anchors. Remembered pleasure will be assessed using a visual analog scale after each exercise test has been completed and the VR headset has been removed.
Subsequent analysis of the metabolic data to identify $\dot{V}O_{2peak}$ and ventilatory threshold will be completed using the software WinBreak, version 3.1.

Procedures

Visit 1 - Familiarization

During the initial visit to the laboratory, participants will complete the PAR-Q survey, sign the informed consent if eligibility criteria were met, and then complete the PRETIE-Q. Height, weight, and body composition will be measured and recorded. Instructions for the CR-10 RPE scale and the feeling scale will be explained in detail and understanding will be verified by the investigator.

Once the HR monitor has been donned and it is verified to be working properly, the cycle ergometer will be adjusted to the comfort and preference of the participant. The seat height and handlebar positions will be adjusted until optimized for cycling exercise and the positions will be recorded for the participant's future visits.

The participant will be fitted for the headgear that will be worn during maximal exercise tests on subsequent study visits. Plastic headgear is worn to keep the mouthpiece and gas collection hose in place during exercise so that expired air can be analyzed in the metabolic cart. The entire gas collection apparatus (headgear, mouthpiece, and gas collection hose) will be adjusted and worn for a brief warm-up on the exercise bike. The participant will pedal at a cadence of 50-90 rpm at a work rate of 50 Watts for 3 min. Work rate is adjusted and maintained at all times during exercise with the use of paired software installed on a computer adjacent to the exercise bike (CompuTrainer Inc., Seattle, WA). Responses to the CR-10 RPE and Feeling scales will be solicited at the end of minutes 1 and 3, to which participants will respond with designated hand gestures indicating the appropriate response. This process will be intended to increase the participants' familiarity with the exercise and gas collection equipment, reduce setup complications on future visits, and practice non-verbal communication of psychological scale responses.

An additional exercise stage of 3 min will follow this familiarization warm-up, during which the VR headset will be added to the gas collection apparatus. The participant will be walked through how to start the accompanying VR application and pedal for the designated time to ensure proper fit and function of all pieces of equipment simultaneously. Once this familiarization session is complete, the next visit to the lab will be scheduled and the participant will be directed from the lab.

Visits 2 and 3 – Experimental sessions

The procedures for the two experimental session visits will be the same, aside from the use of the VR equipment in one of the visits. The order of the visits (control and VR) will be counterbalanced and randomized prior to the study commencement. Upon arrival to the lab, participants verbally confirmed that they had abstained from alcohol and strenuous exercise for the previous 24 hours and attained at least 6 hours of sleep the night prior to the visit. They will don the HR monitor, review the psychological scales, and adjust the exercise bike as needed. The gas collection apparatus will be donned and the collection tube will be connected from the mouthpiece to a metabolic cart that has been previously calibrated to the manufacturer specifications. The participant will sit on the exercise bike seat and, once ready, pedal against no resistance for 3 minutes as a warm-up. The exercise test will begin after the warm-up by increasing the resistance to 50 W and increasing the work rate by 25 W each minute thereafter until the termination of the exercise test (Bird et al., 2019). RPE and affective valence responses will be collected at the end of every odd numbered minute (end of minutes 1, 3, 5, etc.). Heart rate will be collected continuously and monitored throughout the test. See Figure 1 for visual timeline of data collection.

The test will be terminated upon volitional exhaustion (when the participant feels that they can no longer continue), when the participant fails to maintain cadence > 50 rpm for longer than 10 s, or when a plateau in $\dot{V}O_2$ (<100 ml/min increase with an increase in work rate) is observed (Poole, Wilkerson, & Jones, 2008). A cool-down period of 3 min at 0 W (no resistance) will immediately follow the termination of the exercise test. At the end of the cool-down, participants will complete the remembered pleasure scale. This will mark the end of the visit and the participant will be directed from the lab.

The experimental session visit which for which the VR equipment is used will be identical in all ways to the control condition, with the exception that the VR headset will be worn in addition to the other previously mentioned equipment. A video displaying natural scenery from the viewpoint of a cyclist will be viewed by the participant throughout the exercise test. Once both experimental visits have concluded, the participants' participation in the study is complete.

Figure 1. Data collection timeline during exercise tests

	Stage of Exercise Test												
	Warm-up	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**…**	**Cool down**
Work Rate (W)	0	50	75	100	125	150	175	200	225	250	275	…	0
Duration (min)	3	1	1	1	1	1	1	1	1	1	1	1	3
HR	X	X	X	X	X	X	X	X	X	X	X	X	X
Metabolic data	X	X	X	X	X	X	X	X	X	X	X	X	X
Affective Valence	X	X		X		X		X		X		X	
RPE	X	X		X		X		X		X		X	

"X" = measurement taken at this time point

Procedures for risk management

- **Risk of musculoskeletal injury** – The probability of risk will be reduced primarily by excluding high-risk individuals from participation in the study via the PAR-Q screening questionnaire. Participants will also have a sufficient warm-up time built in to the exercise test to minimize the risk of muscle injury. The gradual increase in work rate over the course of the test will also ensure that physiological demands are reasonable and that risk of muscle injury is limited.
- **Risk of lightheadedness and loss of balance** – the research team members will be standing adjacent to the participant during the exercise test on either side of the equipment to prevent the participant from falling off of the bike in the event of excessive fatigue and shortness of breath during and following the exercise. The investigator will also emphasize that the participant is able to terminate the test at any time for any reason, including severe shortness of breath or lightheadedness, simply by ceasing to pedal on the bike. A sufficient cool down period (3 minutes of cycling at no resistance) will be used to prevent blood from pooling in the veins of the lower body and ensure that blood circulation to the brain and the rest of the body continues after the exercise test has ended.
- **Dehydration** – an unopened bottle of drinking water will be made available to the participant at the start of the study. The participant will be allowed to drink *ad libitum* before and after the exercise test. Drinking water during the test is not possible when the facemask is being worn for data collection purposes.
- **Muscle soreness** – some muscle soreness after a maximal exercise test is unavoidable, but the discomfort participants might encounter will be reduced by ensuring participants have a cool down period after the test.
- **Dizziness or disorientation using VR equipment –** There is a small chance that some participants will become disoriented or dizzy when viewing the VR video. A chance to use the VR equipment in Visit 1 will allow participants to familiarize themselves with the technology, note any adverse symptoms, and decide if further participation is feasible. Investigators will be adjacent to participants whenever the VR equipment is used to ensure no falls or loss of balance results.

