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Original Research

Acute Affective Responses and Perceived Exertion during a Single Bout of Virtual Reality Exercise

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Abstract

International Journal of Exercise Science 19(5): 5007, 2026. Virtual reality (VR) exercise has emerged as a promising modality for promoting physical activity engagement, yet its acute psychological effects remain incompletely characterized. This study examined pre-to-post changes in positive affect (PA) and negative affect (NA), as measured by the Positive and Negative Affect Schedule (PANAS), following a single bout of exercise in VR in a community sample ($N = 58$ total enrolled; $n = 52$ exercise group, $n = 6$ passive VR control; ages 16 and older). Participants also rated perceived exertion (RPE) on a 1–10 scale following the exercise session. Paired-samples t-tests revealed that VR exercise produced significant improvements in both PA ($t(51) = 3.66$, $p < .001$, $d = 0.51$) and NA ($t(51) = -5.63$, $p < .001$, $d = -0.78$). These effects were not moderated by RPE: both low-RPE (RPE < 6) and high-RPE (RPE ≥ 6) groups demonstrated significant within-group improvements, and RPE was not significantly correlated with PA or NA change scores. Comparison with the passive VR control group suggested that the physical exercise component—rather than VR immersion per se—was the primary driver of PA enhancement, while the shared VR environment may have contributed to NA reduction in both conditions. Exploratory analyses of gender and age subgroups revealed no statistically significant between-group differences on any PANAS measure, RPE, or affect change score, although these comparisons were limited by small subgroup sample sizes. These findings indicate that a single bout of exercise in VR produces robust acute improvements in affective state across diverse levels of perceived exertion, supporting VR exercise as an accessible modality for eliciting psychological benefit. Future research should employ larger and more balanced samples, objective intensity measures, and adequately powered control designs to further elucidate the independent contributions of VR immersion and exercise to affective outcomes.

Keywords: Health/wellness, physical activity, positive/negative affect, emotional state, exercise psychology

Introduction

Health is increasingly recognized as a multidimensional construct encompassing physical, psychological, and social well-being rather than merely the absence of disease.[1] Within this framework, positive affect, defined as the experience of pleasant emotional states such as enjoyment, enthusiasm, and vitality, has emerged as an important indicator of psychological well-being and overall health. Higher levels of positive affect have been associated with favorable health behaviors, improved physiological functioning, and reduced risk of adverse health outcomes, suggesting that affective states play a meaningful role in health promotion and disease prevention.[2,3]

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Exercise is a well-established contributor to physical health and is also known to influence psychological states.[4,5] Historically, however, much of the exercise psychology literature has focused on the ability of physical activity to reduce negative psychological states such as anxiety, depression, and stress.[6] While this line of research has yielded important clinical insights, it provides an incomplete understanding of the exercise-mental health relationship. More recent perspectives emphasize the need to examine how exercise promotes positive psychological outcomes, including positive affect, engagement, and life satisfaction.[7,8] Positive affect during and following exercise has been shown to be particularly relevant, as it is associated with greater intrinsic motivation and improved exercise adherence, both of which are critical for sustaining long-term physical activity behaviors.[9,10]

Despite the well-documented benefits of exercise, physical inactivity remains prevalent, and lack of enjoyment is consistently reported as one of the most common personal barriers to exercise.[11,12] Consequently, there is a growing interest in exercise modalities that enhance the affective experience of physical activity. Virtual reality (VR)-based exercise represents an emerging approach that integrates immersive digital environments with bodily movement, potentially increasing enjoyment, attentional engagement, and perceived autonomy during exercise. By providing interactive and often gamified experiences, VR exercise may attenuate perceptions of exertion and discomfort while enhancing positive affective responses.

Preliminary evidence suggests that VR-based exercise can elicit greater enjoyment and more positive affect compared to traditional exercise modalities at comparable intensities.[13] This phenomenon is often attributed to the **"distraction hypothesis"** and the psychological state of **presence**—the subjective sensation of "being there" within the virtual environment—which may effectively attenuate the perception of physiological strain while simultaneously enhancing hedonic pleasure. However, empirical data examining the granular relationship between VR-mediated exercise, nuanced affective responses, and objective health-related outcomes remain limited.

