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The effects of competitiveness and challenge level on virtual reality rowing performance

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ABSTRACT

Objectives: The aim of the study was to test the effect of rowing against a moderately challenging competitor compared to an extremely challenging competitor on performance and motivation. The effect of trait competitiveness was also examined.

Design: Sixty-seven male participants were classified as either low (n = 34) or high in competitiveness (n = 33) and assigned to either a moderate or extreme challenge condition.

Method: Participants initially rowed to set a baseline level of performance. Participants rowed again but were accompanied by an on-screen competitor that was set to a speed higher than the baseline performance to create a moderate (5% higher) or extreme (20% higher) challenge level.

Results: The pattern of performance differed between the challenge conditions. Participants in the extreme challenge condition showed an initial high level of power output and distance rowed, but subsequently showed a steep decline in performance that persisted until the end of the row. In contrast, participants in the moderate challenge condition showed a lower initial level of performance followed by a more gradual decline. Moreover, these participants showed a trend of increasing performance towards the end of the row, whereas participants facing an extremely challenging competitor showed a trend of decreasing performance. Trait competitiveness did not moderate the pattern of results.

Conclusions: The findings show that challenge level should be considered in the design of VR-based exercise programs and in matching competitive interactions among exercisers in virtual environments.

1. Introduction

Regular physical exercise is associated with increased physical and psychological well-being (Gerber et al., 2014). Additionally, evidence suggests that exercise intensity is an important factor, with intensity being positively related to the health benefits gained (Swain & Franklin, 2006). Despite this evidence, high levels of physical inactivity are prevalent internationally, with approximately 30% of adults not sufficiently active in high-income countries (World Health Organization, 2017). Finding new ways to increase exercise participation and intensity could have beneficial effects for an individual's health and well-being and attenuate the increasing financial burden of health care on governments (Cadilhac et al., 2011).

One technology that has shown potential to facilitate exercise participation and performance is virtual reality (VR). Recent advances in the accessibility and affordability of consumer technology have made the use of VR during training and exercise a realistic tool for amateur athletes and recreational exercisers. VR is a technology that allows a user to interact with and feel immersed in a virtual world (Neumann, 2016; Neumann et al., 2017). Interaction in VR-based exercise is commonly achieved through an exertion interface, such as a treadmill or ergometer, whereby the person's actions on a machine are translated into movement in the virtual environment. As reviewed by Neumann (2016), different sporting and exercise contexts have been investigated, including cardiovascular tasks like walking and running (Nunes, Nedel, & Roesler, 2014), cycling (Anderson-Hanley, Snyder, Nimon, & Arciero, 2011; Plante, Aldridge, Bogden, & Hanelin, 2003), and rowing (Hoffman, Filippeschi, Ruffaldi, & Bardy, 2014; Murray, Neumann, Moffitt, & Thomas, 2016).

The application of VR has the potential to influence a range of outcomes, including performance, physiological, and psychological effects that are observed concurrently or following exercise (Neumann et al., 2017). Some evidence suggests that the use of VR can increase physical exertion during exercise (Plante, Aldridge et al., 2003) and long-term adherence to an exercise program (Annesi & Mazas, 1997). However, the beneficial effects from VR-based exercise are not always

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observed (Legrand, Joly, Soudain-Pineau, & Marcel, 2011; Plante, Frazier et al., 2003). The differences in findings across studies suggests that there may be multiple factors that can impact upon outcomes and that further research is needed to better understand these factors, particularly those that are salient to VR technology.

Current VR technology allows for other individuals to be present in the virtual environment, even if they are physically located in a different geographic location, and this social dimension could have a major influence on how individuals respond to VR-based exercise. For example, Murray et al. (2016) investigated rowing performance in a virtual environment when the rower was alone or with a team-mate present. Participants rowing with a team-mate showed a higher heart rate and rowed a greater distance than participants rowing alone. Improvements in performance in the presence of others can be explained using the theories of social facilitation (Zajonc, 1965) and social comparison (Festinger, 1954). However, such explanations tend to apply only for non-competitive scenarios.

The introduction of a competitive scenario has traditionally been regarded as a motivating factor that will increase performance (Murayama & Elliot, 2012). It has been argued that the effect of competition on performance will vary depending on individual differences (Anderson-Hanley et al., 2011). As such, the introduction of a competitor does not always lead to a performance increase. For example, evidence has suggested that competition can result in decreased intrinsic motivation for some people (Reeve & Deci, 1996), leading to reduced adherence to exercise or burnout (Cresswell & Eklund, 2005; Ryan, Frederick, Lepes, Rubio, & Sheldon, 1997). As such, it is important to consider the specific factors of the competitive scenario and of the individual that may moderate exercise performance and motivation.

One such factor is the trait of competitiveness. Trait competitiveness has been described as an individual's preference towards competing with others in achievement situations (Murayama & Elliot, 2012). Moreover, it has been defined not just as a preference towards competition, but also as the desire to win in competitive situations (Smither & Houston, 1992). Recent research has begun to explore trait competitiveness in VR exercise contexts. In one such study, cycling performance of older adults was examined in a virtual cycling game with a virtual competitor present (Anderson-Hanley et al., 2011). When in the presence of a virtual competitor, participants low in competitiveness showed a slight increase in performance from baseline (when no competitor was present), while participants high in competitiveness showed a substantial increase in performance. These findings were later replicated by Snyder, Anderson-Hanley, and Arciero (2012) in a sample of young women. Snyder et al. (2012) also found that competitiveness moderated exercise intensity (power output) depending on whether a competitor was present or not. Participants high in competitiveness showed greater exercise intensity when in the presence of a live competitor than when they believed the competitor was a computer-controlled avatar. Additionally, the exercise intensity of participants low in competitiveness did not differ between either types of competitor. In addition to power output, Snyder et al. (2012) also measured exercise intensity using the physiological measure of heart rate, which did not differ between competitiveness groups. However, heart rate is only one of many physiological indices of exertion, and it is currently unclear whether differences exist between competitiveness groups in other measures (e.g. VO_2, VCO_2) when in a competitive scenario.

