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Abstract

Objectives: The aim of the study was to test the performance, motivational, and affective impact of aerobic exercise within an immersive virtual reality environment experienced alone or with another individual. Design: Sixty female participants aged 18-30 years were assigned to one of three conditions: no virtual reality (NVR), individual virtual reality (IVR), or companion virtual reality (CVR). Method: Participants completed 9 min of self-paced rowing on an ergometer without any visual input or performance feedback (NVR), individually within a virtual reality environment (IVR), or within a virtual reality environment that included a companion depicted as an avatar (CVR). Results: The two virtual reality groups rowed a further distance and at a higher power output than the NVR group. Furthermore, the CVR group outperformed the IVR group in distance and had a higher heart rate. Participants in the virtual reality groups did not perceive themselves to be exerting more physical effort and rated the task as more enjoyable than participants in the NVR group. Conclusions: Virtual reality improves performance and the affective response to aerobic exercise, and performance effects are further enhanced by the presence of others in the virtual environment.

Keywords: Virtual reality; Exercise; Rowing; Performance
The Effects of the Presence of Others during a Rowing Exercise in a Virtual Reality Environment

Many people live inactive lifestyles despite substantial evidence that regular physical exercise is associated with physical and psychological benefits (Warburton, Nicol, & Bredin, 2006). An Australian study by Cadilhac et al. (2011) suggested that 70% of adults are sedentary or have a low activity level. Similar levels of physical inactivity are shown in other countries (World Health Organization, 2014). Research is required to investigate new ways to increase participation in physical activity. New approaches have the potential to improve the personal health and lifestyle of individuals and to assist governments faced with the financial burden of disease caused by physical inactivity (Cadilhac et al., 2011).

Novel approaches to promote physical activity include the use of virtual reality (VR) technology. VR refers to a computer-generated environment that can lead to the sense of physical presence in a virtual world (Baños et al., 2000; Steuer, 1992). One approach, termed exergames, incorporates VR to play a game using a system capable of sensing movement (e.g., Xbox Kinect). Physical activity becomes the means by which individuals control features of the game, such as moving an avatar to avoid obstacles or enemies. VR has also been combined with traditional exercise tasks, such as stationary cycling (e.g., Legrand, Joly, Bertucci, Soudain-Pineau, & Marcel, 2011), treadmill running (Nunes et al., 2014), and ergometer rowing (Hoffman, Filippeschib, Ruffaldib, & Bardy, 2014). In such applications, physical exertion on the exercise equipment allows the individual to move through a virtual environment. Unlike exergaming, where playing the game is the main focus, increasing physical fitness, strength, or technique is the main focus for VR-based exercise.

Research using traditional exercise tasks has suggested that the addition of VR can increase physical exertion and adherence to exercise. Using a cycling task, participants have shown greater physical exertion (as measured by revolutions per minute) when cycling in a VR environment than when cycling alone (Plante, Aldridge, Bogden, & Hanelin, 2003).
complete a distance has also shown to be faster when rowing in a VR course than when rowing alone (Hoffman et al., 2014). Similar findings have emerged using other measures of exertion, such as heart rate and ratings of perceived exertion (Plante, Alderidge et al., 2003; Plante, Frazier et al., 2003). Adherence is also enhanced when exercising with VR. Annesi and Maza (1997) found increased adherence over a 14-week period for participants using an exercise bike in a VR environment when compared to those using an exercise bike without VR.

Ijsselsteijn, de Kort, Westernik, de Jager, and Bonants (2004) tested the effects of immersion on the motivation of participants using a stationary home exercise bike linked to a VR environment. Immersion was manipulated by presenting the VR environment from the point of view of the rider (high immersion) or from a bird’s eye view (low immersion). Participants exercising in a higher immersive VR environment cycled faster, rated their experience of presence higher, and found the task more interesting and enjoyable than participants exercising in a lower immersive environment. Although the Ijsselsteijn et al. (2004) study lacked a control group to evaluate the benefits of VR on performance, it did show that there are variables related to the VR environment that might influence performance and psychological outcomes. In particular, these variables might exert an additive effect to further enhance the effects of exercise within a VR environment.

One variable that may increase motivation and exertion during exercise in VR environments is the presence of another individual. This is consistent with the lack of a training partner being cited as a barrier to regular exercise (Weinberg & Gould, 2015). Researchers have included other individuals in the VR environment for the aerobic exercise tasks of cycling (Anderson-Hanley et al., 2011; Snyder, Anderson-Hanley, & Arciero, 2012), rowing (Hoffman et al., 2014), and running (Nunes et al., 2014). The effect of a competitor in the VR environment has been examined in several studies and has shown to produce performance enhancement, particularly for those who report being more competitive (Anderson-Hanley et al., 2011; Nunes et al., 2014; Snyder et al., 2012).
An example of motivational increases in the presence of non-competitive others is the Köhler motivational gain effect. The Köhler effect occurs when a less capable individual performs better in a team or coaction situation than if they were performing individually or independently (Feltz, Kerr, & Irwin, 2011). Most researchers agree that there are two mechanisms underlying the Köhler effect: upward social comparison and group/task indispensability (Kerr & Hertel, 2011). The upward social comparison mechanism states that individuals use their superior co-worker’s performance as a benchmark for their own performance. The group indispensability explanation suggests that weaker members are motivated to work harder in conjunctive tasks due to the increased interdependence and the realisation that their contribution is important to the group’s performance.

Feltz, Forlenza, Winn, and Kerr (2014) measured plank exercise performance while individuals viewed a prerecorded video of a human partner or computer-generated nearly human partner or hardly human partners, all of whom were said to be moderately more capable (+40%) than the participant’s initial performance. Participants performed better with partners, particularly those that were more human-like. There were no significant differences among the partnered conditions in perceived exertion, enjoyment, or intention to exercise the next day. Feltz et al. interpreted the better performance in the partnered conditions as reflecting the Köhler effect. Although a strength-based exercise was used, the findings suggest that the presence of a more capable companion in a VR environment will result in better aerobic exercise performance (see also Irwin, Scorniaenchi, Kerr, Eisenmann, & Feltz, 2012).