In particular, a significant gap exists in the literature regarding the **intensity-affect relationship** within virtual environments. While traditional exercise models, such as the Dual-Mode Model,[14] predict a decline in positive affect as intensity surpasses the ventilatory threshold, VR may serve as a psychological buffer that preserves or even elevates positive affect during strenuous exertion. Few studies have directly assessed how the positive affect generated during VR engagement relates to broader indicators of health, long-term exercise adherence, or the **effort-reward mechanism** across different demographic cohorts.[15,16] This lack of an experimental framework prevents researchers from establishing the magnitude and consistency of VR exercise's acute affective benefits in everyday community settings.

Therefore, the purpose of this study was to examine positive and negative affect elicited by a single VR-based exercise session, as measured by the PANAS, and to explore the extent to which affective responses were related to perceived exertion. By quantifying the interplay between **Perceived Exertion (RPE)** and **Affective Valence (PANAS)**, this study aims to elucidate how VR exercise can be used as a scalable tool for enhancing both physical health and emotional well-being. Demographic subgroup analyses (gender, age group) are reported as exploratory and were not the primary focus of the study.

Methods

Participants

Participants were recruited through convenience sampling from Oklahoma State University Center for Health Sciences community and surrounding area. A total of 58 participants aged 16 years and older were enrolled (20 men, 38 women). Of these, 52 (18 men, 34 women) were assigned to the VR exercise group, which constituted the analytic sample for the primary affective analyses, and 6 (2 men, 4 women) were assigned to the passive VR control group. Gender was self-reported using the response options "man," "woman," "other," or "prefer not to identify." Participants were asked to fill out a demographic survey prior to participation that included information such as gender, age group, Native American heritage, and exercise habits.

Eligibility was limited to individuals aged 16 years and older who were able to provide informed consent (or, for minors, parental permission and youth assent). Exclusion criteria included children under 16 years of age, individuals aged 16–17 years whose parents did not provide consent for participation, and adults who were unable to provide informed consent.

Prior to enrollment, parents of participants aged 16–17 years attended an informational meeting describing the study aims and procedures; these parents signed a parental permission form, and their children signed a youth assent form. All adult participants received the same information and signed an informed consent form. The study was approved by the Institutional Review Board at Oklahoma State University Center for Health Sciences (OSU-CHS). This research was carried out fully in accordance with the ethical standards of the *International Journal of Exercise Science*, including each of the ethics statements in the work of Navalta et al.[17]

A post-hoc power analysis was conducted to evaluate the statistical adequacy of the exercise-group sample ($n=52$) using observed effect sizes and a significance level of $\alpha=0.05$. For positive affect, a medium effect size was observed ($d_z=0.48$), yielding a statistical power of 0.96. For negative affect, a medium-to-large effect size was observed ($d_z=0.61$), yielding a statistical power of 0.99. Both values exceed the conventional power threshold of 0.80, indicating that the study was highly sensitive to the observed changes and the risk of a Type II error was minimal. These results confirm that the sample size provided sufficient precision to detect the significant improvements in participant effect ($p<.001$ for both measures).

Protocol

Data collection took place in an open indoor area at Oklahoma State University Center for Health Sciences during daytime hours. After consent was obtained, each participant completed a self-reported PANAS questionnaire reflecting their affect over the previous week, followed by a demographic survey. The demographic survey collected information on age group, gender, Native American descent, regular sport or exercise participation, time spent exercising per week, perceived barriers to exercise, preference for indoor or outdoor activity, and favorite types of exercise.