Another factor of the VR-based competitive scenario that might affect performance and motivation is the challenge level presented by a competitor. Social comparison theory suggests that people have a drive to assess their own performance against the performance of others in the environment (Corning, Krumm, Angela, & Smitham, 2006). For example, Plante, Madden, Mann, and Lee (2010) conducted a non-VR based study involving stationary bike riding. Performance, as measured through physiological and perceived exertion, was compared between participants who were riding with either a high fit or low fit riding partner. While both groups were told to maintain a moderate heart rate throughout the ride, participants paired with a high fit partner had significantly higher heart rates and perceived exertion than participants paired with a low fit partner. These findings suggest that participants compared their performance to their partner's perceived performance and adjusted appropriately to match the partner. Currently, it is unclear what effect social comparison might have on performance in a competitive scenario when comparisons are made with a competitor of varying level of ability.

In VR-based exercise there is the potential for users to interact or compete with others who might be substantially different in ability to themselves. Having a highly challenging partner in the virtual environment could be detrimental. Park, Yoo, Choe, Park, and Song (2012) found that differences in the physical ability of participants affected exertion during an exercise video game task that incorporated running on a treadmill. One participant reported that they could not maintain the pace of the other participant and felt that they had overexerted themselves. Importantly, overexertion and burnout are related to reduced motivation (Cresswell & Eklund, 2013; Gould, 1996) and lower likelihood of training adherence (Parfitt, Olds, & Eston, 2015). In related research, it has been shown that striving to match an unrealistic exercise goal can be detrimental to performance. In a non-VR study investigating sit-up performance, participants given an extreme challenge of increasing their sit-up by 40% showed less improvement after 4 weeks than participants given a moderate challenge of a 20% increase (Bar-Eli, Tenenbaum, Pie, Btesch, & Almog, 1997). Given evidence suggesting that individuals low in trait competitiveness experience a performance and motivation decrement in competitive scenarios, it is possible that performance decrements would be magnified in these individuals with the addition of a virtual competitor who would be an extreme challenge to defeat. Conversely, individuals high in competitiveness may experience less of a performance decrement when facing an extremely challenging competitor because of their greater motivation to win.

The current study used an ergometer rowing task in a VR environment to test the effects of competitiveness and challenge level on performance and psychological outcomes. Participants initially rowed alone in the environment to establish a baseline level of performance. Subsequently, participants rowed against a virtual competitor who rowed 5% or 20% further than they did at baseline. Performance measures such as metres rowed, stroke rate, and power output, as well as measures of physiological and psychological effort such as perceived exertion, heart rate, and respiration frequency were measured to test three hypotheses. First, participants high in competitiveness were expected to row more metres, show higher power output, and exert greater physiological effort than those low in competitiveness. Second, the extreme challenge condition was expected to elicit a detrimental effect on performance as shown by fewer metres rowed, lower power output, and less physiological effort exerted than the moderate challenge condition. Third, these detrimental effects of an extreme challenge was expected to be enhanced for participants low in competitiveness than for participants high in competitiveness.

2. Method

2.1. Participants

A power calculation employing G*Power version 3.1 indicated a minimum total sample size of 57 using the input estimates of power = 0.90, α = 0.05, and effect size f = 0.44, with the effect size based on performance differences between high and low trait competitiveness individuals in virtual cycling with a competitor (f = 0.66; Anderson-Hanley et al., 2011) and the effect of the presence of a more capable virtual other in VR rowing (f = 0.34; and 0.32; Murray et al., 2016). Sixty-seven male novice rowers with a mean age of 23.37 years (*SD* = 5.78) were recruited from a psychology credit participation scheme. Participants were assigned to a moderate challenge condition (n = 35) or an extreme challenge condition (n = 32) through matched assignment based on level of competitiveness, age, body mass index (BMI), and physical activity level as measured by the International Physical Activity Questionnaire – Long Form (IPAQ-LF; Craig et al., 2003). Challenge conditions did not differ in mean age (t = 0.42, p = .674), BMI (t = 0.33, p = .746), or IPAQ-LF categories, Likelihood ratio = 3.98, p = .142. The moderate challenge condition included 3 low, 15 moderate, and 17 high activity level participants, while the extreme challenge condition included 1 low, 8 moderate, and 23 high activity level participants. Additionally, no significant difference in METS mins per week was found between the moderate challenge (M = 4662.74, SD = 4136.73) and extreme challenge conditions (M = 6682.22, SD = 4721.54), F (1, 65) = 3.48, p = .067. Informed consent was obtained to a protocol granted ethical approval from the institutional review board.

2.2. Apparatus

The rowing task used a Concept 2 Model D Indoor Rowing ergometer set with a drag factor of 105, which corresponds to a moderate level of resistance. The PM3 monitor of the rower was covered from view. Participant's heart rate was collected using a wireless Polar Electro T31 chest heart rate monitor in conjunction with an Acumen receiver. Respiratory measures were acquired with an 8/35 PowerLab (ADInstruments, Sydney) data acquisition system using a sampling rate of 1000 Hz (Neumann & Thomas, 2009, 2011). Gas exchange was acquired with a Gas Analyser (ADInstruments ML206) via a Gas Mixing Chamber (ADInstrumens MLA246). Additionally, air temperature from the gas mixing chamber was measured using a Thermistor Temperature Sensor (ADInstruments MLT415/M) attached to a Thermistor Pod (ADInstruments ML309). Participants wore a medium sized face mask (ADInstruments MLA1029) which separated inspired and expired air prior to gas exchange analysis.

The VR environment was created using Netathlon 2 XF software interfaced with the ergometer and projected 2.5 m × 1.35 m in size in front of the ergometer with a MW870UST BenQ data projector. Participants were positioned approximately 2 m from the screen when in the catch position of the row and were given a first-person view of the VR environment, looking in the direction of travel. Markers representing the position of the participant's and competitor's boats on the course were visible at the top of the screen, allowing the participant to be aware of the competitor even when they were not visible in the first-person view.

