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Persistence and pleasure in VR: Enhancing Exercise Endurance and Enjoyment through Virtual Environments

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A R T I C L E I N F O

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A B S T R A C T

Virtual Reality (VR) provides an enjoyable addition to stationary physical exercise and can improve performance while exercising. The aim of this study is to explore the effectiveness of three interactive virtual environments (i.e., social, relaxing, stressful) on enjoyment and persistence during strength-based exercises. In a within-subjects experiment, 97 healthy young adults completed four consecutive sets of two strength-based exercises. Participants completed one set as baseline and then each participant completed three more sets in three different interactive environments, experienced through a VR headset. Results showed that both the stressful virtual environment, where participants were hanging suspended over a city, and the social virtual environment where participants were audibly encouraged in a stadium, increased participants' persistence in both exercises, when compared to the relaxing virtual environment. Specifically, the relaxing sunny beach environment caused poorer performances in a dead hang exercise among men ($n = 30$), and poorer performances in a core exercise among women ($n = 66$). Somewhat paradoxically, this relaxing virtual beach environment was considered the most enjoyable environment among both male and female participants. The potential of VR in exercise lies in its ability to provide pleasurable and performance-enhancing immersive environments that may be too expensive or dangerous in reality.

1. Introduction

Physical exercise enhances health and helps prevent premature death by lowering risks of contracting cardiovascular diseases, certain types of cancer, and other chronic diseases (Warburton, Nicol, & Bredin, 2006). In Europe, 26% of men and 35% of women are insufficiently physically active, and almost half of them never play sport or exercise (OECD, 2023). Exercise (i.e., structured and repetitive physical activity) is often perceived as boring, hard or painful, causing people to defer from this type of activity after long days of work or study. Research has shown that exercise can become more appealing when individuals are provided with stimuli that distract them from physical discomfort (McClure & Schofield, 2020). Both visual stimuli (screens) and spatial stimuli (surroundings) can draw attention away from negative bodily sensations such as fatigue, pain and discomfort while exercising (Filbrich, Alamia, Blandiaux, Burns, & Legrain, 2017). The introduction of Virtual Reality (VR) headsets can provide an entertaining alternative for those who struggle with regular physical exercise, as this immersive technology may engage individuals who might not be inclined to participate otherwise (Bird, 2020). Moreover, VR can enhance the effectiveness of exercise by providing stimulating environments and scenarios that may be too dangerous or expensive in reality.

A review of 20 studies on the application of VR to stationary sport exercise (e.g. cycling, running, rowing) indicated that it increased enjoyment and reduced tiredness when compared to performance of the exercise on its own (Neumann et al., 2018). Similarly, a meta-analysis of 35 studies found that virtual-supported exercises caused more enjoyment, and increased intrinsic motivation to continue the physical activity (Gao, Chen, Pasco, & Pope, 2015). Despite consistent use the term 'virtual reality' to describe their approach, none of the studies that were included in the review or meta-analysis actually used a VR headset. VR headsets can completely replace real perceptions with computer-generated stereoscopic virtual environments that are experienced through natural sensorimotor contingencies (Slater & Sanchez-Vives, 2016). Because of these immersive qualities, VR headsets are more effective at evoking emotional and physiological responses than traditional two-dimensional screens (Lemmens, Simon, & Sumter, 2022).

Studies that examined the effects of using VR headsets during exercise have shown that they make stationary exercise more enjoyable and

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more effective (Dolu & Camliguney, 2022; Matsangidou et al., 2019; McClure & Schofield, 2020; McDonough, Pope, Zeng, Liu, & Gao, 2020). Because the enjoyment that is experienced while performing an exercise is a stable predictor of continued time spent on physical activity (Penko and Barkley, 2010; Campelo, Donaldson, Sheehan, & Katz, 2015) enjoyable VR exercises may lead to health benefits by encouraging continued use. Despite consistent indications that a VR headset can improve exercise enjoyment, persistence and performance, there is ambiguity concerning the specific mechanisms that explain its effectiveness. Most researchers assume that VR effectively distracts our sensory receptors away from bodily discomfort, reducing any experienced pain, thereby increasing performance (Bowman, Weber, Tamborini, & Sherry, 2013; De Bourdeaudhuij et al., 2002). The specific means of distraction is expected to moderate the effectiveness of VR. Exciting or stressful environments likely increase heart rate, whereas relaxing environments likely decrease heart rate (Dolu & Camliguney, 2022). Furthermore, social facilitation may positively influence exercise performance due to the perceived presence of virtual others. The presence of others may not only provide distraction from discomfort, the benefits of social encouragement have been found across numerous types of athletic performances (Jamieson, 2010) and may therefore also improve performance in VR. Because of the theoretical and empirical evidence for the effectiveness of different mechanisms and associated virtual environments, the aim of the current study is to explore the effect of VR headsets on persistence and enjoyment during physical exercises in three types of interactive virtual environments: *social, relaxing,* and *stressful*.