Participants were then assigned to either the exercise group (n = 52) or the control group (n = 6). Group assignment was determined by random allocation. Participants in the exercise group received standardized instructions and selected from a curated set of four virtual reality exercise applications: Walkabout Mini Golf, Gorilla Tag, Creed: Rise to Glory, and FitBeat Combat. These applications were chosen to represent a range of movement types, intensities, and physical demands, allowing participants to choose an option that aligned with their preferences and comfort level. Each participant then completed ten minutes of their selected activity using a Meta Quest 3 Virtual Reality headset. Participants in the control group completed ten minutes of stillness while viewing meditative visuals and listening to ambient music through the same VR headset.

Immediately following the ten-minute session, all participants completed the PANAS questionnaire a second time to assess post-intervention affect, along with a Rating of Perceived Exertion (RPE) scale.

Statistical Analysis

To examine changes in affect from pre- to post-exercise PANAS scores, paired-samples t-tests were conducted for both the positive and negative subscales of the PANAS. Statistical significance was defined at an alpha level of a=0.05. Effect sizes were calculated using Cohen's dz for dependent samples, with values of 0.2, 0.5, and 0.8 representing small, medium, and large effects, respectively. Exploratory subgroup analyses were also conducted: independent-samples t-tests compared affective measures and RPE between men and women, and one-way analyses of variance (ANOVAs) examined whether age group was associated with differences in pre- and post-exercise PANAS scores, affect change scores, or RPE. These subgroup analyses were not the primary focus of the study and were limited by small and unequal subgroup sample sizes; they are reported as descriptive and hypothesis-generating. Bivariate relationships between RPE and affective change were assessed using Pearson product-moment correlation coefficients. Specifically, correlation analyses were performed to examine the association between RPE and the mean change scores for both positive and negative affect. The magnitude of the correlation coefficients was interpreted based on standard conventions: small ($r=0.10$), medium ($r=0.30$), and large ($r=0.50$). Statistical significance for all correlations was set at a=0.05. Statistical analyses were conducted in Excel and BioRender.

Results

Overall effects

Prior to VR exercise, participants reported moderate levels of positive affect (M=33.46, SD=6.62) and low-to-moderate levels of negative affect (M=17.56, SD=6.30). Following VR exercise, positive affect scores increased (M=36.52, SD=7.93) and negative affect scores decreased (M=14.02, SD=5.02). Mean RPE across participants was 4.52 (SD=1.78, range 1-9), indicating a low-to-moderate perceived exertion level overall. Paired-samples t-tests were conducted to examine changes in positive and negative affect from pre- to post-exercise. Results are illustrated in Figures 1 and 2. Positive affect increased significantly following VR exercise, $t(51)= 3.66$, $p<0.001$, Cohen's d= 0.51, representing a medium effect size. Negative affect decreased significantly following VR exercise, $t(51)= -5.63$, $p<0.001$, Cohen's d= -0.78, representing a medium-to-large effect size. These findings indicate that a single bout of VR exercise produced significant improvements in both dimensions of affective state. The distribution of individual change scores (Figure 2) further illustrates the directionality of these effects: the majority of participants increased in positive affect and decreased in negative affect following the VR exercise session.