The present study investigated the effects of different types of VR environments on the aerobic exercise task of rowing. Performance, heart rate, and affective responses were examined in three conditions: (i) an individual condition with no virtual reality (NVR), (ii) an individual virtual reality (IVR) condition, and (iii) a companion virtual reality (CVR) condition where another team-mate’s boat was included in the VR environment. Participants in the CVR condition were informed that their team-mate had performed moderately better than them in a
baseline row. The present design allowed for testing the hypothesis that the two VR conditions would produce better performance outcomes than the NVR condition, consistent with previous findings of performance enhancement when cycling (Plante, Aldridge et al., 2003) and rowing (Hoffman et al., 2014) in a virtual environment. Although Hoffman et al. (2014) previously examined rowing, their study used a combination of a VR environment and an avatar of another rower to implicitly train participants to adopt “fast start” strategy. In contrast, the present study included a condition in which the VR environment did not show other rowers (IVR condition) and there was no explicit instructions regarding pacing. In addition to enhanced performance, it was hypothesised that rowing in a VR environment would increase motivation and enjoyment relative to rowing alone, consistent with prior findings of enhanced motivation (Ijsselsteijn et al., 2004), positive mood (Plante, Aldridge et al., 2003; Plante, Frazier et al., 2003) and enjoyment (Mestre et al., 2011) when exercising in VR environment.

The design also allowed an examination of the additive effect of another non-competitive individual in the VR environment by comparing the CVR and IVR groups. It was hypothesised that the CVR group would show a performance enhancement due to the Köhler motivational gain effect. Irwin, Scorniaenchi, Kerr, Eisenmann, and Feltz (2012) examined the Köhler effect while participants cycled in a VR environment. In the partnered conditions, participants watched a video feed of the other participant on a different screen and performance was measured by how long participants maintained the required level of intensity during the task. In contrast, the present experiment showed the partner as an avatar within the VR environment and performance was measured by distance and power output. It was hypothesised that performance would be higher in the CVR condition than in the IVR condition, consistent with the findings of a Köhler motivational gain effect by Irwin et al. (2012). In addition, participants in CVR condition were predicted to rate the activity as more motivating than those in the IVR condition.
Method

Participants

Sixty-two female students with a mean age of 20.20 years ($SD = 2.73$) enrolled in a psychology course participated in exchange for partial course credit. Two participants in the CVR group were excluded and replaced because they reported a disbelief of the CVR manipulation. The remaining 60 participants were assigned to the NVR group, IVR group, or CVR group through matched assignment such that there were 20 participants in each group. Matching was based on age, body mass index and physical activity level as measured by the International Physical Activity Questionnaire - Short Form (IPAQ-SF; Craig et al., 2003). The groups did not differ significantly in mean age, BMI, Exercise Thought Questionnaire (ETQ) scores, or Exercise Benefits/Barrier Scale (EBBS) scores, all $F$s < 1. The frequencies of the IPAQ categories were also similar across groups, Likelihood ratio = 1.26, $p = .868$. The descriptive statistics for each group are shown in the Supplementary Material.

Apparatus

The experiment was completed in a 8.1 m × 2.7 m climate-controlled room set with a light intensity of 10.1 lux. Participants rowed on a Concept 2 Model D Indoor Rowing ergometer fitted with a PM3 monitor. The PM3 monitor stored measurements of time, distance, speed, stroke rate, power output, and heart rate at 30-s intervals. The heart rate signal was transmitted through a wireless Polar Electro T31 chest strap heart rate monitor to an Acumen receiver that was connected to the PM3 monitor. The PM3 monitor display was covered throughout the experiment. The drag factor of the ergometer was set to 105, which is a moderate level of resistance.

The ergometer was interfaced with the Netathlon 2 XF software, which created the VR environment. The VR environment was projected onto a white wall in front of the ergometer at a screen size of 2.5 m × 1.35 m using a model MW870UST BenQ data projector. The participants were 1.8 m from the wall at the catch position. Participants had a third-person view...
in which they could see an avatar from behind (i.e., the opposite direction of travel). The timing of the rowing strokes of the avatar matched that made on the ergometer. The Head of the Charles course was used depicting a river with several gentle turns and passing scenery of trees, bridges and buildings. The display did not show any quantitative information regarding the rowing trial, such as time elapsed, pace, stroke rate, or power output.

**Self-Report Measures**

**Exercise Thoughts Questionnaire.** The frequency of exercise avoidant thoughts was measured by the Exercise Thoughts Questionnaire (ETQ; Kendzierski & Johnson, 1993). The ETQ is a 25-item questionnaire in which participants respond to first-person statements about thoughts they have in regards to exercise. Responses are made on a 5-point scale ranging from 1 = *not at all* to 5 = *all of the time*. The ETQ has a high Cronbach’s alpha value of .91 and is positively correlated with exercise intention (Kendzierski & Johnson, 1993).

**Exercise Benefits/Barrier Scale.** Perceived benefits and barriers to exercise were measured with the Exercise Benefits/Barrier Scale (EBBS; Sechrist, Walker, & Pender, 1987). Participants indicate how much they agree or disagree with each of the 43 statements on a 4-point scale ranging from 1 = *strongly agree* to 4 = *strongly disagree*. In past research, a Cronbach’s alpha value of .95 was obtained for internal consistency and it showed a good test-retest correlation of \( r = .89 \) (Sechrist et al., 1987). Prior studies have shown positive correlations with objective measures of physical activity, although there has been some inconsistency in findings (Lee, Macfarlane, Lam, & Stewart, 2011).

**International Physical Activity Questionnaire (Short Form).** The International Physical Activity Questionnaire – Short Form (IPAQ-SF; Craig et al., 2003) was used to classify participants into one of three categories of physical activity (low, medium, and high). The IPAQ-SF has seven items asking participants about the amount of time spent engaging in various forms of exercise over the last 7 days. The IPAQ-SF is positively correlated with physical fitness (Kurtze, Rangul, & Hustvedt, 2008).
Ratings of Perceived Exertion. Perceived exertion was measured using the Borg (1982) Ratings of Perceived Exertion (RPE) scale. The scale ranges from 6 to 20 where 6 = no exertion at all and 20 = maximal exertion. The RPE has been shown to be positively correlated \( r = .8 \) to .9) with heart rate (Borg, 1982). The RPE has shown high test-retest reliability \( r \geq .9 \) and validity with endurance sports (Ceci & Hassmén, 1991; Russell & Weeks, 1994).

Feeling Scale and Felt Arousal Scale. Affect was measured using the two dimensions of valence and arousal. Valence was measured using the Feeling Scale (FS; Hardy & Rejeski, 1989). Responses to a single item are made on an 11-point bipolar scale that ranges from -5 = very bad to +5 = very good, with neutral at 0. The FS correlates between \( r = .51 \) and .88 with the Self Assessment Manikin which also measures affect valence (Rose & Parfitt, 2008). Arousal was measured with the Felt Arousal Scale (FAS; Svebak & Murgatroyd, 1985). The single item scale ranges from 1 = low arousal to 6 = high arousal. The FAS has been used in previous physical activity studies, demonstrating strong convergent validity (Van Landuyt, Ekkekakis, Hall, & Petruzzello, 2000).