1.1. The effects of virtual environments

Social exercise environments are virtual spaces where users perceive the presence of others, which can positively influence performance through social facilitation (Hutchinson & Tenenbaum, 2007). Social facilitation generally means that performance on simple tasks improves when others are present (Strauss, 2002). For example, while playing a competitive video game, the perceived presence of an audience significantly increased player performance (Bowman et al., 2013). For social facilitation to occur in VR, it seems imperative that 'others' are perceived as real, regardless of whether actual humans are virtually present. A study that examined social facilitation with a VR headset found that the presence of virtual bystanders improved performance of firefighters during a simulated rescue procedure, but only if these bystanders were perceived as realistic (Strojny, Dużmańska-Misiarczyk, Lipp, & Strojny, 2020). The facilitating effect of social presence is likely even stronger when these others are supportive of the actions performed by the individual. This *home field advantage* has shown to enhance a range of real-life athletic performances (Jamieson, 2010). Although supportive audiences may generally improve performance, it can cause some athletes to experience performance pressure and reduced satisfaction depending on the outcome (Wallace, Baumeister, & Vohs, 2005). Although performance pressure may detract from enjoying a social VR environment for some, it likely has a positively influence on exercise performance for most, due to distraction and encouragement coming from the perceived virtual presence of others.

Relaxing before physical exercise can aid self-regulation for optimal activation, thereby supporting performance and well-being (Kellmann et al., 2018). Research has shown that participants who received mindfulness training before exercising showed significantly better endurance on a treadmill than a control group (Nien et al., 2020). Attempts at relaxing during exercise can be used as a coping strategy to alleviate emotional and physical distress. The effectiveness of a relaxation technique depends on the ability of athletes to visualize themselves in a pleasant and calming environment during moments of intense pain or discomfort (Karageorghis & Terry, 2011). VR environments can facilitate visualization of these relaxing environments. A recent experiment among healthy adults found that participants with a VR headset that displayed a virtual tour of a national park, endured longer during a wall squat test than those without a headset (Dolu & Camliguney, 2022). Scenes of natural environments (e.g., beaches, mountains, trees) have shown to cause significant reductions in blood pressure and heart rate when experienced through a VR headset (Gerber et al., 2017), and can therefore be considered relaxing. Another experiment had young-adult participants ride an exercise bike either with- or without a headset that exposed them to a virtual environment where they were riding down a sidewalk with trees on a pleasant sunny day (McClure & Schofield, 2020). Their results showed that this relaxing virtual environment increased satisfaction and heart rate, but did not decrease participants' attention to bodily sensations (e.g., respiration, anxiety, dizziness, pain). These studies suggest that a relaxing VR environment may contribute to an enjoyable exercise that is more effective than exercising without VR. However, relaxing virtual environments, due to limited physiological activation, may not be as effective as exciting virtual environments.

Exciting or stressful environments likely increase physiological activation and arousal (Dolu & Camliguney, 2022) thereby improving performance during exercise. Physiological arousal is considered an integral part of emotional processing, as affective states consist of two continuous dimensions: excitation intensity (i.e., high–low arousal) and valence (i.e., pleasant-unpleasant). Arousal can thereby exist as a positive affective state (excitement) or as a negative state (stress). VR experiences can increase physiological arousal through negatively-valenced emotions that are elicited by a scary environment (Lemmens et al., 2022). Fear causes the adrenal glands to release adrenaline into the bloodstream, which increases heart rate and leads to a noticeable increase in strength and performance (Borer, 2003). Scary environments can thereby increase performance through increased heart rate and adrenaline that accompany an expected stressful emotional and physiological response. Concurrently, when the mind is preoccupied with perceived threats to the autonomic nervous system, it is distracted from pain and fatigue, which decreases realization of bodily discomfort, allowing for increased endurance during extensive exercise (De Bourdeaudhuij et al., 2002; Lindsay & Anderson, 2000). Thus, although enjoyment may suffer, a stressful virtual environment likely enhances persistence during strength-based exercises.

The aim of the current study is to explore the effectiveness of three virtual environments (i.e., social, relaxing, and stressful) on persistence and enjoyment during physical exercises with a VR headset among healthy young adults. The main research question is: *Which virtual environment is most effective and enjoyable during strength-based exercise?* Relaxing virtual environments, although likely very enjoyable. may not be as effective at improving performance due to limited physiological activation. Stressful environments on the other hand, are expected to increase performance, likely through increased stressful emotional and physiological response. Since men and women show strong differences in their preference for competitive sports activities (Swain & Jones, 1991) and competitiveness in game activities (Hartmann & Klimmt, 2006), gender may moderate the effects of the social environment. Specifically, this interactive environment may prove more effective and enjoyable among men due to their preference for competitive activities. To answer the research question and find support for our assumptions regarding the effectiveness and enjoyment of virtual environments, a VR experiment with three interactive virtual environments and two strength-based exercises was conducted among 97 young adults.

2. Method

2.1. Sample

In February and March 2022, 97 participants aged 17 to 34 (M = 20.96, SD = 2.81), took part in the lab experiment. Most of the participants were women (n = 67; 69.1%) and most were students at the University of [*Blinded for Review*] (n = 78). All participants were informed beforehand that the experiment would involve strenuous physical activity and VR. The experiment received approval from the departmental ethical committee. Informed consent was obtained from all participants and each received either payment (€10) or research credits for their collaboration. One female participant performed very poorly during all exercises and was removed from the dataset for being an influential outlier (i.e., more than three standard deviations below the mean performances on all exercises). Thus, data from 96 participants was analyzed. Among these participants, 22% ($n = 21$) spent no time on sport or exercise whatsoever, 30% ($n = 29$) spent up to 2 h per week on sport or exercise, and 42 participants (44%) spent 3 h or more per week on exercise or sports. The type of physical activity most mentioned ($n = 26$) was *fitness* (including *spinning* and *Pilates*), followed by running ($n = 13$). Most participants had experienced VR once or twice before (59%, $n = 57$), whereas 29% ($n = 28$) had never used a VR headset prior to the experiment.