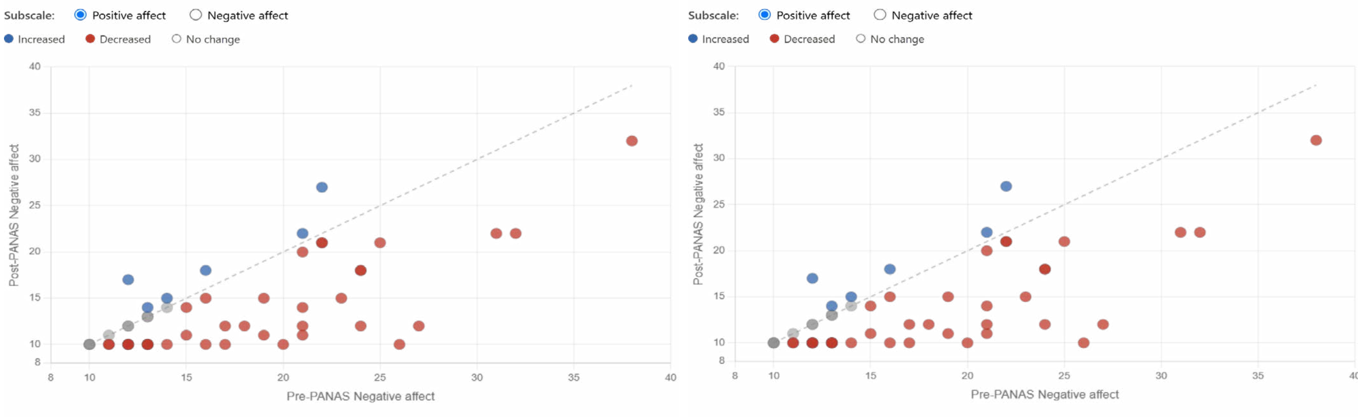

Figure 1. Pre- and post-exercise mean PANAS Positive Affect (PA) and Negative Affect (NA) scores. Alternate text: Paired-samples t-tests were conducted to examine changes in positive and negative affect from pre- to post-exercise. Positive affect increased significantly following VR exercise and negative affect decreased significantly following VR exercise.

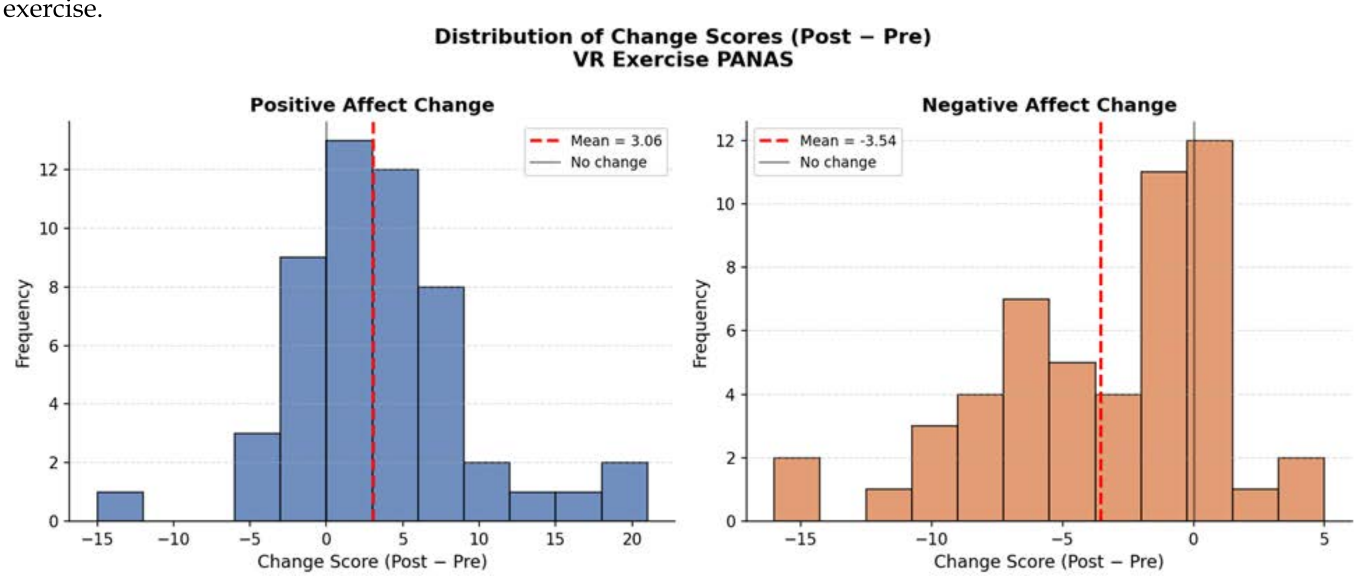

Figure 2. Histograms depicting the distribution of individual change scores (Post − Pre) for Positive Affect (left) and Negative Affect (right). The dashed red line indicates the group mean change score; the solid black line indicates zero change. Alternate text: Two side-by-side histograms showing the distribution of individual change scores from pre- to post-exercise. The left panel displays positive affect change scores (mean = 3.06), with most participants falling between −5 and +10 and a right-skewed tail extending past +15. The right panel displays negative affect change scores (mean = −3.54), with most participants showing reductions clustered between −10 and 0 and a small number showing little or slightly positive change. The shapes of the distributions indicate that the majority of participants experienced increases in positive affect and decreases in negative affect following VR exercise.