Intrinsic Motivation Inventory. The Intrinsic Motivation Inventory (IMI; Ryan, 1982) is a multidimensional questionnaire that measures subjective experience in a goal-related laboratory experiment. Four of seven subscales were used: Effort, Perceived Competence, Interest/Enjoyment, and Tension. The factor structure and internal consistency of the subscales has been supported (McAuley, Duncan, & Tammen, 1989).

Physical Activity Enjoyment Scale. Enjoyment of physical activity was measured using the Physical Activity Enjoyment Scale (PACES; Motl et al., 2001). The scale consists of 16 statements relating to physical activity. Participants respond to the statements on a Likert scale ranging from 1 = totally disagree to 5 = totally agree. The four subscales have shown high internal consistency with Cronbach’s alpha values ranging from .85 to .90 (Carpenter, Tompkins, Schmiege, Nilsson, & Bryan, 2010).

Physical Activity Affect Scale. The Physical Activity Affect Scale (PAAS; Lox,
Jackson, Tuholski, Wasley, & Treasure (2000) is modified from the Exercise-Induced Feelings Inventory (EFI; Gauvin & Rejeski, 1993) and measures momentary experience of feeling states. Participants respond on a 5-point Likert-type scale ranging from 0 = *do not feel* to 4 = *feel very strongly*. The 12-item PAAS consists of four subscales: Positive Affect, Tranquility, Fatigue, and Negative Affect. The factor structure of the PAAS and the convergent validity and internal consistency of its subscales has been supported in research (Lox et al., 2000).

**Procedure**

On arrival, participants provided informed consent, demographic information, and responses to the Sports Medicine Australia pre-exercise screening system (Sports Medicine Australia, 2005). Participants next completed the IPAQ-SF and had their height and weight measured. The first 20 participants were randomly assigned to one of the three groups. The remaining 40 participants were matched to the original 20 on their IPAQ activity level, BMI, and age, and assigned to one of the other groups. Participants were fitted with the wireless chest heart monitor. The experimenter gave participants instructions on correct rowing technique and participants were shown a video of an expert rower using the ergometer. All participants were given a 5-min warm-up period rowing on the ergometer for familiarisation with no visual display or performance feedback. During this time, participants practiced answering the RPE, FAS, and FS scales. These scales were printed on paper for ease of reference and participants called out their ratings when prompted. Participants were next given a 5-min rest period during which time they completed the ETQ.

Before the main rowing task, all participants were asked to complete a baseline assessment of rowing performance. Participants were asked to row at 75% of their maximum capacity for 2 min after which time their distance travelled was disclosed. The baseline measurement was not used in data analysis - its purpose was to collect information for the CVR group manipulation. Participants were next given a 7-min rest break and were asked to complete the EBBS questionnaire.
Following the 7-min rest period, the main task began. All participants were instructed to row on the ergometer to the best of their ability so that they achieved the longest distance possible in 9 min. Participants were informed they would be told when they had passed the halfway mark of the row. Just prior to the task and at the 3-min, 6-min, and 9-min time points, participants were asked to verbally report their RPE, FAS, and FS ratings. Heart rate and rowing performance was recorded throughout the row.

The presence of the VR environment and or an avatar in the VR environment that represented the participant’s team-mate was manipulated across the NVR, IVR, and CVR groups. Participants in the NVR group received no VR display or feedback of their own performance. In addition, no mention was made of a team-mate nor were any comments made regarding their baseline rowing performance.

Participants in the IVR group saw the VR environment. The experimenter explained the VR environment to participants, including that their boat would travel in the water according to their stroke rate and power output on the ergometer. Participants were instructed to focus their attention on aspects of the VR environment, such as the movement of their boat through the water and the passing scenery throughout the trial. Only one boat (the participant’s boat) was shown in the VR environment. Similar to the NVR group, no mention was made of a team-mate or their baseline rowing performance.

Like the participants in the IVR group, participants in the CVR group viewed the VR environment during the trial. However, the VR environment depicted two boats. Participants were informed that one boat was their own and the other boat was that of their team-mate who was completing the experiment in the same VR environment over the Internet from another campus of the university. Participants were further informed that they were rowing alongside this team-mate in real-time and the shorter distance travelled over the 9 min by a member of their team would count as their team score. To increase the believability of this manipulation, participants telephoned their team-mate (a confederate) to exchange demographic information.
participants were told the distance that their team-mate had rowed in the initial 2-min baseline row. This distance was manipulated to be always 40% longer than the participant’s own performance. Participants next completed the 9-min row. In reality, however, the second boat in the virtual environment was controlled by the VR software using the UltraRabbit setting so it travelled, on average, slightly faster than the average speed of the participant’s boat. The speed of the boat was variable so that it would slow down and let the participant pass, but also speed up and pass the participant’s boat.

After completing the 9-min rowing task all participants were given a 1-min recovery break and completed the IMI, the PACES, and the PAAS. All participants were debriefed and thanked for their participation. Participants in the CVR condition were asked a series of questions about their belief in rowing with a real person in the VR environment. Two participants disclosed that they did not believe the cover story and were excluded from further analyses. All remaining participants were informed that the companion was a confederate and that they were rowing with a computer-controlled avatar.

**Scoring and Statistical Analyses**

Performance and physiological measures were converted to 1-min epoch scores prior to statistical analysis. Distance was summed across each epoch, whereas power, strokes per minute (SPM), and heart rate were averaged across each epoch. Heart rate for three participants was not recorded due to technical difficulties, leaving 19 participants in each group for this measure. The distributions of the dependent variables were initially examined. Due to minor violations of normality and outliers, Winsorising was applied to 1.7% of the data. Statistical analyses used mixed model ANOVAs with the Huynh-Feldt correction applied when there was violation of the sphericity assumption (the adjusted degrees of freedom are reported). Planned comparisons between groups used linear contrasts. The first compared the two VR groups combined (IVR and CVR) with the NVR group and the second compared the IVR group with
the CVR group. The \( \alpha \)-level was set at .05 for all analyses.

**Results**

**Performance Measures**

The relationships among the performance measures, heart rate, and subjective measures were examined through correlational analyses and are presented in the Supplementary Material. A 3 (group: NVR, IVR and CVR) × 9 (epoch: 1 min, 2 min, 3 min, 4 min, 5 min, 6 min, 7 min, 8 min, and 9 min) mixed factorial ANOVA was conducted for each performance measure of distance, power, and stroke rate. Mean performance is shown in Figure 1 for distance (top panel), power (middle panel), and stroke rate (bottom panel).