2.3. Measures

2.3.1. Performance and physiological measures

Distance rowed, power output, stroke rate, and heart rate were quantified in 1 s intervals using the Netathlon 2 XF software. Physiological effort was measured using heart rate, oxygen consumption (VO_2), carbon dioxide production (VCO_2), volume of expired air corrected for body temperature and pressure (V_E (BTPS)), respiration frequency, and respiration exchange ratio (RER).

2.3.2. Sports medicine Australia (SMA; Sports Medicine Australia, 2005) pre-exercise screening system

The SMA pre-exercise screening system assessed whether a potential participant was at a high risk of experiencing complications from exercise. The screening system includes 17 Yes or No questions regarding a person's health and exercise history. No participants were excluded.

2.3.3. International Physical Activity Questionnaire – long form (Craig et al., 2003)

The IPAQ-LF is a standardised measure of physical activity. The long form version is a comprehensive evaluation of time spent on any physical activity ranging from sitting to intense exercise. In a study of the IPAQ-LF across 12 countries, Craig et al. (2003) reported good test-retest reliability (most ρ < .80) as well as good concurrent and criterion validity.

2.3.4. Borg rating of perceived exertion scale (RPE; Borg, 1982)

The Borg RPE requires participants to rate their perceived exertion using a single item rating scale from 6 (*no exertion at all*) to 20 (*maximal exertion*). The RPE has a strong positive linear correlation (r = .8 to .9) with heart rate (Borg, 1982) and high test-retest reliability (r ≥ .9) and validity in endurance sports (Ceci & Hassmen, 1991).

2.3.5. Revised competiveness index (RCI; Houston, Harris, McIntire, & Francis, 2002)

The RCI is a 14 item measure of interpersonal competitiveness and uses a 5-point Likert response format (1 = *Strongly disagree* to 5 = *Strongly agree*). Scores range from 14 to 70 with higher scores indicating higher competitiveness. The RCI has good internal consistency (Cronbach's α = .90) and strong convergent validity with other self-report measures of competitiveness (Houston et al., 2002). In the present study, scores ranged from 28 to 65 and showed good internal consistency (Cronbach's α = .85).

2.3.6. Intrinsic motivation inventory (IMI; Ryan, 1982)

The IMI is a multidimensional questionnaire measuring subjective experience in goal-related laboratory experiments. The IMI was completed twice. Internal consistency (Cronbach's α) was good on both occasions for Interest/Enjoyment of .94 and .92, and Perceived Competence of .93 and .94. The subscale of Pressure/Tension showed acceptable internal consistency in the first administration (α = .71), but was lower on the second administration (α = .60). The Perceived Choice subscale showed lower internal consistency of α = .55 and .60 for the first and second instances, respectively.

2.3.7. Reality Judgment and presence questionnaire (RJPQ; Baños et al., 2000)

The RJPQ is an 18 item measure of three dimensions regarding experiences in a VR environment: Reality Judgment, Internal/External Correspondence, and Attention/Absorption. Evidence of good internal consistency for the overall RJPQ has been found, with a Cronbach's α = .82 (Baños et al., 2000), although subscale internal consistencies have not been reported. Item 18 was reworded to increase suitability with the equipment used in the present study. The three subscales of the RJPQ were administered twice with respective Cronbach's α of .90 and .96 for the Reality Judgment subscale, .84 and .90 for the Internal/External Correspondence subscale, and .83 and .89 for the Attention/Absorption subscale.

2.4. Procedure

After providing informed consent, participants completed the SMA Pre-Exercise Screening System (Sports Medicine Australia, 2005), the IPAQ-LF, and height and weight were measured. Participants were fitted with a heart rate monitor and watched an instructional video on correct ergometer rowing technique as demonstrated by an expert rower. Next, participants were fitted with the face mask to measure gas exchange and given instructions regarding the use of the Borg RPE. Participants completed 5 min of free rowing with no visual display for warm up and familiarisation. Next, participants were shown the VR environment and were informed that the speed of their boat was dependent on their stroke rate and power output. Participants were informed that they would complete two rows of 9 min duration.

The first row (baseline row) was used to establish the performance of participants without a competitor present and to obtain a measure of performance that could be used to set the speed of a competitor avatar in the second row. Before the baseline row, participants were told that their performance would be recorded and that it was important for the experiment that they try their best to row as far as they can in the given time. Participants were instructed to take up the rowing handle and to begin rowing as soon as the given countdown finished. Participants were prompted to rate their perceived exertion using the Borg RPE at the 3, 6, and 9 min points during the row. At the completion of the row participants were given a resting period of 15 min during which they completed the RJPQ, IMI, and RCI. Participants completed the RJPQ and IMI only at the end of the row because the questions related to their experiences during the row. The RCI was completed only after the row to avoid prematurely revealing the competitive nature of the second row. The questionnaires also extended the break in between the two rows and allowed participants to fully recover.

The second row (competitive row) was completed after the rest period. Participants were assigned to either a moderate challenge level or an extreme challenge level. The first 20 participants in the experiment were allocated to a challenge level at random. Subsequent participants were allocated to challenge level using matched assignment with one of the first 20 participants. Matching was based on baseline distance, RCI score, IPAC-LF activity level, BMI, and age. Participants were instructed that they had been randomly matched with a pre-recorded competitor from another campus of the university based on their age, BMI, and IPAQ-LF activity level. Further, participants were told that their competitor rowed a distance that equated to 5% (moderate challenge condition) or 20% (extreme challenge condition) further than them in the first row. In both conditions, however, participants actually competed against a computer-controlled avatar that was set to row at a constant speed congruent with the challenge condition (e.g., the avatar rowed 20% further than the participant's first row in the extreme challenge condition). Regardless of the challenge condition, participants were told to row to the best of their ability. During the row, participants rated their perceived exertion at the 3, 6, and 9 min points. After completing the row, participants completed the RJPQ and IMI.