To examine whether the intensity of perceived exertion moderated the affective response to VR exercise, participants were classified into two groups based on their RPE scores: low RPE (RPE <6, n=37) and high RPE (RPE ≥6, n=15). Both groups demonstrated significant pre-to-post improvements in positive affect (low RPE: t(36)=2.60, p=0.013; high RPE: t(14)=2.72, p=0.017) and significant reductions in negative affect (low RPE: t(36)=-4.45, p<0.001; high RPE: t(14)-3.41, p=0.004). However, independent-samples t-tests revealed no significant difference between low and high RPE groups in the magnitude of change for positive affect, t(50)=-0.87, p=.0389, Cohen's d=0.27, or negative affect, t(50)=0.74, p=0.466, Cohen's d=-0.22. Furthermore, Pearson correlations indicated no significant linear relationship between RPE and positive affect change (r=0.22, p=.0118) or negative affect change (r=-0.07, p=0.627). Collectively, these findings suggest that the affective benefits of VR exercise were not contingent upon the level of perceived exertion, as participants experienced significant improvements regardless of RPE group.

Within the control group, positive affect showed a small, non-significant pre-to-post increase (MΔ=1.50, t(5)=0.80), p=0.46), Cohen's d=0.33), while negative affect showed a large but non-significant reduction (MΔ=-4.25, t(5)=-2.03, p=0.099, Cohen's d=-0.83). Between-group comparisons revealed no statistically significant differences between the VR exercise and relaxing VR conditions for either positive affect change (t=0.76, p=0.471, d=0.29) or negative affect change (t=0.32, p=0.757, d=0.15). Control participants exhibited substantially lower perceived exertion than the VR exercise group (control M=1.83, SD=1.33 vs VR M=4.52, SD=1.78).

Exploratory analyses by gender

As an exploratory analysis, participants in the exercise group were stratified by gender (men: n=18; women: n=34). Descriptive statistics and between-group comparisons for all measures are depicted in Figure 3. Prior to VR exercise, men and women reported comparable levels of positive affect (men: M=33.22, SD=8.28; women: M=33.59, SD=5.69) and negative affect (men: M=18.78, SD=6.23; women: M=16.91, SD=6.34). Mean RPE was identical across genders (men: M=4.50, SD=1.86; women: M=4.50, SD=1.73). Independent-samples t-tests revealed no statistically significant differences between men and women on any PANAS measure, RPE, or affect change score (all ps>0.15). Pre-exercise positive affect, t(50)=-0.19, p=0.852, d=-0.06; post-exercise negative affect, t(50)=0.35, p=0.727, d=0.10; pre-exercise negative affect, t(50)=1.02, p=0.315, d=0.30; post-exercise negative affect, t(50)=1.45, p=0.154, d=0.42 were all non-significant. Similarly, the magnitude of positive affect change did not differ by gender, t(50)=0.17, p=0.865, d=0.05. Effect sizes for these comparisons were uniformly small. Paired-samples t-tests were conducted separately for each gender to examine pre-to-post exercise changes in affect. Among men, negative affect decreased significantly from pre- to post-exercise, t(17)= -3.36, p=0.004, Cohen's d=-0.79, a large effect. The increase in positive affect among men approached but did not reach statistical significance, t(17)=1.95, p=0.068, Cohen's d=0.46, a medium effect likely reflecting reduced statistical power associated with the smaller subsample of men. Among participants who identified as women, both positive and negative affect changed significantly following VR exercise. Positive affect increased significantly, t(33)=3.46, p=0.002, Cohen's d=0.59, and negative affect decreased significantly, t(33)=-4.47, p<0.001, Cohen's d=-0.77, both representing medium-to-large effects. Neither gender showed a significant relationship between RPE and any PANAS measure. Given the small and unequal subsample sizes, these subgroup analyses are reported as exploratory.