**Distance.** As shown in Figure 1 (top panel), the CVR group rowed further at every epoch than the other two groups, whereas the IVR group rowed further than the NVR group in the earlier part of the trial. The overall difference in distance between groups was confirmed by a main effect of distance, \( F(2, 57) = 4.17, p = .020, \eta^2_p = .13 \). Based on the recommendations that \( \eta^2_p \) effect sizes of .01, .059, and .138 represent small, medium, and large effects, respectively (Cohen, 1988), the group effect on distance was close to large in magnitude. Further planned comparisons showed that the two VR groups combined rowed significantly further than the NVR group, \( t(58) = 2.06, p = .044, d = 0.55 \). In addition, the CVR group rowed significantly further than the IVR group, \( t(29.48) = 2.15, p = .040, d = 0.68 \).

There was no significant main effect of epoch, \( F(2, 114) = 3.06, p = .051, \eta^2_p = .05 \). There was, however, a significant group × epoch interaction, \( F(4, 114) = 3.01, p = .021, \eta^2_p = .10 \). To investigate the interaction, simple effects analyses were conducted using \( t \)-tests with a Bonferroni adjusted \( \alpha \) to examine the change across epochs separately for each group. Comparisons were made between successive epochs (i.e., 1 vs 2, 2 vs 3, etc.) evaluated against \( \alpha' = .002 \). In the CVR group, distance significantly increased from minute 1 to minute 2, \( t(19) = 4.06, p < .001, d = 0.91 \). There were no differences across the remaining epochs and no differences across epochs for the NVR and IVR groups using \( \alpha \)-protected tests.
**Power.** The patterns observed for power, as shown in Figure 1 (middle panel), were similar to those seen for distance. The CVR group exerted the most power followed by the IVR and NVR groups, respectively. The group differences were supported by a significant main effect of group, $F(2, 57) = 4.20, p = .020, \eta^2 = .13$. The VR groups produced greater power than the NVR group, $t(58) = 2.07, p = .043, d = 0.57$. There was no significant difference between the CVR and IVR groups, $t(32.5) = 2.01, p = .053, d = 0.64$. There was no overall main effect of epoch and no group × epoch interaction, both $Fs < 2.31$.

**Strokes per Minute.** As can be seen in Figure 1 (bottom panel), the three groups were ranked in the same order for SPM as they were for distance and power. However, the group differences did not reach statistical significance, $F(2, 57) = 1.70, p = .191, \eta^2 = .06$. Unlike the other performance measures, there was an overall effect of epoch on SPM, $F(2.78, 158.51) = 8.10, p < .001, \eta^2 = .12$. Further analysis revealed a significant linear trend, $F(1, 57) = 14.06, p < .001, \eta^2 = .20$, reflecting the overall increase in SPM across the trial for all groups. The epoch × group interaction was not significant, $F < 1$.

**Heart Rate**

A 3 (group: NVR, IVR and CVR) × 9 (epoch: 1 min, 2 min, 3 min, 4 min, 5 min, 6 min, 7 min, 8 min, and 9 min) mixed factorial ANCOVA was conducted for heart rate. Baseline heart rate was used as a covariate to account for individual variability in tonic heart rate. As seen in Figure 2, the CVR group had the highest heart rate across epochs, which is consistent with the performance measures. The analyses yielded a main effect for group, $F(2, 53) = 3.42, p = .040, \eta^2 = .11$. Planned comparisons showed no significant difference between the combined VR groups and the NVR group, $t(55) = 0.004, p = .997, d < .001$. However, heart rate in the CVR group was higher than in the IVR group, $t(36) = 2.24, p = .032, d = 0.73$.

The analyses also showed a main effect of epoch, $F(3.38, 179.01) = 12.90, p < .001, \eta^2 = .20$, and a group × epoch interaction, $F(6.76, 179.01) = 2.95, p = .007, \eta^2 = .10$. Similar to distance, simple effects analyses were conducted to compare across each successive epoch.
separately for each group ($\alpha' = .002$). The NVR group showed the most extensive differences (1 vs 2, 2 vs 3, 4 vs 5, and 5 vs 6), with fewer differences for the IVR group (1 vs 2, 2 vs 3, and 5 vs 6) and CVR group (1 vs 2, 4 vs 5), all $t$s > 3.55, $p < .002, d > 0.81$. As shown in Figure 2, the NVR groups showed a more unstable pattern of increasing heart rate across the trial.

**Subjective Measures**

The valence (FS) and arousal (FAS) dimensions were mapped onto a circumplex affective space (Russell, 1980) as shown in the Supplementary Material. All groups showed a similar pattern across the trial of increasing high activation unpleasant affect that is indicative of distress or tension. A 3 (group: NVR, IVR, CVR) × 4 (epoch: 0 min, 3 min, 6 min, 9 min) mixed factorial ANOVA was used to analyse ratings on the FS and FAS.

**Feeling Scale.** There was no significant difference between the three groups on the FS, $F < 1$. There was an overall effect of epoch, $F(2.41, 137.45) = 20.32$, $p < .001, \eta^2 = .26$. Post hoc analyses using paired samples $t$-tests were conducted to investigate the differences across the 3-min intervals. Feelings were rated significantly more positive at 0 min than at 3 min, $t(59) = 5.39, p < .001, d = 0.77$. There was no significant change in ratings from 3 min to 6 min, $t(59) = 1.23, p = .224, d = 0.10$, or from 6 min to 9 min, $t(59) = 1.93, p = .058, d = 0.17$. The group × epoch interaction was not significant, $F < 1$.

**Felt Arousal Scale.** There was no significant difference between groups on the FAS, $F < 1$. However, there was an overall effect of epoch, $F(1.94, 110.61) = 51.58$, $p < .001, \eta^2 = .48$. Post hoc analyses showed that arousal increased from 0 min to 3 min, $t(59) = 8.27, p < .001, d = 1.15$, and from 3 min to 6 min, $t(59) = 3.83, p < .001, d = 0.41$. There was no significant difference, from 6 min to 9 min, $t(59) = 1.83, p = .172, d = 0.12$, and no group × epoch interaction, $F < 1$.

**Ratings of Perceived Exertion.** A 3 (group: NVR, IVR, CVR) × 3 (epoch: 3 min, 6 min, 9 min) mixed factorial ANOVA was conducted for RPE and descriptive statistics can be found in the Supplementary Material. The main effect of group was not significant, $F < 1$, but
the main effect of epoch was significant, $F(1.61, 91.99) = 85.81, p < .001, \eta^2 = .60$. Post hoc analysis revealed a significant increase in perceived exertion from 3 min to 6 min, $t(59) = 6.88, p < .001, d = 0.67$, and from 6 min to 9 min, $t(59) = 8.33, p < .001, d = 0.48$. The group × epoch interaction was not significant, $F < 1$.