Estimated sample size was based on the smallest effect size considered theoretically or practically interesting. Considering the size of the population that the sample of participants was taken from, even small effects could have enormous societal impact. The effect size distribution, analyses, and sample sizes of related studies (e.g., $n = 56$, Campelo et al., 2015; $n = 61$, Riva et al., 2007), indicated that the current split-plot (3x2) repeated-measures design would require a slightly larger sample size (see Lakens, 2022 for elaboration on sample size justification). Since no a priori power analysis was conducted, a post hoc power analysis was conducted using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) to determine the adequacy of the sample size. Results indicated that the minimum sample size for detecting small effect sizes using within-between interaction ANCOVA repeated measures (at least $p < .05$) was $N = 82$. Thus, the current sample of 96 should be sufficient even for detecting small effects.

2.2. Procedure

After providing informed consent, participants height and weight were measured. Then they were asked to do a baseline test of their persistence using two strength-based exercises: *Dead hang* and *Core*. In the dead hang exercise, participants used a stool to grab a pull-up bar that was more than 2 m in the air. The only instructions were to hang on as long as they could and let go when they could not hang on anymore. This *dead hang* exercise is an effective way to test forearm muscles and grip strength. Time was measured from the moment their feet left the stool until they landed on the floor (range 12–133 s, $M = 60.76$, $SD = 25.43$). After resting for 2 min, they performed a core exercise, using different muscle groups. This core exercise required them to keep themselves elevated as long as possible while resting their elbows on two cushioned pads located at chest-height. This exercise targeted the abdominal muscles and lower back muscles. This core exercise lasted from the moment their feet left the ground until their feet touched the ground (range 8–128 s, $M = 41.11$, $SD = 21.42$). Four participants could not keep themselves suspended at all, and their performances on this exercise were not included in the analyses. The two exercises are displayed in Fig. 1.

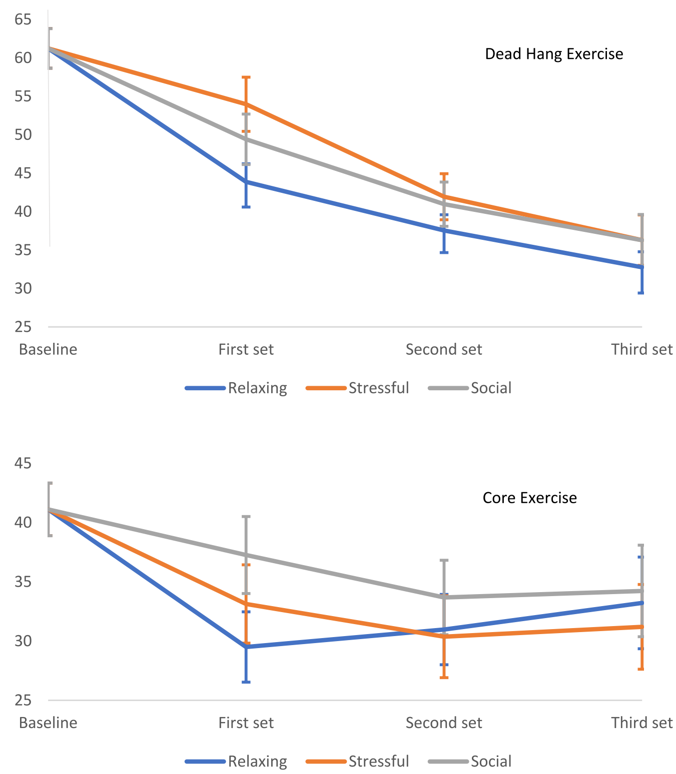

Fig. 2. Persistence-Attrition in Seconds for Two Exercises across Virtual Environments
Note: Vertical bars represent standard error bars for environments at each persistence measure.

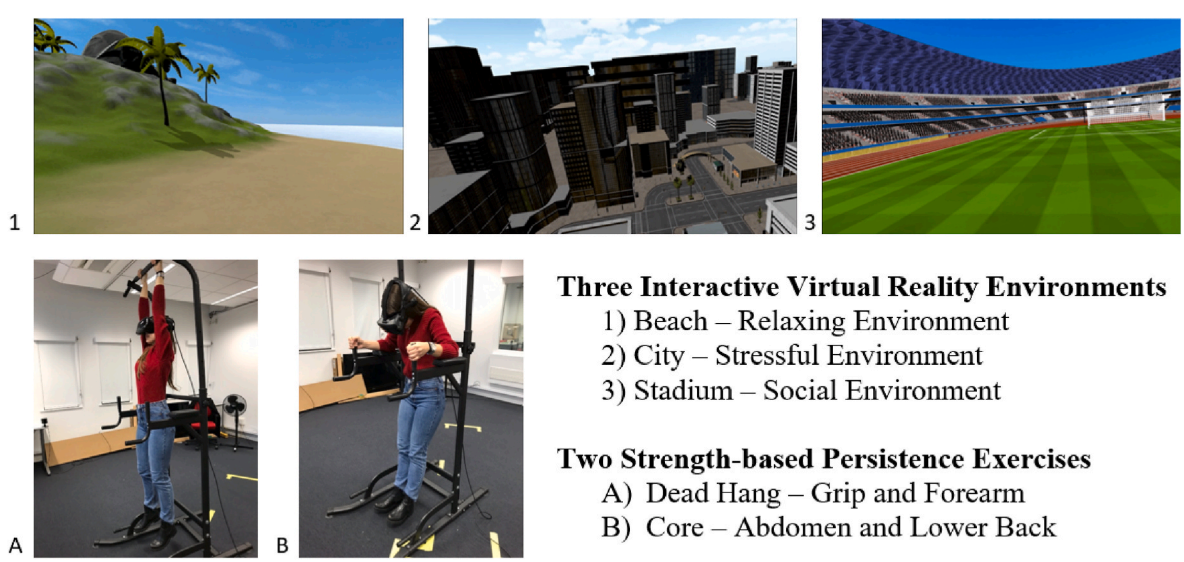

Fig. 1. Three virtual environments and two exercise types.