Exploratory analyses by age group

As an exploratory analysis, participants were stratified into six age groups: 16-17 (n=2), 18-24 (n=4), 25-34 (n=17), 35-44 (n=9), 45-54 (n=14), and 55+ (n=4). Two participants did not provide age information and were therefore excluded from this analysis (analytic n=50). One-way analysis of variance (ANOVAs) were conducted to assess whether age group was associated with differences in pre- and post-exercise PANAS scores, affect change scores, or RPE. Results showed no statistically significant between-group differences on any measure: pre-exercise positive affect, F(5,44)=0.74, p=0.598; post-exercise positive affect, F(5,44)=0.61, p=0.694; positive affect change,

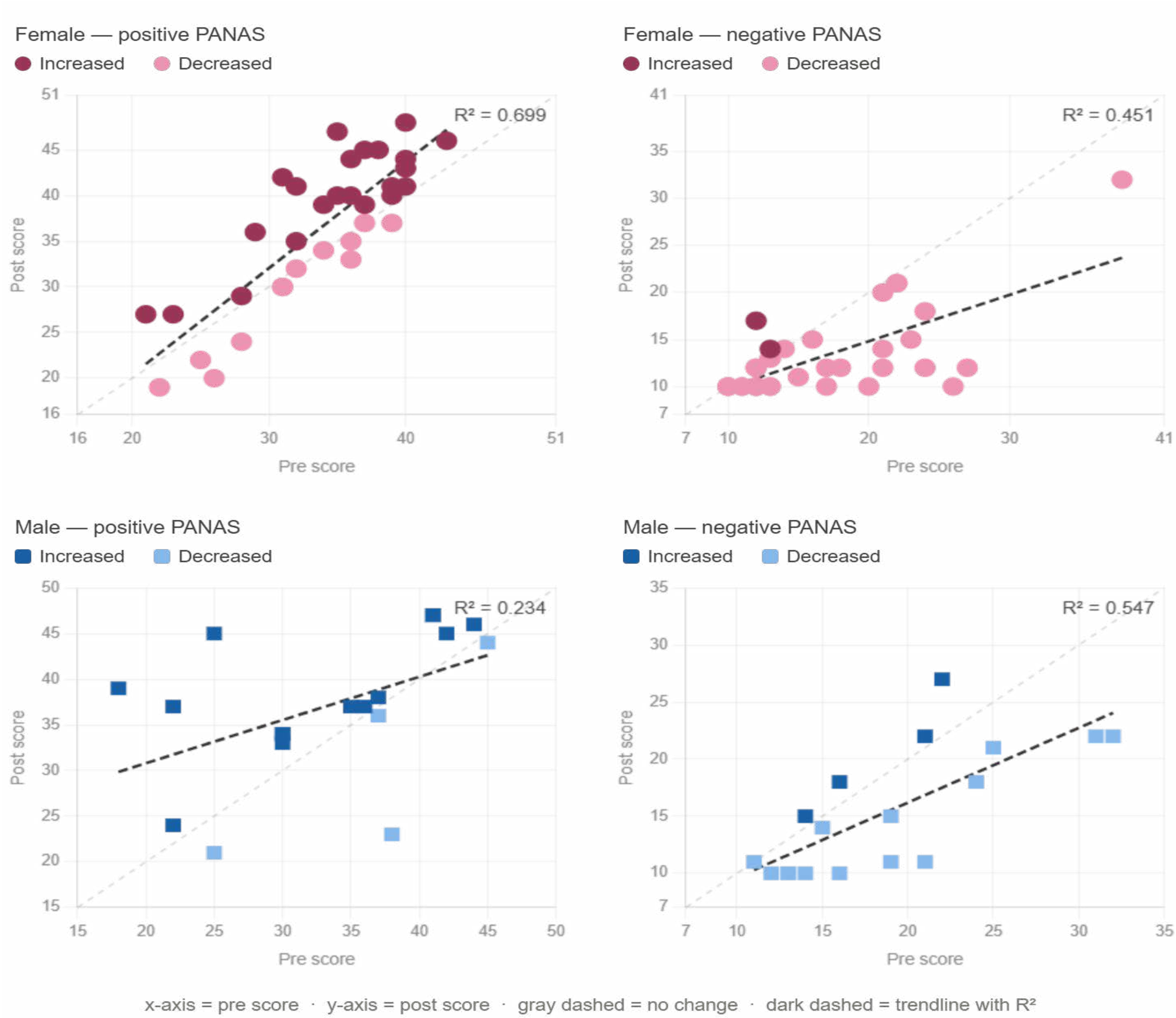

Figure 3. Pre- and post-exercise PANAS Positive Affect (PA) and Negative Affect (NA) scores by gender (Male n = 18, Female n = 34). Alternate text: A two-by-two grid of scatterplots showing pre-exercise scores on the x-axis and post-exercise scores on the y-axis. The top row displays results for female participants (in pink and maroon), with positive affect on the left ($R^2 = 0.699$) and negative affect on the right ($R^2 = 0.451$). The bottom row displays results for male participants (in light and dark blue), with positive affect on the left ($R^2 = 0.234$) and negative affect on the right ($R^2 = 0.547$). In each panel, points above the gray diagonal reference line indicate participants whose scores increased from pre- to post-exercise, and points below the line indicate participants whose scores decreased. The dark dashed line in each panel shows the linear regression trendline. Across both genders, most positive affect points fall above the diagonal and most negative affect points fall below it, consistent with the overall pre-to-post improvements observed in the full sample.