**Intrinsic Motivation Inventory.** The subcales of the IMI showed acceptable internal consistency with respective Cronbach’s alpha values of Effort = .75, Perceived Competence = .83, Interest/Enjoyment = .89, and Tension = .77. A one way between-groups ANOVA was conducted for each subscale of the IMI. Means and standard deviations for each subscale are displayed in Table 1. Groups differed in Interest/Enjoyment, $F(2, 57) = 3.75, p = .029, \eta^2 = .12$. Planned comparisons showed that the combined VR groups rated the task as significantly more interesting than the NVR group, $t(28.67) = 2.29, p = .030, d = 0.66$. There was no significant difference between the CVR group and the IVR group, $t(38) = 1.11, p = .276, d = .35$. There were no differences between groups for the subscales of Perceived Competence, Effort, or Tension, all $Fs < 1.03$.

**Physical Activity Enjoyment Scale.** Cronbach’s alpha in the present study was .89 for the PACES. A one way between-groups ANOVA conducted for the PACES scale yielded a significant group difference, $F(2, 57) = 3.85, p = .027, \eta^2 = .11$. As shown in Table 1 and found with the Interest/Enjoyment scale of the IMI, the VR groups reported higher enjoyment than the NVR group, $t(58) = 2.75, p = .008, d = .71$. In contrast, there was no significant difference between the two VR groups, $t(38) = 0.52, p = .604, d = 0.17$.

**Physical Activity Affect Scale.** Cronbach’s alpha values for the PAAS subscales were: Positive Affect = .67, Tranquillity = .82, Fatigue = .74, and Negative Affect = .65. Each subscale of the PAAS was examined with a one way between-groups ANOVA. There were no significant group differences in any of the subscales, all $Fs < 1.79$.

**Discussion**

The aim of the present study was to test the performance, motivational and affective
impact of exercising with ergometer rowing equipment interfaced with an immersive VR environment. The findings show that rowing in a VR environment increased performance as measured by distance rowed and power output when compared to rowing without any VR input. Participants who rowed in the VR environment rated the task just as strenuous but more enjoyable than the participants without VR. The results also show that the presence of others in the VR environment produces a further improvement in performance. The presence of others increased distance rowed and physical exertion as measured by heart rate when compared to rowing individually in the VR environment. Taken together, the results point to the potential benefits of VR to enhance physical exertion and improve affective responses for the aerobic exercise task of rowing.

Although the present experiment used a rowing exercise, the findings are likely to generalise to other aerobic exercises, such as cycling on an ergometer or running on a treadmill. Supporting this suggestion are similar findings of higher revolutions per minute when cycling in a VR environment than when cycling alone (Plante, Aldridge et al., 2003). Some studies have reported no performance enhancement when aerobic exercise has been combined with VR input. However, the lack of an effect may be attributed to the instructions asking participants to control their exercise intensity level (e.g., Anderson-Hanley et al., 2012; Mestre, Ewald, & Maino, 2011). For example, in the study by Mestre et al. (2011), participants were instructed to maintain a stable and minimal heart rate during the cycling task. In the present study, exercise intensity was not explicitly mentioned. Rather the instructions emphasised the goal of rowing the longest distance in the set time. Further research could examine the effects of different goals on performance with VR-based exercise tasks.

Similar to prior research with rowing (Hoffman et al., 2014) and cycling (Plante, Aldridge et al., 2003) the present study shows that participants achieved a higher level of performance when completing the exercise task in a VR environment than without any VR input. Unlike the study of Hoffman et al. (2014), the present experiment included an IVR
condition in which no avatar of another person was present during the row. The present design was thus able to separate the effects of the VR environment from the presence of others in examining performance during the rowing exercise.

It is noteworthy that the performance increase observed in the IVR group did not result in significantly higher ratings of perceived exertion or increased negative affect when compared to the NVR group. Although no group differences were found, correlational analyses suggested that higher levels of performance were associated with less positive global feelings as measured by the FS. Thus, the VR environment may have acted to reduce the impact of negative feeling states on performance. According to Mestre et al. (2011), the VR environment can act as a distracter from exercise intensity. It is suggested that thoughts that compete with sensory feedback distract from the pain or discomfort experienced during exercise, resulting in lower perception of exertion (Longman et al., 2014). The sensory input that the IVR group received from the VR environment could have competed with and counteracted the pain and discomfort typically experienced from extra effort exerted. Prior research has shown that attentional focus can influence performance, feeling states, and heart rate during sport and exercise (e.g., Neumann & Brown, 2013; Neumann & Piercy, 2013; Neumann & Thomas, 2011). Further research would be required to provide a more direct test of this explanation by measuring attentional focus at different levels of exertion in a VR environment.

Following the rowing trial, participants in the IVR group (and CVR group) rated their experiences as significantly more interesting and enjoyable than the NVR group. Similar to the perceived exertion ratings, this difference is noteworthy because it was found in the context of higher performance. However, it is also relevant to note that these scales were posttask measures. In the present experiment, participants also rated their feeling and felt arousal at 3-min intervals during the trial. No significant differences were observed between groups in affect for these in-task measurements. The difference in results between the in-task and posttask measures could be due to the fact that participants may focus on their current
physiological state when rating in-task measures. For posttask measures, however, participants may reflect upon the experience in a more holistic way, which may discount transient physical feeling states or emphasise cognitive aspects such as interest or novelty.

The patterns of performance for the NVR group showed an increase in distance per minute across the trial in contrast to the more consistent pace for the two VR groups. It might be expected that the NVR group’s performance would drop away across epochs as there was less stimulation in their environment to distract participants from exercise intensity. However, the NVR group may have set their initial expectation of the task quite low in comparison to the VR groups and performed as such initially. As the task progressed, the NVR group may have found they had unspent energy from earlier underperforming and this allowed them to increase their performance across epochs. It is also possible that without the distraction of the VR environment the NVR group may have focused on their rowing technique, making adjustments and efficiency improvements across epochs to result in a faster pace.

The comparison between the CVR group and IVR group allowed for an examination of the effect of the presence of others in the virtual environment. The results showed that, relative to the IVR group, the CVR group rowed for a longer distance. There was also a corresponding increase in heart rate in the CVR group. The CVR and IVR groups did not differ in self-reports of affect, perceived exertion, enjoyment, or intrinsic motivation. As such, these psychological states are unlikely to provide an explanation for the different performance outcomes.

The Köhler effect is one example where there are increases in performance in the presence of a more capable companion and this may provide an explanation for the present findings. The mechanisms that underlie the Köhler effect are suggested to be upward social comparison and group/task indispensability (Kerr & Hertel, 2011). Both mechanisms could have contributed to the present findings, although Kerr et al. (2007) suggested that group indispensability is more important than upward social comparison for females. Despite there being no extrinsic reward for high performance, participants in the CVR group were told that
the distance travelled by the last boat at the 9-min mark would count as their team score. This would be expected to make participants in the CVR group feel instrumental in the task, thereby increasing performance. Participants in the IVR group had lower instrumentality because it was an individual task, thus contributing to the lower performance.