At the end of the experiment, participants were asked a series of questions regarding their belief in the competitor cover story. No participants were excluded from further analyses on the basis of their responses to these questions. Participants were lastly debriefed and thanked for their participation.

2.5. Scoring and statistical analysis

Spiroergometry data were scored to obtain measures of VO_2, VCO_2, V_E (BTPS), respiration frequency, and RER. The measures were scored using the Metabolic module of the LabChart (ADInstruments, Sydney) software package across 30 s epochs. A preset air flow detection setting with a 0.5 SD threshold was used to determine respiration frequency. Additionally, a 2-point calibration was applied for the VO_2 and VCO_2 measurements. Prior to statistical analysis, performance and physiological measures were converted to 1.5 min epoch scores to create six epochs for analysis. For each 1.5 min epoch, distance was summed, while power, stroke rate, and physiological measures were averaged.

Following data screening, one participant was excluded from analyses because of performing in excess of 3 standard deviations below the mean in both rows. Another participant was excluded because they stopped during the competitive row. Heart rate data was not recorded for two participants in the baseline row and one participant in the competitive row due to equipment failure. Additionally, due to equipment problems, all other physiological measures were not recorded for five participants in the baseline row and four participants in the competitive row. In cases where there was missing data for an entire measure, the participant was excluded from the statistical analyses for that measure but was included for the analyses of the other measures. In cases where data was collected for a measure but there was a missing value for one or more epochs (e.g. due to movement artefact), linear interpolation was used to replace the missing value. Approximately 3.97% of physiological data measured during the baseline row and 0.64% measured during the competitive row was missing. A median split procedure using RCI scores was conducted to classify participants into either low ($M = 43.47$, $n = 34$) or high ($M = 56.20$, $n = 33$) competitiveness groups.

Initial analyses used ANOVAs to test for performance or physiological differences between challenge level and competitiveness groups in the baseline row. To avoid order effects, subsequent ANOVAs were conducted on all measures only for the competitive row between the challenge levels and competitiveness groups, rather than between the baseline performance and competitive row performance. The factor of epoch was included as a within-subjects variable for those dependent measures where relevant. In cases of a violation of the assumption of sphericity, the Huynh-Feldt correction was applied, with adjusted degrees of freedom reported. Significant positive skew was present in the baseline row for RER, and in both rows for VO_2, VCO_2, and V_E (BTPS). Square root transformations were conducted to normalise the distributions. Further analyses used trend analysis to investigate the changes in performance across epochs or *t*-tests with α-adjusted Bonferroni corrections to investigate pairwise differences.

3. Results

3.1. Baseline row

As shown in Table 1, performance and physiological measures differed across epochs. Separate 2 (challenge level) × 2 (competitiveness) × 6 (epoch) mixed model ANOVAs were conducted for all performance and physiological measures. No significant three or two-way interactions were found for any measure, all $Fs < 2.66$, all $ps > .05$. The baseline row also acted as a manipulation check for differences between the challenge level groups. As expected, there was no significant main effect of challenge level for any measure at baseline, all $Fs < 1.25$, all $ps > .05$, confirming that there were no differences between the challenge levels prior to the experimental manipulation of the competitive row.

However, performance in the baseline row differed as a function of competitiveness, as reflected in a significant main effect of competitiveness for distance, $F\ (1, 61) = 5.50$, $p = .022$, $\eta_p^2 = .08$, and power, $F\ (1, 61) = 5.81$, $p = .019$, $\eta_p^2 = .09$, but not for stroke rate, $F\ (1, 61) = 3.34$, $p = .072$. The main effect of competitiveness was not significant for the physiological measures, all $Fs < 3.97$, all $ps > .05$. These results suggest participants high in competitiveness rowed further than participants low in competitiveness by outputting more power on each stroke, with no significant increased physiological cost.

Analyses also showed a significant main effect of epoch for distance, $F\ (1, 109) = 17.03$, $p < .001$, $\eta_p^2 = .22$, and power, $F\ (1, 101) = 24.05$, $p < .001$, $\eta_p^2 = .28$, but not for stroke rate, $F\ (2, 135) = 2.59$, $p = .073$. The main effect of epoch was significant for all physiological measures, all $Fs > 8.16$, all $ps < .001$, all $\eta_p^2 > .13$, except for RER, $F\ (2, 159) = 1.11$, $p = .345$. Further analyses conducted for distance rowed indicated that there was a significant linear, $F\ (1, 61) = 14.03$, $p < .001$, $\eta_p^2 = .19$, and quadratic trend, $F\ (1, 61) = 47.15$, $p < .001$, $\eta_p^2 = .44$, across epochs. Taking the measures together, the results indicated that participants maintained a consistent stroke rate throughout the baseline row, but varied in their effort exerted on each stroke. As such, a linear decline of mean distance travelled was observed over the first 6 min before a relative increase in the last 3 min. This trend was reflected in the physiological data, which showed a linear increase in effort exerted over the first half of the row before a flattening out, and then followed by another increase in effort at 6 min.

A 2 (challenge level) × 2 (competitiveness) × 3 (epoch) mixed model ANOVA was conducted to test for differences between the difficulty groups and competitiveness levels for perceived exertion. A significant main effect of epoch was found, $F\ (2, 122) = 186.01$, $p < .001$, $\eta_p^2 = .75$, with perceived exertion increasing across time.

Table 1
Means and Standard Deviations (in parentheses) for the Dependent Measures in the Baseline Row in the Low and High Competitiveness Groups.