References

Bird, J. M., Karageorghis, C. I., Baker, S. J., & Brookes, D. A. (2019). Effects of music, video, and 360-degree video on cycle ergometer exercise at the ventilatory threshold. *Scandinavian journal of medicine & science in sports*, *29*(8), 1161-1173. https://doi.org/10.1111/sms.13453

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise*, *14*(5), 377-381.

Ekkekakis, P., Hall, E. E., & Petruzzello, S. J. (2005). Some like It vigorous: Measuring individual differences in the preference for and tolerance of exercise intensity. *Journal of Sport and Exercise Psychology*, *27*(3), 350-374. https://doi.org/10.1123/jsep.27.3.350

Farrow, M., Lutteroth, C., Rouse, P. C., & Bilzon, J. L. J. (2019). Virtual-reality exergaming improves performance during high-intensity interval training. *European journal of sport science*, *19*(6), 719-727. https://doi.org/10.1080/17461391.2018.1542459

Gillman, A. S., & Bryan, A. D. (2020). Mindfulness versus distraction to improve affective response and promote cardiovascular exercise behavior. *Annals of Behavioral Medicine*, *54*(6), 423-435. https://doi.org/10.1093/abm/kaz059

Grannell, A., & De Vito, G. (2018). An investigation into the relationship between heart rate variability and the ventilatory threshold in healthy moderately trained males. *Clinical Physiology and Functional Imaging*, *38*(3), 455-461. https://doi.org/10.1111/cpf.12437

Hardy, C. J., & Rejeski, W. J. (1989). Not what, but how one feels: The measurement of affect during exercise. *Journal of Sport and Exercise Psychology*, *11*(3), 304-317. https://doi.org/10.1123/jsep.11.3.304

Hoogeveen, A. R., Schep, G., & Hoogsteen, J. (1999). The ventilatory threshold, heart rate, and endurance performance: Relationships in elite cyclists. *International Journal of Sports Medicine*, *20*(02), 114-117. https://doi.org/10.1055/s-2007-971103

Hutchinson, J. C., Jones, L., Vitti, S. N., Moore, A., Dalton, P. C., & O'Neil, B. J. (2018). The influence of self-selected music on affect-regulated exercise intensity and remembered pleasure during treadmill running. *Sport, Exercise, and Performance Psychology*, *7*, 80-92. https://doi.org/10.1037/spy0000115

Leprêtre, P.-M., Bulvestre, M., Ghannem, M., Ahmaidi, S., Weissland, T., & Lopes, P. (2013). Determination of ventilatory threshold using heart rate variability in patients with heart failure. *Surgery*, *12*(3), 1-6. https://doi.org/10.4172/2161-1076.S12-003

Liguori, G. (2020). *ACSM's Guidelines for Exercise Testing and Prescription*. Lippincott Williams & Wilkins.

Lind, E., Welch, A. S., & Ekkekakis, P. (2009). Do 'mind over muscle' strategies work? *Sports Medicine*, *39*(9), 743-764. https://doi.org/10.2165/11315120-000000000-00000

Midgley, A. W., Earle, K., McNaughton, L. R., Siegler, J. C., Clough, P., & Earle, F. (2017). Exercise tolerance during VO2max testing is a multifactorial psychobiological phenomenon. *Research in Sports Medicine*, *25*(4), 480-494. https://doi.org/10.1080/15438627.2017.1365294

Poole, D. C., & Jones, A. M. (2017). Measurement of the maximum oxygen uptake V̇o2max: V̇o2peak is no longer acceptable. *Journal of applied physiology*, *122*(4), 997-1002. https://doi.org/10.1152/japplphysiol.01063.2016

Poole, D. C., Wilkerson, D. P., & Jones, A. M. (2008). Validity of criteria for establishing maximal O_2 uptake during ramp exercise tests. *European Journal of Applied Physiology*, *102*(4), 403-410. https://doi.org/10.1007/s00421-007-0596-3

Rutkowski, S., Szary, P., Sacha, J., & Casaburi, R. (2021). Immersive virtual reality Influences physiologic responses to submaximal exercise: A randomized, crossover trial. *Frontiers in Physiology*, *12*. https://doi.org/10.3389/fphys.2021.702266

Santos, F., & Teixeira, D. (2023). Are preference and tolerance measured with the PRETIE-Q (Preference for and Tolerance of the Intensity of Exercise Questionnaire) relevant constructs for understanding exercise intensity in physical activity? A scoping review. *Kinesiology Review*, 1. https://doi.org/10.1123/kr.2023-0021

Warburton, D. E. R., Jamnik, V., Bredin, S. S. D., Shephard, R. J., & Gledhill, N. (2019). The 2020 Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and electronic Physical Activity Readiness Medical Examination (ePARmed-X+): 2020 PAR-Q+. *The Health & Fitness Journal of Canada*, *12*(4), 58-61. https://doi.org/10.14288/hfjc.v12i4.295

Zeng, 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), 453-457. https://doi.org/10.1089/cyber.2017.0042