Participants in the CVR group were led to believe that their team-mate travelled 40% further than they did in a baseline assessment. According to Lount et al. (2008) and in line with the upward social comparison model, participants in the CVR group may have used their superior team-mate’s performance as a benchmark standard for their own performance. Participants may have formed a goal of performing better during the main trial than they did in the baseline trial. In contrast, the IVR group, did not have a team-mate as a benchmark or an external reason to set a goal for improved performance. This may have also contributed to their declining performance across epochs.

The superior performance in the CVR group may also be at least partly attributed to a more advantageous pacing strategy. Garland (2005) observed that elite athletes in the 2000 Olympic Games, 2001-2002 World Championships, and the 2001 and 2002 British Indoor Rowing Championships rowed with a similar strategy. For example, individuals who rowed on an ergometer began with a fast start by rowing at approximately 101.5% of their mean whole race velocity for the first 500 m with the subsequent three 500 m sections rowed at 99.8%, 99.0%, and 99.7% of whole race velocity. Although the present task was a time-based trial rather than a distance-based trial, participants in the CVR group were observed to start the trial at their fastest pace, show a slower pace during the middle, and finish with a relatively faster pace (although the final pace did not exceed the initial pace)\(^1\). It has been argued that the fast-start strategy is advantageous for tactical, psychological, and physiological reasons (Garland, 2005; Hoffman et al., 2014). It is also a strategy that is trainable by instructing participants to match the pace of another virtual rower set to row with this strategy as done in the study by

\(^1\)See Supplementary Material for further discussion and analyses.
Hoffman et al. (2014). The present experiment suggests that participants naturally adopted the optimal fast-start strategy when placed in a coaction situation with another virtual rower.

The current study examined the presence of others in a virtual environment utilising a between-groups design. There are benefits of between-groups designs as they can help reduce practice effects, fatigue, and attrition found in within-subject designs. However, there can be individual variance associated with between-groups designs that is better controlled in a within-subjects design (e.g., Neumann & Heng, 2011). For example, in the current study total distance rowed for the IVR group ranged from 958 m to 2122 m. Future research using a within-subjects design would provide better control for individual differences in performance. It would also allow for the inclusion of both males and females as the present study included only females to minimise the impact of variability in performance due to gender differences. Kerr et al. (2007) suggested that group indispensability (i.e., letting one’s team-mate down) is more important to women, whereas social comparison/competition is more important to men. Such hypothesised differences remain to be examined in the context of aerobic VR exercise tasks such as the rowing task used in the present study.

Another important aspect of the present design was that the social comparison condition was only implemented within a VR environment. Although the present findings suggest that the effects of the VR environment and social comparison are additive, it is not known whether one has a larger effect than the other. Lee et al. (2012) conducted a survey study of golfers who practiced using a VR golf system. The investigators compared the relative importance of immersion in the VR environment and the presence of others on psychological outcomes. It was concluded that social presence rather than presence within the VR environment was predictive of perceived enjoyment, perceived value, and behavioural intentions. Although the primary focus of the present study was on performance outcomes, it would be useful for further research to include a condition in which participants row without VR input but receive feedback of the other rower’s performance. The inclusion of a companion with no VR group
(CNVR) would result in a balanced 2 × 2 design (NVR, CNVR, IVR, CVR) to more precisely assess the relative contributions of VR input and the Köhler motivational gain on performance.

Participants in the CVR group believed they were rowing with a real person via a live Internet link. However, the avatar of the other person was actually computer-controlled. Further research could have an additional companion group where no cover story is provided and participants are made aware the second boat is computer-generated. Snyder et al. (2012) had female college students use a cybercycle to compare the impact of virtual and live partners on exercise intensity. More competitive participants exerted greater effort than non-competitive participants when exposed to a live competitor than a virtual competitor, whereas there were no differences between live and virtual competitors for less competitive participants. In a study of plank exercise performance in which the companion was shown on a video, Feltz et al. (2015) showed that the Köhler effect decreased as the partner became less lifelike in appearance. Future research that compares a live partner with a computer-controlled partner in the VR rowing task would extend upon both the Snyder et al. and Feltz et al. studies.

The current study has contributed to the body of research highlighting the benefits of VR for performance and affect during exercise. Exercising in VR environments in locations such as the home may help increase physical activity by overcoming numerous barriers to exercise. Exercising in home allows people to do so conveniently, without travel time and concerns over judgement from others that can be associated with exercising in public. Results from the current study suggest exercising in virtual environments produces higher physical exertion. The presence of others in the virtual environment further increases performance. Equipment designers should ensure their in-home exercise equipment can be interfaced with immersive VR environment systems. Compatible VR software should also have various options to manipulate the presence of others in the virtual environment. With technology moving at a fast pace, the virtual exercise experience will only improve for the user and future research will need to act accordingly to inform this work.
References


Table 1

Means and Standard Deviations (in parentheses) for the Intrinsic Motivation Inventory (IMI), Physical Activity Enjoyment Scale (PACES) and Physical Activity Affect Scale (PAAS) in the No Virtual Reality (NVR) Group, Individual Virtual Reality (IVR) Group, and Companion Virtual Reality (CVR) Group.

<table>
<thead>
<tr>
<th></th>
<th>NVR</th>
<th>IVR</th>
<th>CVR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IMI</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Perceived Competence</strong></td>
<td>4.33 (0.95)</td>
<td>4.75 (1.05)</td>
<td>4.86 (0.91)</td>
</tr>
<tr>
<td><strong>Interest/Enjoyment</strong></td>
<td>4.81 (1.26)</td>
<td>5.38 (0.87)</td>
<td>5.69 (0.88)</td>
</tr>
<tr>
<td><strong>Effort</strong></td>
<td>5.58 (0.92)</td>
<td>5.65 (0.072)</td>
<td>5.47 (0.86)</td>
</tr>
<tr>
<td><strong>Felt Pressure and Tension</strong></td>
<td>2.57 (1.34)</td>
<td>2.75 (1.05)</td>
<td>2.65 (1.07)</td>
</tr>
<tr>
<td><strong>PACES</strong></td>
<td>3.91 (0.56)</td>
<td>4.22 (0.39)</td>
<td>4.29 (0.44)</td>
</tr>
<tr>
<td><strong>PAAS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positive Affect</strong></td>
<td>2.65 (0.67)</td>
<td>2.90 (0.76)</td>
<td>3.03 (0.49)</td>
</tr>
<tr>
<td><strong>Tranquillity</strong></td>
<td>2.25 (0.81)</td>
<td>2.17 (0.83)</td>
<td>2.10 (0.96)</td>
</tr>
<tr>
<td><strong>Fatigue</strong></td>
<td>1.07 (0.73)</td>
<td>1.31 (0.79)</td>
<td>1.38 (0.96)</td>
</tr>
<tr>
<td><strong>Negative Affect</strong></td>
<td>0.33 (0.58)</td>
<td>0.15 (0.31)</td>
<td>0.13 (0.33)</td>
</tr>
</tbody>
</table>
Highlights