Measure	Epoch					
	1.5 min	3 min	4.5 min	6 min	7.5 min	9 min
Low Competitiveness Group						
Distance (m)	325.6 (47.8)	315.8 (37.3)	307.2 (34.9)	306.1 (34.9)	308.2 (34.5)	309.9 (35.2)
Power Output (watts)	146.3 (56.5)	126.9 (40.6)	117.1 (36.3)	115.4 (36.0)	117.8 (36.8)	120.8 (39.4)
Stroke Rate (SPM)	30.6 (5.5)	30.8 (5.2)	30.2 (4.7)	29.7 (4.4)	30.1 (5.0)	30.2 (4.5)
Heart Rate (BPM)	135.8 (17.8)	154.1 (20.2)	156.1 (19.7)	157.2 (19.0)	158.6 (17.4)	162.7 (15.1)
VO_2 (L/Min)	0.038 (0.030)	0.046 (0.035)	0.050 (0.037)	0.050 (0.041)	0.052 (0.043)	0.051 (0.039)
VCO_2 (L/Min)	0.038 (0.031)	0.047 (0.038)	0.051 (0.040)	0.051 (0.044)	0.053 (0.047)	0.053 (0.043)
RER	0.91 (0.32)	0.94 (0.27)	0.95 (0.27)	0.92 (0.32)	0.94 (0.27)	0.91 (0.32)
V_E (BTPS) (L/Min)	0.19 (0.15)	0.25 (0.19)	0.25 (0.20)	0.25 (0.22)	0.26 (0.23)	0.27 (0.21)
Respiratory Frequency (Hz)	0.49 (0.16)	0.54 (0.19)	0.58 (0.20)	0.57 (0.20)	0.59 (0.20)	0.60 (0.21)
Perceived Exertion	–	12.41 (1.48)	–	13.91 (1.84)	–	15.16 (1.78)
High Competitiveness Group						
Distance (m)	346.8 (41.5)	336.2 (34.2)	329.5 (34.3)	325.6 (34.6)	325.9 (37.5)	328.8 (33.3)
Power Output (Watts)	173.4 (58.2)	151.7 (43.8)	143.3 (42.0)	138.6 (41.1)	140.0 (46.1)	143.9 (44.7)
Stroke Rate (SPM)	31.9 (4.8)	32.2 (4.8)	32.0 (4.3)	31.9 (4.4)	32.3 (4.3)	33.0 (4.6)
Heart Rate (BPM)	130.2 (37.5)	150.4 (42.7)	153.4 (43.2)	155.9 (43.8)	157.0 (44.1)	160.0 (44.5)
VO_2 (L/Min)	0.055 (0.032)	0.062 (0.037)	0.063 (0.037)	0.062 (0.038)	0.070 (0.038)	0.073 (0.040)
VCO_2 (L/Min)	0.058 (0.037)	0.066 (0.044)	0.068 (0.042)	0.066 (0.042)	0.074 (0.041)	0.077 (0.045)
RER	0.97 (0.28)	0.97 (0.28)	0.98 (0.29)	0.97 (0.28)	0.97 (0.28)	0.97 (0.28)
V_E (BTPS) (L/Min)	0.26 (0.17)	0.31 (0.20)	0.32 (0.20)	0.32 (0.20)	0.36 (0.19)	0.38 (0.20)
Respiratory Frequency (Hz)	0.50 (0.21)	0.55 (0.21)	0.58 (0.24)	0.59 (0.24)	0.61 (0.25)	0.63 (0.26)
Perceived Exertion	–	12.49 (1.92)	–	14.42 (2.02)	–	15.79 (2.07)

Note. VO_2 and VCO_2 shown to three decimal places to ensure precision. BPM = Beats per min, SPM = Strokes per min.

Table 2
Means (M) and standard deviations (SD) for the intrinsic motivation inventory (IMI) and reality judgement and presence questionnaire (RJPQ) following both rows in the moderate and extreme challenge conditions.

Measure	Baseline Row				Competitive Row			
	Moderate Difficulty		Extreme Difficulty		Moderate Difficulty		Extreme Difficulty	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
IMI								
Interest/Enjoyment	4.95	1.02	4.95	1.46	5.14	0.94	4.82	1.44
Perceived Competence	4.76	1.30	4.54	1.16	4.91	1.40	4.21	1.36
Perceived Choice	5.89	0.78	6.08	0.74	5.97	0.79	6.10	0.81
Pressure/Tension	2.95	0.92	3.01	1.28	3.21	1.02	3.26	1.24
RJPQ								
Reality Judgment	41.21	11.34	42.40	12.21	43.52	14.02	43.00	15.10
Internal/External Correspondence	32.67	8.53	35.13	8.24	36.40	10.51	36.20	9.12
Attention/Absorption	17.28	7.52	17.88	7.98	22.64	7.98	21.47	9.02

No other significant main effects or interactions were found, all *Fs* < 2.99, all *ps* $> .05$. Table 2 shows means and standard deviations for the IMI and RJPQ subscale scores. As a manipulation check, a 2 (challenge level) × 2 (competitiveness) between-groups ANOVA was conducted to test for differences between challenge conditions and competitiveness levels on the subscales of the IMI and RJPQ administered following baseline performance. No significant main effects or interactions were found for any of the subscales, all *Fs* < 1.50, all *ps* $> .05$. Finally, mean total competitiveness scores for the moderate challenge level ($M = 50.33$, $SD = 7.72$) and the extreme challenge level ($M = 49.84$, $SD = 8.27$) were examined and no significant differences were found, t (63) = 0.86, $p = .392$. These findings suggest that there was no difference between the challenge level groups in any of the self-report measures prior to the competitive row manipulation.

3.2. Competitive row

As shown in Table 3, performance and physiological measures in the competitive row differed across epochs and between challenge conditions. Fig. 1 illustrates that the differences in distance and power are reflected in a different trend of performance across epochs between the challenge difficulty groups.