After the baseline measures, participants rested for 5 min while they were aided with applying the VR headset (Valve Index), which was adjusted to their inter-pupillary distance and head size. Then each participant performed the same two exercises (*dead hang* and *core*) consecutively in three interactive virtual environments. The order in which participants experienced the three virtual environments (i.e., social, relaxing, stressful) was counterbalanced, meaning that the six different sequences of presenting the three environments were repeated after six participants. Throughout the experimental procedure, there were 2-min breaks between the two strength-based exercises, and 5-min breaks between environments. During the 5-min breaks, the VR headset was removed and participants could eat snacks and drink water as they pleased. After approximately 40 min, they started the post-experiment questionnaire on a tablet. When asked about the three different environments, these were referred to as *stadium* (social)*, beach* (relaxing), and *city* (stressful), based on their most striking visual characteristics. Upon completing the questionnaire, participants were thanked and debriefed.

3. Stimulus material

The three virtual environments: *Social, Relaxing,* and *Stressful* were built with Unity and are displayed in Fig. 1. The social environment, labeled *stadium*, displayed the center of a football field with a stadium surrounding the pitch. Audio contained continued cheering and applauding from a large crowd and an occasional finger whistle. Although participants could not identify individual members of the audience, it was implied that the cheers came from the crowd present in the stadium. The relaxing environment, labeled *beach*, displayed a tropical beach with a palm tree, shoreline, and mountain in the background. Audio contained rolling waves, wind, and an occasional seagull squawk. The stressful environment, labeled *city*, displayed an aerial view of a city with the tops of skyscrapers and other buildings surrounding the participant. Audio included wind and the sound of traffic from far below. All environments contained a virtual pull-up bar suspended from ropes that disappeared into the clouds. Touching the bar provided haptic feedback as its position matched the position of the pull-up bar in the lab.

A manipulation check was performed to examine whether the stressful environment was indeed experienced as the most stressful, and the relaxing environment as the least stressful environment. In the post-exercise questionnaire, three items (one for each environment) were used to assess this subjective experience: *The stadium/city/beach experience was stressful.* Items were rated on a 7-point Likert scale ranging from (1) *Completely disagree* to (7) *Completely agree.* Overall, participants experienced some stress in the virtual environments ($M = 3.21$, $SD = 0.96$). Repeated measures ANOVA pairwise comparison with Bonferroni correction indicated that reported stress differed significantly between virtual environments $F(2,190) = 84.06$, $p < .001$, $\eta p^2 = 0.47$. The virtual city ($M = 4.53$, $SD = 1.62$) was much more stressful than the virtual beach ($M = 1.91$, $SD = 1.11$), $SE = 0.19$, $p < .001$, CI [2.16, 3.10], and also more stressful than the virtual stadium ($M = 3.19$, $SD = 1.67$), $SE = 0.22$, $p < .001$, CI [0.80, 1.89]. The virtual stadium was perceived as more stressful than the virtual beach, $SE = 0.19$, $p < .001$, CI [0.82, 1.74]. The manipulation of the environments was successful as the stressful city environment was indeed more stressful that the other two virtual environments. Conversely, the relaxing beach environment was indeed significantly less stressful than the other two environments.

3.1. Measures

Body Mass Index (BMI). BMI is a convenient measure to categorize a person as underweight, normal weight, overweight, or obese. Participants weight in kilograms ($M = 65.56$, $SD = 10.21$) was divided by their squared height in meters ($M = 1.75$, $SD = 0.09$) to assess their BMI ($M = 21.45$, $SD = 2.61$). Four participants were overweight (BMI >25), and two were obese (BMI >30), whereas nine participants were underweight (BMI <18.5).

Presence. Players' sense of spatial presence in each of the three virtual environments was measured using selected items from the *Spatial Presence Experience Scale* (Hartmann et al., 2015). Spatial presence was measured on a 1 (*completely disagree*) to 5 (*completely agree*) answer-scale. The 6-item scale measured the extent to which a participant felt that the in-game environments presented accurate representations of a plausible reality. Participants were asked to reflect on their VR experiences with *Beach, City,* or *Stadium* when answering items such as 'I had a precise idea of the spatial surroundings presented in the experience' and 'It seemed as though I was present in the environment'. All three presence scales showed acceptable reliability (beach $\alpha = 0.74$, city $\alpha = 0.78$, stadium $\alpha = 0.77$). Overall, participants experienced considerable presence in the virtual environments ($M = 3.49$, $SD = 0.60$). Repeated-measures ANOVA indicated that participants sense of presence did not differ across social- ($M = 3.45$, $SD = 0.73$), relaxing- ($M = 3.45$, $SD = 0.72$), and stressful environments ($M = 3.58$, $SD = 0.73$), $F(2,188) = 1.68$, $p = .190$, $\eta p^2 = 0.02$.