- Rowing in a virtual reality environment increased performance and enjoyment
- Performance effects were enhanced by the inclusion of a virtual team-mate
- Virtual reality can improve physical and affective aerobic exercise outcomes
Supplementary Material to accompany:

The Effects of the Presence of Others during a Rowing Exercise in a Virtual Reality Environment
Participant Group Descriptive Statistics

The descriptive statistics for each of the Individual No Virtual Reality (NVR), Individual Virtual Reality (IVR), and Companion Virtual Reality (CVR) groups are shown in Supplementary Table 1. As can be seen, the groups had a similar age, body mass index, scores on the Exercise Benefits and Barriers Scale, and scores on the Exercise Thoughts Questionnaire. In addition, the proportion of low, medium, and high participants on the International Physical Activity Questionnaire – Short Form were similar.

Supplementary Table 1

Descriptive Statistics for Individual No Virtual Reality (NVR), Individual Virtual Reality (IVR), and Companion Virtual Reality (CVR) Groups for the International Physical Activity Questionnaire – Short Form (IPAQ-SF), Body Mass Index (BMI), Exercise Benefits/Barrier Scale (EBBS), and Exercise Thoughts Questionnaire (ETQ).

<table>
<thead>
<tr>
<th>Group</th>
<th>IPAQ-SF Category(^a)</th>
<th>Age(^b) (SD)</th>
<th>BMI(^b) (SD)</th>
<th>EBBS(^{b,c}) (SD)</th>
<th>ETQ(^{b,d}) (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NVR</td>
<td>2,10,8</td>
<td>21.16 (3.41)</td>
<td>21.75 (3.04)</td>
<td>2.81 (0.22)</td>
<td>2.40 (0.61)</td>
</tr>
<tr>
<td>IVR</td>
<td>4,8,8</td>
<td>19.55 (1.70)</td>
<td>22.05 (2.82)</td>
<td>2.82 (0.16)</td>
<td>2.45 (0.91)</td>
</tr>
<tr>
<td>CVR</td>
<td>2,11,7</td>
<td>19.90 (2.67)</td>
<td>22.85 (4.03)</td>
<td>2.79 (0.19)</td>
<td>2.31 (0.65)</td>
</tr>
<tr>
<td>Total</td>
<td>8,29,23</td>
<td>20.20 (2.73)</td>
<td>22.22 (3.32)</td>
<td>2.81 (0.19)</td>
<td>2.39 (0.72)</td>
</tr>
</tbody>
</table>

Notes: \(^a\)Category order is low, medium, high; \(^b\)mean is shown with standard deviation in parentheses. \(^c\)Cronbach’s alpha for the current sample was .95; \(^d\)Cronbach’s alpha for the current sample was .93.
Relationships between the Measures

The relationships between the dependent variables were examined through bivariate correlations. The first set of analyses examined the relationships between feeling states reported in the last minute of the trial, mean heart rate across the last minute of the trial, and performance outcomes across the entire trial. The correlations are shown in Supplementary Table 2. As can be seen, ratings on the feeling scale (FS) in the last minute were negatively correlated with mean distance and power across the entire trial and negatively correlated with heart rate and ratings of perceived exertion (RPE) in the last minute of the trial, suggesting that more negative feelings were associated with better performance and greater physical exertion. RPE was also positively correlated with ratings on the felt arousal scale (FAS) to suggest that higher perceived exertion was associated with increased arousal.

The second set of analyses examined the relationships between feeling states and heart rate in the last minute of the trial with scores on the self-report questionnaires administered immediately after the trial. As shown in Supplementary Table 3, FS ratings were positively correlated with both the IMI tension subscale ratings and PAAS tension subscale ratings and negatively correlated with the PAAS fatigue subscale ratings. FAS ratings were negatively correlated with ratings on the PAAS negative affect subscale. The correlations suggest that global feeling states experienced in the last minute of the task were strongly associated with posttask feelings of tension and fatigue.
Supplementary Table 2

**Correlations between heart rate, ratings of perceived exertion, feeling scale, and felt arousal scale reported in the last minute of the trial and mean performance measures across the entire trial**

<table>
<thead>
<tr>
<th></th>
<th>HR</th>
<th>RPE</th>
<th>FS</th>
<th>FAS</th>
<th>Distance</th>
<th>Power</th>
<th>SPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>-</td>
<td>.20</td>
<td>-.31*</td>
<td>.13</td>
<td>.64**</td>
<td>.64**</td>
<td>.24</td>
</tr>
<tr>
<td>RPE</td>
<td>-</td>
<td>-.31*</td>
<td>.45*</td>
<td>.19</td>
<td>.22</td>
<td>.02</td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>-</td>
<td>.11</td>
<td>-.26*</td>
<td>-.29*</td>
<td>-0.01</td>
<td></td>
<td></td>
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<tr>
<td>FAS</td>
<td>-</td>
<td>-.01</td>
<td>.02</td>
<td>-.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>-</td>
<td></td>
<td>.98**</td>
<td>.57**</td>
<td></td>
<td></td>
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<tr>
<td>Power</td>
<td>-</td>
<td></td>
<td>.53**</td>
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<tr>
<td>SPM</td>
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</tbody>
</table>

Notes: *p < .05, **p < .01, HR = heart rate, RPE = ratings of perceived exertion, FS = feeling scale, FAS = felt arousal scale, SPM = strokes per minute
Supplementary Table 3

Correlations between heart rate, rating of perceived exertion, feeling scale, and felt arousal scale reported in the last minute of the trial (minute 9) and scores on self-report questionnaires for intrinsic motivation, enjoyment, and affect.