A significant main effect of epoch was found for all performance measures, all *Fs* > 9.56, all *ps* $< .001$, all $\eta_p^2 > .13$, showing a general decline in performance across time before stabilising in the last 3 min. However, the trend across epochs differed across challenge level groups, as reflected in a significant challenge level × epoch interaction for distance, F (2, 153) = 5.07, $p = .004$, $\eta_p^2 = .08$, and power, F (2, 150) = 6.57, $p = .001$, $\eta_p^2 = .10$, but not for stroke rate, F (2, 149) = 1.30, $p = .276$. The interactions were investigated further by examining the effect of epoch separately for each challenge condition. As can be seen in Fig. 1, participants in the extreme challenge condition began the row with a relatively high performance output in the first 1.5 min, but subsequently showed a steep decline in performance and a further reduction in the final 1.5 min. This pattern was supported by a significant cubic trend across epochs for distance rowed, F (1, 30) = 20.26, $p < .001$, $\eta_p^2 = .40$, and power, F (1, 30) = 22.53, $p < .001$, $\eta_p^2 = .43$. In contrast, participants in the moderate challenge condition showed a more stable decline in performance before a small increase in the last 1.5 min, reflected in the finding of a significant quadratic trend for distance, F (1, 31) = 15.94, $p < .001$, $\eta_p^2 = .34$, and power, F (1, 31) = 27.82, $p < .001$, $\eta_p^2 = .47$. Unlike the extreme challenge condition, there was no cubic trend in the moderate challenge condition for distance, F (1, 31) = 0.01, $p = .916$, or power, F (1,

Table 3
Means and Standard Deviations (in parentheses) for the Dependent Measures in the Competitive Row for Both Challenge Conditions.

	Epoch					
Measure	1.5 min	3 min	4.5 min	6 min	7.5 min	9 min
Moderate Challenge						
Distance (m)	348.3 (29.8)	337.4 (28.6)	333.9 (30.6)	327.0 (32.7)	327.4 (36.7)	329.7 (32.7)
Power Output (watts)	171.8 (40.8)	152.1 (35.4)	147.9 (36.7)	139.5 (38.2)	141.2 (42.5)	144.3 (39.1)
Stroke Rate (SPM)	33.8 (6.7)	33.3 (6.8)	33.4 (6.8)	32.8 (6.8)	33.0 (6.6)	32.6 (6.0)
Heart Rate (BPM)	143.8 (29.6)	161.9 (32.2)	165.0 (32.6)	166.1 (32.6)	166.4 (32.8)	168.4 (33.6)
VO_2 (L/Min)	.058 (.054)	.064 (.042)	.071 (.042)	.074 (.050)	.077 (.048)	.080 (.048)
VCO_2 (L/Min)	.061 (.057)	.073 (.050)	.082 (.049)	.085 (.056)	.089 (.055)	.100 (.054)
RER	1.10 (0.30)	1.20 (0.34)	1.25 (0.35)	1.26 (0.35)	1.24 (0.34)	1.25 (0.34)
V_E (BTPS) (L/Min)	0.29 (0.27)	0.33 (0.22)	0.38 (0.23)	0.40 (0.26)	0.41 (0.26)	0.43 (0.26)
Respiratory Frequency (Hz)	0.56 (0.25)	0.61 (0.25)	0.65 (0.26)	0.66 (0.26)	0.68 (0.27)	0.69 (0.29)
Perceived Exertion	–	13.6 (1.8)	–	15.4 (1.5)	–	16.6 (1.9)
Extreme Challenge						
Distance (m)	361.3 (40.2)	337.3 (34.1)	326.6 (31.5)	324.8 (32.4)	328.4 (32.6)	320.6 (30.8)
Power Output (Watts)	195.3 (60.6)	153.5 (46.8)	138.9 (41.9)	137.2 (41.9)	142.5 (45.9)	132.8 (38.7)
Stroke Rate (SPM)	34.5 (4.5)	33.8 (4.0)	33.2 (3.5)	32.5 (3.2)	32.8 (3.4)	32.4 (3.5)
Heart Rate (BPM)	150.3 (14.9)	169.3 (14.6)	170.1 (14.3)	171.8 (13.9)	173.7 (12.7)	174.5 (13.8)
VO_2 (L/Min)	.062 (.042)	.071 (.041)	.070 (.040)	.071 (.036)	.080 (.048)	.075 (.044)
VCO_2 (L/Min)	.063 (.045)	.080 (.048)	.080 (.045)	.081 (.042)	.085 (.047)	.086 (.051)
RER	1.05 (0.32)	1.21 (0.36)	1.25 (0.36)	1.23 (0.36)	1.21 (0.35)	1.23 (0.35)
V_E (BTPS) (L/Min)	0.30 (0.22)	0.37 (0.23)	0.37 (0.21)	0.38 (0.20)	0.40 (0.23)	0.40 (0.24)
Respiratory Frequency (Hz)	0.57 (0.21)	0.64 (0.25)	0.65 (0.23)	0.62 (0.22)	0.67 (0.22)	0.68 (0.22)
Perceived Exertion	–	14.2 (2.0)	–	15.7 (1.8)	–	16.8 (1.8)

Note. VO_2 and VCO_2 shown to three decimal places to ensure precision. BPM = Beats per min, SPM = Strokes per min.