Enjoyment. The positive emotional outcome of each environment was measured using an enjoyment scale consisting of two items, that was based on a 3-item enjoyment scale by Wirth, Hofer, and Schramm (2012): 'The beach/city/stadium experience was enjoyable', and 'The beach/city/stadium experience was pleasant'. Both items were rated on a 7-point Likert scale. Cronbach's alpha and Spearman-Brown split-half reliability coefficients for this 2-item measure of enjoyment showed acceptable internal consistency across measurements in the three virtual environments: beach enjoyment ($\alpha = 0.78$, $r = 0.78$), city enjoyment ($\alpha = 0.76$, $r = 0.76$), and stadium enjoyment ($\alpha = 0.75$, $r = 0.75$). Overall, participants reported considerable enjoyment across virtual environments ($M = 4.87$, $SD = 0.79$).

3.2. Data analysis

Data was analyzed using SPSS version 29. Multiple repeated measures analysis of variance (ANOVA) were performed to examine the effects of the three virtual environments on persistence (in seconds) in the *Dead hang* and *Core* exercises. Repeated measures reduce the error variance by measuring differences in variability within each participant, not differences between participants, as regular ANCOVAs would. The within-subjects factors were the three virtual environments, the between-subjects factor was gender, and BMI was controlled for. Thus, the analysis was a split-plot repeated measures ANCOVA (including a within-groups factor VR condition with 3 levels and a between-groups factor gender with 2 levels). Data screening procedures were performed to ensure the assumptions of normality and homogeneity of variance were met. There was consistent homogeneity of variances, as assessed by the Levene's test of equality of error variances (all $ps > .1$). The assumption of sphericity was evaluated using Mauchly's test of sphericity, and in case of violation, the Greenhouse-Geisser correction was applied to adjust the degrees of freedom and estimate effect size. Post-hoc analyses were conducted to explore pairwise comparisons and determine the specific differences between virtual environments when significant main effects were found. Bonferroni tests ($p < .05$) were used to adjust for multiple comparisons and control the family-wise error rate (type 1 errors). Effect sizes were calculated to assess the practical significance of the results. Partial eta-squared (ηp^2) values were reported as measures of effect size for the main effects and interactions.

4. Results

4.1. Initial analyses

Participants showed decreased performances after each consecutive dead hang exercise that followed the baseline (see Fig. 2). Across environments, persistence on the dead hang exercise decreased between the baseline ($M = 61.61$, $SD = 25.01$), the first environment ($M = 49.59$, $SD = 27.34$), the second environment ($M = 40.46$, $SD = 14.88$), and the third environment ($M = 35.40$, $SD = 16.43$), $F(1.69, 153.95) = 8.73$, $p < .001$, $\eta p^2 = 0.09$. The core exercise did not show significant persistence-attrition between the baseline ($M = 41.46$, $SD = 21.27$), the first environment ($M = 33.53$, $SD = 17.65$), the second environment ($M = 31.86$, $SD = 17.61$), and the third environment ($M = 33.10$, $SD = 20.88$), $F(2.53, 76.28) = 0.16$, $p = .899$, $\eta p^2 = 0.00$. There were no significant interactions on either exercise with gender or BMI, indicating that the gradual decrease in persistence did not differ significantly between men and women, and was not influenced by participants' BMI across the four sets of exercises. Additional analyses also indicated there were no sequence effects for the presentation of virtual environments.

Overall, men performed better on both exercises than women did. When performing a *t*-test for gender differences in average persistence (i.e., mean persistence-time across baseline and three environments), results from the dead hang exercise ($M = 41.06$, $SD = 15.85$) showed that men held on about 15 s longer ($M = 51.34$, $SD = 19.39$) than women did ($M = 36.46$, $SD = 11.44$), $t(95) = 4.73$, $p < .001$. Results from the core exercise ($M = 32.38$, $SD = 17.84$) showed that men held out twice as long ($M = 50.31$, $SD = 16.12$) as women did ($M = 24.38$, $SD = 11.76$), $t(41.85) = 7.79$, $p < .001$. As expected, participants' BMI negatively affected overall persistence on both the dead hang exercise ($r = -0.36$, $p < .001$) and the core exercise ($r = -0.21$, $p = .044$). Although the current counterbalanced within-subjects design carries individual differences in BMI into every environment, thereby reducing the need to control for individual differences, it may be that BMI interacts to some degree with some environments more than others. Since higher BMI diminishes persistence, it reduces exposure time to the virtual environments, which may also limit the potential positive effects these environments can have. Therefore, BMI was added as a covariate to examine potential interaction effects with the environments. Considering presumed differences between men and women in the effects of the social stadium environment, gender was added as a between-subjects independent factor when assessing the effectiveness and enjoyment of the three virtual environments.