<table>
<thead>
<tr>
<th></th>
<th>HR</th>
<th>RPE</th>
<th>FS</th>
<th>FAS</th>
<th>IMI Effort</th>
<th>IMI Comp</th>
<th>IMI Tension</th>
<th>IMI Interest</th>
<th>PACES</th>
<th>PAAS PA</th>
<th>PAAS T</th>
<th>PAAS F</th>
<th>PAAS NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>-</td>
<td>.20</td>
<td>-.31*</td>
<td>.13</td>
<td>.17</td>
<td>.07</td>
<td>.20</td>
<td>-.11</td>
<td>.08</td>
<td>.01</td>
<td>-.06</td>
<td>.08</td>
<td>-.13</td>
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<tr>
<td>RPE</td>
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<td></td>
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<tr>
<td>FS</td>
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<td>FAS</td>
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<td>IMI Effort</td>
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<td>IMI Comp</td>
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<td>IMI Tension</td>
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<td>IMI Interest</td>
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<td>PACES</td>
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<td>PAAS PA</td>
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<td>PAAS F</td>
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<tr>
<td>PAAS NA</td>
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</tr>
</tbody>
</table>

Notes: * p < .05, ** p < .01, HR = heart rate, RPE = rating of perceived exertion, FS = feeling scale, FAS = felt arousal scale, IMI Effort = Intrinsic Motivation Inventory Effort subscale, IMI Comp = Intrinsic Motivation Inventory Perceived Competence subscale, IMI Tension = Intrinsic Motivation Inventory Tension subscale, IMI Interest = Intrinsic Motivation Inventory Interest/Enjoyment subscale, PACES = Physical Activity Enjoyment Scale, PAAS PA = Physical Activity Affect Scale Positive Affect subscale, PAAS T = Physical Activity Affect Scale Tension subscale, PAAS F = Physical Activity Affect Scale Fatigue subscale, PAAS NA = Physical Activity Affect Scale Negative Affect subscale.
Feeling States, Felt Arousal, and Perceived Exertion during the Rowing Task

The circumplex space resulting from ratings on the FS and FAS during the trial are shown in Supplementary Figure 1. Means and standard deviations for the ratings on the FS, FAS, and RPE are shown in Supplementary Table 4. Please refer to the main article for statistical analyses and interpretation of the results.

Supplementary Figure 1. Circumplex space for the Feeling Scale (X-axis) and Felt Arousal Scale (Y-axis) for No Virtual Reality (NVR), Individual Virtual Reality (IVR) and Companion Virtual Reality (CVR) groups.
Supplementary Table 4

**Means and Standard Deviations (in parentheses) for the Feeling Scale, Felt Arousal Scale, and Ratings of Perceived Exertion Across Epochs in the Individual No Virtual Reality (NVR), Individual Virtual Reality (IVR), and Companion Virtual Reality (CVR) Groups.**

<table>
<thead>
<tr>
<th></th>
<th>NVR</th>
<th>IVR</th>
<th>CVR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeling Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 min</td>
<td>3.47 (0.82)</td>
<td>3.57 (0.88)</td>
<td>3.75 (1.12)</td>
</tr>
<tr>
<td>3 min</td>
<td>2.70 (1.74)</td>
<td>2.60 (1.64)</td>
<td>2.60 (1.76)</td>
</tr>
<tr>
<td>6 min</td>
<td>2.40 (1.31)</td>
<td>2.56 (1.63)</td>
<td>2.45 (2.06)</td>
</tr>
<tr>
<td>9 min</td>
<td>2.04 (1.73)</td>
<td>2.46 (1.76)</td>
<td>2.00 (2.38)</td>
</tr>
<tr>
<td>Felt Arousal Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 min</td>
<td>2.48 (0.88)</td>
<td>2.45 (0.83)</td>
<td>2.81 (1.01)</td>
</tr>
<tr>
<td>3 min</td>
<td>3.55 (0.89)</td>
<td>3.70 (0.98)</td>
<td>3.48 (0.60)</td>
</tr>
<tr>
<td>6 min</td>
<td>4.10 (1.21)</td>
<td>3.90 (1.12)</td>
<td>3.95 (1.00)</td>
</tr>
<tr>
<td>9 min</td>
<td>4.20 (1.40)</td>
<td>4.15 (1.31)</td>
<td>4.00 (1.03)</td>
</tr>
<tr>
<td>Rating of Perceived Exertion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 min</td>
<td>12.50 (2.44)</td>
<td>13.30 (1.98)</td>
<td>13.22 (1.59)</td>
</tr>
<tr>
<td>6 min</td>
<td>14.35 (2.62)</td>
<td>14.62 (1.95)</td>
<td>14.40 (2.33)</td>
</tr>
<tr>
<td>9 min</td>
<td>15.35 (2.72)</td>
<td>15.98 (1.95)</td>
<td>15.40 (2.39)</td>
</tr>
</tbody>
</table>
Examination of the Pacing Across the Trial in the Companion Virtual Reality Group

To examine the pacing strategy that appeared to be adopted in the companion virtual reality (CVR) group, further analyses were conducted on the distance measure. The first minute of the trial was disregarded due to participants starting at rest and to allow for four even time periods (minutes 2-3, 4-5, 6-7, and 8-9). For each participant, the mean for each 2-min time period was expressed relative to the mean across the entire 8 min. As shown in Supplementary Table 5, the resulting values for the CVR group showed a similar pattern to the “fast start” velocity profile reported by Garland (2005). In contrast, a linear pattern was shown in the other groups in which the IVR group slowed across time and the NVR group increased across time. A 3 (group: NVR, IVR, CVR) × 4 (epoch: 2-3 min, 4-5 min, 5-6 min, 7-8 min) mixed factorial ANOVA yielded a significant group × epoch interaction, $F(1.26, 72.09) = 3.92$, $p = .017$, $\eta^2_p = .12$, supporting the different pacing between groups. Further analyses showed that the quadratic trend was significant for the CVR group, $F(1, 19) = 6.20$, $p = .02$, $\eta^2_p = .25$, but not for the NVR and IVR groups, both $F$s < 1.42, $p > .05$.

Supplementary Table 5

Means and Standard Deviations (in parentheses) for Time at each 2 Minute Interval Expressed as a Percentage of the Mean of the Entire 8 Minute Period for the No Virtual Reality, Individual Virtual Reality, and Companion Virtual Reality Groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Minute 2-3</th>
<th>Minute 4-5</th>
<th>Minute 5-6</th>
<th>Minute 8-9</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Virtual Reality</td>
<td>96.29 (8.23)</td>
<td>97.08 (5.44)</td>
<td>102.43 (3.93)</td>
<td>104.20 (9.30)</td>
</tr>
<tr>
<td>Individual Virtual Reality</td>
<td>100.98 (3.99)</td>
<td>100.03 (1.82)</td>
<td>99.53 (1.78)</td>
<td>99.45 (3.16)</td>
</tr>
<tr>
<td>Companion Virtual Reality</td>
<td>100.95 (4.85)</td>
<td>98.98 (2.08)</td>
<td>99.63 (2.27)</td>
<td>100.44 (4.32)</td>
</tr>
</tbody>
</table>