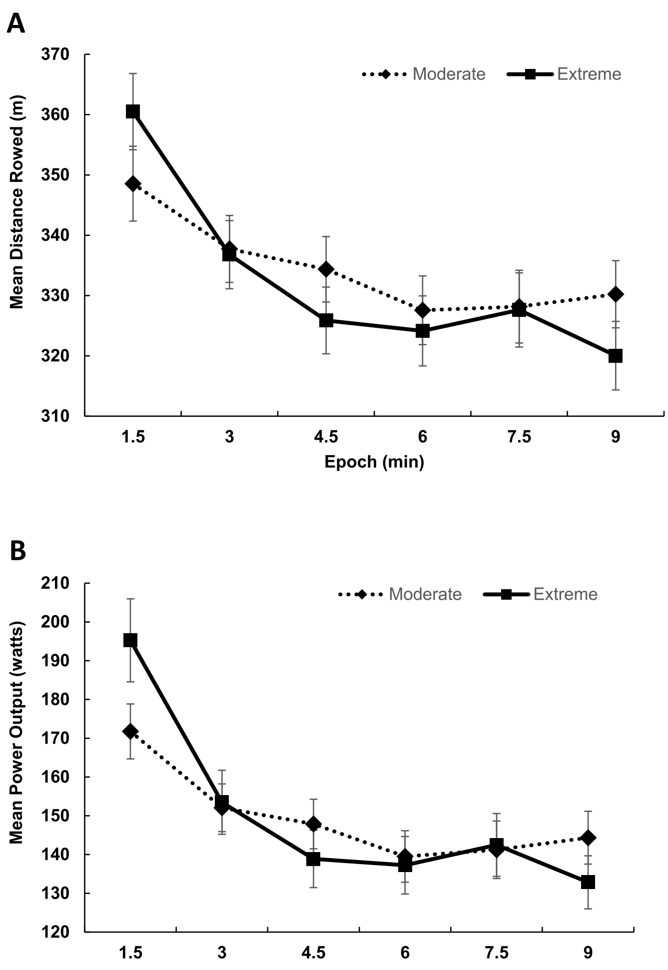

Fig. 1. Mean distance rowed (Panel A) and power output (Panel B) in each epoch for both difficulty groups. Error bars represent the standard error of the mean.

31) = 0.94, $p = .33$. No other main effects or interactions were significant for the performance measures, all $Fs < 2.30$, all $ps > .05$.

No significant challenge level × competitiveness × epoch three-way or two-way interactions were found for any of the physiological measures, all $Fs < 3.53$, all $ps > .05$, with the exception of a significant competitiveness × epoch interaction for VCO_2, F (2, 169) = 2.73, $p = .046$, $\eta_p^2 = .05$. Participants low in competitiveness showed a significant linear, quadratic, and cubic trend, all $Fs > 4.16$, all $ps < .05$, all $\eta_p^2 > .12$, with VCO_2 increasing through the first half of the row, before stabilising, and then increasing again at 7.5 min. In contrast, participants high in competitiveness showed only a significant linear trend, F (1, 32) = 29.71, $p < .001$, $\eta_p^2 = .48$, reflecting that VCO_2 increased consistently across the row. The competitiveness × epoch interaction for VO_2, F (2, 169) = 2.34, $p = .076$, $\eta_p^2 = .04$, and V_E (BTPS), F (2, 168) = 2.65, $p = .052$, $\eta_p^2 = .04$, both approached significance. Both measures showed a similar difference in the pattern across epochs between participants high and low in competitiveness as that seen for VCO_2. Similar to baseline performance, a significant main effect of epoch was observed for all physiological measures, all $Fs > 11.65$, all $ps < .001$, all $\eta_p^2 > .17$, with physical exertion increasing across epochs. The main effects for challenge level and competitiveness were not significant for any physiological measures, all $Fs < 2.20$, all $ps > .05$.

As with the baseline row, perceived exertion increased across epochs, F (1, 84) = 99.80, $p < .001$, $\eta_p^2 = .62$. However, no other significant main effects or interactions were found, all $Fs < 1.05$, all $ps > .05$. A 2 (challenge level) × 2 (competitiveness) between-groups ANOVA was conducted on the IMI subscales of Interest/Enjoyment and Perceived Competence, and on all subscales of the RJPQ. An effect of challenge level on Perceived Competence, F (1, 61) = 3.98, $p = .050$, $\eta_p^2 = .06$, suggested that participants in the moderate challenge condition reported greater Perceived Competence than participants in the extreme challenge condition. Challenge levels did not differ on Interest/Enjoyment, F (1, 61) = 1.09, $p = .30$. Additionally, no main effect of competitiveness or significant challenge level × competitiveness interaction was found for either subscale, all $Fs < 2.35$, all $ps > .05$. No significant main effects or interactions were found for the RJQP subscales, all $Fs < 3.35$, $ps > .05$.

4. Discussion

The aim of the present study was to examine the effect of varying the level of challenge presented by a competitor on rowing performance in a VR environment, and to examine how trait competitiveness might influence performance independently or combined with challenge level. Overall, the results indicate that manipulating the challenge level presented by a virtual competitor changed the approach that participants took in completing the competitive row, although this did not interact with participant's level of competitiveness. The effect of challenge level was observed in the performance measures of distance rowed and power output. An effect of trait competitiveness was observed during the competitive row in the physiological measure of VCO_2 in that there was a different pattern across epochs between participants low and high in competitiveness.

Prior to the competitive row, participants completed a baseline row without any competitor being present. In this baseline row, an effect of trait competitiveness was found, with participants high in competitiveness rowing further than those low in competitiveness, consistent with the first hypothesis and previous research investigating competitiveness in a VR environment (Anderson-Hanley et al., 2011; Snyder et al., 2012). This is an interesting finding given that participants were given little indication of a competitive aspect to the experiment prior to and during the baseline row beyond that their performance would be recorded. This suggests that trait competitiveness may significantly influence performance in a non-competitive sporting or exercise task. As such, studies investigating competitiveness need to be careful in taking this effect into account and ensure that appropriate counterbalancing takes place.

This finding for the baseline row also raises the question of why no effect of competitiveness on performance measures such as metres rowed or power output was found in the competitive row, a situation in which competitive individuals are expected to excel. Past research has suggested that non-athletes low in competitiveness benefit from a clear outcome goal to strive towards (such as winning), whereas highly competitive athletes perform well with more flexible performance goals, such as doing one's best (Gill & Dzewaltowski, 1988). The competitive row had a clear outcome goal and this may have reduced the potential for competitiveness to influence performance. Future research could investigate the difference in performance between competitiveness groups when participants are aware their solo performance will be subsequently used as a competitive benchmark for others. Such research has implications for virtual reality technology. Most VR systems have the capability for the software to record performance for an exercise or training session. The resulting data could be used to control the performance of an avatar in the VR system so that an individual can compete against the past performance of others or even of their own past performance (see Nunes et al., 2014 for an example).