4.2. Differences in virtual environments

To evaluate the effects of the three virtual environments on persistence within the two exercises, two split-plot repeated-measures ANCOVAs were performed, with gender as a between-subjects factor, and BMI as a covariate. In the first repeated measures ANCOVA, the dependent variable was time spent hanging on the dead hang exercise. Because Mauchly's test of sphericity showed that the assumption of sphericity was transgressed, $\chi^2(2) = 7.02$, $p = .029$, the Greenhouse-Geisser correction was used to estimate effect size. There was no significant main effect of the three virtual environments on persistence in the dead hang exercise, $F(1.86, 171.29) = 0.19$, $p = .811$, $\eta p^2 = 0.00$. However, when BMI was removed as a covariate, the main effect of virtual environments on persistence in the dead hang was significant, $F(1.86, 175.24) = 4.34$, $p = .017$, $\eta p^2 = 0.04$. Pairwise comparisons with Bonferroni correction showed that participants' persistence was higher in the social stadium condition ($M = 42.09$, $SD = 17.48$) than in the relaxing beach condition ($M = 39.81$, $SD = 16.48$), $SE = 1.34$, $p = .033$, CI [0.21, 6.72]. No other significant differences between environments were found. In the second repeated measures ANCOVA, the dependent variable was time spent elevated in the core exercise, again BMI was a covariate, and gender a between-subjects factor. This time, the main assumption of sphericity had not been violated, $\chi^2(2) = 3.21$, $p = .201$. Similar to the results from the dead hang, there was no significant main effect of the three virtual environments on persistence in the core exercise, $F(2, 178) = 2.39$, $p = .095$, $\eta p^2 = 0.03$. Contrary to the dead hang exercise, this effect was not significant when BMI was removed as a covariate, $F(2, 182) = 2.42$, $p = .092$, $\eta p^2 = 0.03$.

Both split-plot repeated-measures ANCOVAs showed significant interaction effects between persistence (in seconds) and gender. No interaction effects between persistence and BMI were found. Gender moderated the effects of virtual environments on persistence in the dead hang exercise $F(1.86, 171.29) = 4.23$, $p = .018$, $\eta p^2 = 0.04$. Similarly, In the core exercise, gender moderated the effect of virtual environments on persistence $F(2, 178) = 4.50$, $p = .012$, $\eta p^2 = 0.05$. Both exercise analyses thereby indicated that virtual environments influence persistence differently for men and women. The differences in persistence between men and women across the three environments are displayed in Fig. 3. Pairwise comparisons with Bonferroni correction in the dead hang exercise, showed that men in the relaxing virtual beach environment ($M = 48.07$, $SD = 20.09$) performed worse than in the stressful city environment ($M = 53.47$, $SD = 19.09$), $SE = 2.02$, $p = .028$, 95% CI [-10.31, −0.44]. Men also performed worse in the beach environment than in the social stadium environment ($M = 54.70$, $SD = 20.89$), $SE = 2.24$, $p = .012$, 95% CI [-12.08, −1.17]. Among men, there were no significant differences between city and stadium environments, $SE = 1.76$, $p = 1.000$, 95% CI [-5.54, 3.03]. For women in the dead hang exercise, there were no significant differences between beach ($M = 36.15$, $SD = 13.17$), city ($M = 35.51$, $SD = 12.93$), and stadium ($M = 36.52$, $SD = 12.07$). Pairwise comparisons with Bonferroni correction in the core exercise, showed no differences among women between beach ($M = 49.28$, $SD = 16.11$), city ($M = 47.69$, $SD = 17.81$), and stadium ($M = 50.93$, $SD = 15.43$). However, women performed worse in the relaxing virtual beach environment ($M = 22.89$, $SD = 10.90$) than in the stressful city environment ($M = 29.21$, $SD = 13.53$), $SE = 1.58$, $p < .001$, 95% CI [-10.13, −2.42]. Women also performed worse in the beach environment than in the social stadium environment ($M = 26.62$, $SD = 15.99$), $SE = 1.36$, $p = .025$, 95% CI [-7.02, −0.36]. There were no significant differences between city and stadium environments, $SE = 1.59$, $p = .320$, 95% CI [-1.29, 6.47]. Overall, the relaxing beach VR environment induced the poorest performance across exercises: for men in the dead hang exercise, and for women in the core exercise.

In order to determine if enjoyment differed between the three types of virtual environments, another split-plot repeated-measures ANCOVA was performed, with gender as a between-subjects factor, and BMI as a covariate. Mauchly's test of sphericity was not transgressed, $\chi^2(2) = 5.66$, $p = .059$. There was a significant main effect of the three virtual environments on enjoyment, $F(2, 174) = 3.29$, $p = .039$, $\eta p^2 = 0.04$. Pairwise comparisons with Bonferroni correction showed that enjoyment of the beach environment ($M = 5.90$, $SD = 0.73$) was significantly higher than enjoyment of the city environment ($M = 3.91$, $SD = 1.26$), $SE = 0.17$, $p < .001$, 95% CI [1.56, 2.37]. The stadium environment was also more enjoyable ($M = 4.84$, $SD = 1.12$) than the city environment, $SE = 0.17$, $p < .001$, 95% CI [-1.36, −0.54]. Finally, the beach environment was more enjoyable than the stadium environment, $SE = 0.14$, $p < .001$, 95% CI [0.69, 1.35]. Enjoyment showed no significant interaction effects with gender or BMI. Perceived stressfulness seemed inversely related to enjoyment as indicated by strong negative correlations within the relaxing environment ($r = -0.72$, $p < .001$), within the stressful environment ($r = -0.81$, $p < .001$), and to a lesser degree within the social environment ($r = -0.37$, $p < .001$).

5. Discussion

The aim of this study was to examine the effectiveness of three virtual environments (i.e., social, relaxing, stressful) on strength-based persistence and enjoyment during two types of strength-based exercises using a VR headset. Data was analyzed from 96 healthy young adults who had completed four consecutive sets of two persistence exercises, while each experienced three different interactive virtual environments. Both a stressful environment, where participants were hanging suspended over a city, and a social environment where participants were audibly encouraged in a stadium, showed some improvements in persistence compared to a relaxing environment, but this effect differed in exercise-type between men and women. Gender interaction

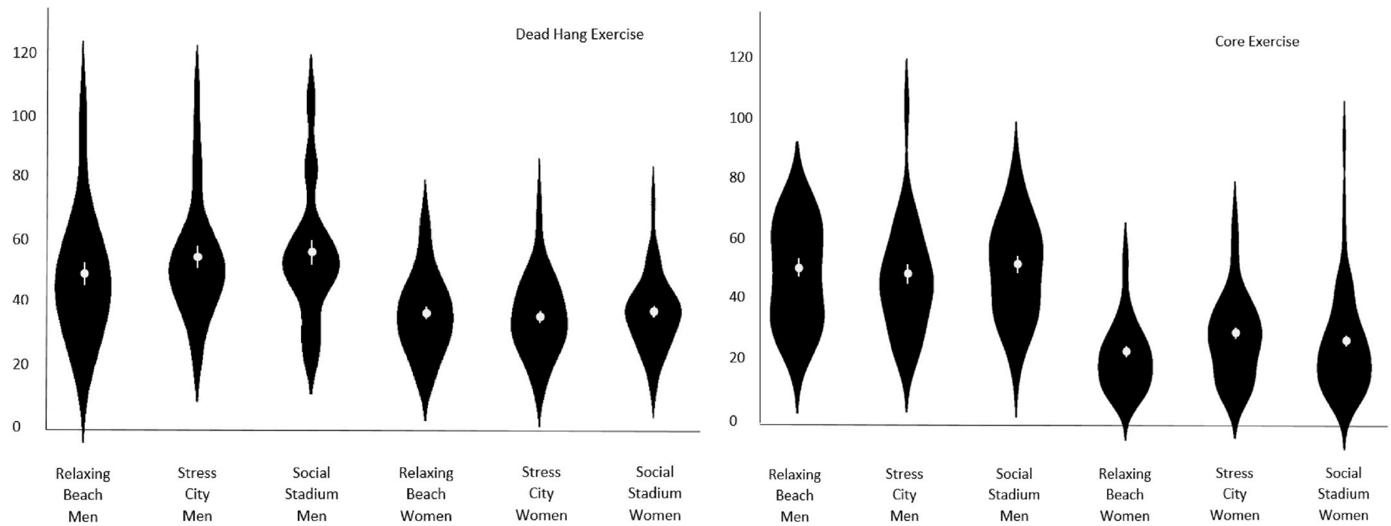

Fig. 3. Gender Differences in Persistence (in Seconds) across Virtual Environments
Note: Violin plots with means and standard errors (white circles, vertical bars) for men (n = 30) and women (n = 66) in two exercises.

effects were expected and found for both exercises. Specifically, the relaxing sunny beach environment caused poorer performances in the dead hang exercise among men, and poorer performances in the core exercise among women. Somewhat paradoxically, this relaxing virtual beach environment was considered the most enjoyable environment among both male and female participants.

Despite the decrease in perceived stress and increase in enjoyment that came with exercising in a relaxing virtual beach environment, this environment was less effective at inducing exercise persistence when compared to the other virtual environments. In general, sports scientists warn against relaxation before competitive events, as it might diminish the motivational drive that precipitates optimal performance (Nien et al., 2020). Indeed, the relaxing virtual environment did not seem to elicit the physiological- and psychological activation needed for prolonged persistence during strenuous strength exercises. The benefit of the relaxing beach environment is that it was significantly more enjoyable and less stressful than the social stadium environment, which in turn was less stressful and more enjoyable than the city environment. Although several studies have shown that using a VR headset while exercising increases enjoyment and improves performance (Matsangidou et al., 2019; McDonough et al., 2020), the current findings clearly indicate that enjoyment itself is not the underlying mechanism that leads to improved performance. The association that numerous studies have found between enjoyment and using VR during exercises may simply mean that static training exercises are more enjoyable with VR than without. Nevertheless, enjoyment of virtual environments may be relevant for long-term health benefits, as those who avoid exercising because of expected discomfort and exhaustion may be more inclined to participate in an exercise if the experience is relaxing and enjoyable. Even though enjoyable and relaxing virtual environments may not provide the best circumstances for optimal performance, they may be beneficial by increasing long-term commitment and regular exercise. Indeed, continuous enjoyment contributes to the motivation needed to sustain extended exercise programs (Penko and Barkley, 2010; Campelo et al., 2015).

Both social- and stressful VR environments proved more effective at promoting persistence than a relaxing virtual environment, with different positive effects between exercises for men and women. There are several theoretical explanations for the effectiveness of specific environments over others. Generally, participants' sense of presence in virtual environments contributes to the specific effects of an environment. Despite the relatively crude graphical representations, participants consistently felt these interactive environments presented relatively accurate representations of a plausible reality. Since the presence in VR influences emotional and physiological responses (Lemmens et al., 2022), the current sense of presence while exercising likely mediated the effects of each environment on physiological and emotional responses. Being present in an environment may even lead to a temporary shift in participants' self-perception, causing them to perceive not only the environment, but also themselves and their attributes more reflective of to their virtual setting (Klimmt, Hefner, Vorderer, Roth, & Blake, 2010; Yee & Bailenson, 2007). The virtual settings may have provided users with cues that altered their perception of themselves as athletic, strong or relaxed, and thereby influenced their persistence on the exercises. Presence may thereby facilitate the effects of different virtual experiences on persistence, stress and enjoyment, but it does not explain *why* certain environments are more effective or enjoyable.