While there was no difference found in the performance measures between the competitiveness groups for the competitive row, a different trend of effort exerted between the groups was seen for the physiological measure of VCO_2, with a similar, albeit marginally significant, difference in the trend of VO_2 and V_E (BTPS). Participants high in competitiveness were found to have an increase in VCO_2 and VO_2 over the course of the row, whereas these parameters for participants low in competitiveness first increased, then showed little or no further increase after the first half of the competitive row. These results are similar to that found by Snyder et al. (2012), in which participants high in competitiveness showed greater overall exercise intensity (power output) when competing against another individual than participants low in competitiveness. Taken together, the findings of the current study and Snyder et al. (2012) suggest that individuals high in competitiveness might show greater exertion and be more likely to maintain their effort over time than participants low in competitiveness when competing against a virtual competitor.

The second hypothesis was not supported, with overall rowing performance, such as metres rowed and physiological effort exerted, not differing between the two challenge conditions. However, the trend of performance throughout the row did differ. Participants in the extreme challenge condition showed a sudden decline in performance which continued to decrease over the course of the row, whereas the performance of participants in the moderate challenge condition declined gradually before stabilising and increasing slightly towards the end of the row. Given that participants in the extreme challenge condition showed evidence of greater power output at the start of the competitive row than participants in the moderate challenge condition, it is possible that the different trends in performance are due to overexertion at the start of the row leading to exhaustion or decreased motivation towards the end of the row. Participants in the moderate challenge condition reported greater perceived competence than those in the extreme challenge condition. Given the finding that greater perceived competence for an exercise task has been associated with longer exercise periods and greater adherence to exercise programs (Ryan et al., 1997), it is possible that the use of a moderately challenging competitor could encourage greater motivation and exercise adherence over that of an extremely challenging one. In related research, Aral and Nicolaides (2017) explored the effects of the presence of a peer on running performance and motivation. Extreme differences in running performance between oneself and a peer were found to less motivating than slight differences in performance. For example, runners were more influenced by other runners who performed slightly better than they do, but not runners who perform far better. Aral and Nicolaides have suggested that social comparison theory may explain this finding, with runners finding motivation through the goal of self-improvement when making upward comparisons. However, downward comparisons to runners performing slightly worse was found to have a larger effect than upward comparisons. As such, future research could compare the effects of competitors in VR who are slightly higher and slightly lower in ability on measures of performance and motivation.

Another explanation for the different trends in performance may be found in interpreting the results through the lens of the challenge point framework (Guadagnoli & Lee, 2004). This framework proposes that each individual has a unique optimal level of challenge that they can learn from that is dependent on their current skill level. As the current study utilized novice rowers, it is possible that a moderate challenge may have been the optimal challenge level for participants to learn from and gauge their own performance. The trend of participants in the extreme condition also gives support to the challenge point framework, which proposes that excessive difficulty provides little valuable information and that those below the requisite skill level for such a challenge would therefore become overwhelmed and show a steep decline in performance. While the findings of the current study and the challenge point framework suggests that a moderate challenge may be most beneficial for novice rowers, it is possible that experienced and elite rowers would benefit more from an extreme challenge over a moderate one.

Regardless of the underlying mechanism, it is important to consider the differing trends in distance and power across the trial between the challenge conditions in the context of promoting adherence to an exercise program. Based on the present findings, a moderately challenging VR competitor should be preferred to naturally promote a better pacing strategy because it allowed for a more consistent performance across a trial than using an extreme challenge. In addition, participants in the moderate challenge condition showed a trend of performance that more closely resembled that used by elite rowers (Garland, 2005) than participants with an extreme challenge. Elite rowers have been shown to use a fast-start strategy that involves beginning at a higher performance, followed by maintaining a reduced pace throughout the middle of the row, with an increase in performance in the final quarter of the race (Garland, 2005). Murray et al. (2016) found that participants naturally adopted this strategy when rowing with a virtual teammate in a conjunctive scenario (the slowest performer was to be taken as the level of performance for the pair). Results of the present study suggests that a moderately challenging competitor also naturally promotes adoption of the first component of this strategy (i.e., the initial fast start). Given the physiological, psychological, and performance benefits provided by using the fast-start strategy (Garland, 2005), using a moderately challenging competitor to promote this strategy may be more beneficial in promoting exercise motivation and adherence than an extremely challenging competitor. However, further work is required to better approximate the speed profile of elite rowers towards the end of the row. The present study did not find that participants increased their distance and power towards the end of the row to the same levels as that shown at the start. It may be necessary to reduce the challenge level of the competitor avatar further or to use an avatar that varies its pace during the row (see Hoffmann, Filippeschi, Ruffaldi, & Bardy, 2014).

Several limitations of the present study need to be considered when interpreting the results. First, previous research guiding the choice of challenge levels in a rowing task was unavailable. As such, the challenge levels of 5% and 20% better than baseline may not accurately reflect a moderate and extreme challenge, respectively. Second, with a mean score of 43.47 out of a possible 70 on the RCI, it is possible the low competitiveness group was not sufficiently low in competitiveness to observe performance effects in the competitive row. As norms and classification guidelines for the RCI are unavailable, it is unclear whether the group distinctions used in the current study were appropriate. Third, due to poor internal consistencies, the subscales of Pressure/Tension and Perceived Choice in the IMI could not be analysed. Poor internal consistencies have been found previously for the Pressure/Tension subscale when administered in a sporting context (Goudas & Biddle, 1994), with appropriate rewording of the questions suggested. However, it is unclear why internal consistency for both administrations of the Perceived Choice subscale was low.

The present study provides evidence that the level of challenge presented by a virtual competitor affects the performance of an individual in a virtual environment. Results from the present study suggest that competing against a moderately challenging competitor may be more beneficial for pacing and motivation than an extremely challenging competitor. Designers of virtual exercise systems looking to motivate exercise participation, encourage adherence, and facilitate greater performance should be mindful of the interaction their users have with both virtual competitors and other users. Virtual competition that is challenging, yet achievable, encourages the use of optimal performance strategies and elicits greater feelings of competence. The use of VR technology to improve exercise motivation, adherence, and performance is increasing, and VR exercise systems should be designed to incorporate competition in a way that facilitates these goals.

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