Another common theoretical explanation for improved performance when using VR comes from the distraction provided by virtual environments. Several studies found benefits of virtual distraction from physical discomfort during exercise (De Bourdeaudhuij et al., 2002; Filbrich et al., 2017; McClure & Schofield, 2020). For the social stadium environment, the current findings may suggest that the (virtual) presence of noncompetitive others leads to motivational increases in performance of simple tasks, likely because the attention paid to others distracts from attention to the task (Sanders, Baron, & Moore, 1978; Straus, 2002). In the stadium environment, the audible presence of a large group of spectators may have contributed to the perception of these virtual others as realistic, a presumably essential component for social facilitation in VR (Bowman et al., 2013; Strojny et al., 2020). Moreover, the audible support through cheering and clapping in the virtual sports stadium may have contributed to persistence through the feeling of a *home field advantage* that has been found to improve performance among athletes in numerous real-life sport events (Jamieson, 2010). Conversely, the perceived presence of others in the stadium environment may have caused performance pressure among some participants (Wallace et al., 2005), which would explain why participants perceived considerably increased stress and diminished enjoyment compared to the beach environment. Similarly, self-consciousness about their body mass may explain why removing BMI as a covariate strengthens the effect of the stadium environment. Although there was no significant interaction between environment and BMI on persistence, removing BMI as a covariate led to an increase in persistence in the social stadium environment on the dead hang exercise among all participants (not just men), compared to the relaxing beach environment.

Similar to the potential effectiveness of distraction caused through social facilitation, the stressful environment may have improved performance for some through preoccupation with perceived threats to the autonomic nervous system, thereby distracting from pain and fatigue (Lindsay & Anderson, 2000). Even though virtual beaches may serve as an enjoyable and relaxing distraction, the other two environments were likely more effective at distracting individuals with exciting or supportive means, thereby causing more physiological activation. Since stress is also an indicator of increased excitation intensity, the increase in perceived stress in the stadium environment and especially the city environment, may have contributed to increased persistence through physiological activation (Dolu & Camliguney, 2022). The theoretical effectiveness of the stressful environment can also be explained from a fear appeal perspective. A fear appeal aims to stimulate behavior through a threat of impending danger or harm (Maddux & Rogers, 1983). For participants, their vulnerability to an imminent risk is clear (i.e., falling to your death) and so is the suggested form of protective action from this risk (i.e., do not let go of the bar), thereby stimulating them to endure as long as possible. A shortcoming of the current procedure could be found in the combination of a stressful city environment and the dead hang exercise. Because sweaty palms are one of the common symptoms of visual height intolerance (Kapfhammer, Huppert, Grill, Fitz, & Brandt, 2015), participants who experienced fear of mid-air suspension between skyscrapers, may have slipped from the bar prematurely due to sweaty palms. Anecdotal evidence suggests this may have been the case for some. It is important to note that these interpretations are merely speculative, since measures for self-perception, social support and performance pressure were not included in the current study. Future studies are encouraged to include these measures, and measures for distraction, acrophobia and realism to determine the effectiveness of underlying mechanisms.

Since there was abundant evidence that VR headsets would provide more enjoyment during exercise and improve performance (Dolu & Camliguney, 2022; Matsangidou et al., 2019; McClure & Schofield, 2020; McDonough et al., 2020), the aim was not to confirm the overall effectiveness of VR, but to determine which virtual environments were more effective. Nevertheless, it would be better to include a control condition, or in the current within-subjects design, it would have been better to also counterbalance the exposure to non-VR exercises instead of using these only as a baseline. Although the abundance of evidence makes it plausible to assume the VR exercises caused more enjoyment and better performances than a non-VR exercise, it is not possible to definitively make this claim without a counterbalanced control condition that did not experience VR. Future studies might also benefit from different ways to measure performance. Since the current findings apply to persistence in relatively short and strenuous strength-based exercises, it may be interesting to see if these virtual environments show similar effects in prolonged aerobic exercises. Furthermore, it could be interesting to compare the effectiveness of exposure to virtual environments that induce specific responses, such as increasing self-esteem, or confidence (Yee & Bailenson, 2007), or less immersive environments to further examine the role of presence. It may also be relevant to examine the enjoyment of virtual environments longitudinally, to determine whether the appeal of relaxing environments may lead to repeated physical activity, or whether virtually encouraged persistence effectively increases physical strength. The current findings should be considered exploratory, as they provide a small step towards determining which virtual environments provide either more appealing or more effective physical exercises. Hopefully further research can point towards VR experiences that provide both simultaneously.

6. Conclusion

Several studies have shown that VR headsets can make exercise more enjoyable and effective, but none have examined how these effects may occur. The current study is the first to provide evidence that specific virtual environments are more appealing, while others provide greater exercise benefits by increasing persistence in strength-based exercises. Although the current stressful and social environments improved performance considerably, these effects differed between men and women, and these virtual environments were substantially less enjoyable than a relaxing environment. Overall, successful application of VR environments in sport and exercise may not be found in their ability to provide enjoyable reproductions of reality but rather in their capacity to offer intense emotions and excitement that complement physical activity. VR headsets can provide performance-enhancing *exercitement* through engagement with stimulating interactive environments that may be too expensive or dangerous in reality.

Declaration of competing interest

The Paradox of Pleasure and Performance: A Virtual Reality Experiment on Exercise Endurance.

The author certifies that he has NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Data availability

Data will be made available on request.

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