F(5,44)=0.99, p=0.432; negative affect change, F(5,44)=1.43, p=0.232; RPE, F(5,44)=1.25, p=0.301. These findings suggest that affective responses to VR did not differ significantly as a function of age group. Paired-samples t-tests were conducted within each age group to evaluate the significance of pre-to-post exercise changes in affect. Notably, the 16-17 and 55+ age groups had very small samples sizes (n=2 and n=4, respectively), substantially limiting statistical power. Among the 25-34 age group, both positive and negative affect changed significantly from pre- to post-exercise. Positive affect increased significantly t(16)=3.95, p=0.001, Cohen's d=0.96, a large effect, and negative affect decreased significantly, t(16)=-3.00, p=0.008, Cohen's d=-0.73, a medium-to-large effect. The 35-44 age group exhibited a distinctive pattern: positive affect showed virtually no change (□=-0.11), t(8)=-0.04, p=0.966, d=-0.02, while negative affect decreased significantly, t(8)=-3.39, p=0.010, Cohen's d=-1.13, a large effect representing the greatest negative affect reduction of any age group. Among the 45-54 age group, positive affect increased significantly, t(13)=2.70, p=0.018, Cohen's d=0.72, and negative affect decreased significantly, t(13)=-3.70, p=0.003, Cohen's d=-0.99, both medium-to-large effects. The 18-24 group demonstrated moderate-to-large effect sized for both positive affect (d=0.56) and negative affect (d=-0.98) change, though neither reached statistical significance, likely due to small sample size. Pearson correlations between RPE and PANAS measures were computed within each age group (Table 1). In the 45-54 group (n=14), RPE was significantly negatively correlated with pre-exercise positive affect and post-exercise positive affect, indicating that higher perceived exertion was associated with lower positive affect. In the 35-44 age group, RPE was positively correlated with post-exercise positive affect- the opposite direction- though the small sample size warrants caution. The 18-24 group showed a large negative correlation between RPE and post-exercise positive affect but is also a small sample size. No significant RPE correlations with negative affect or affect change scores were found in any age group (Figure 4).

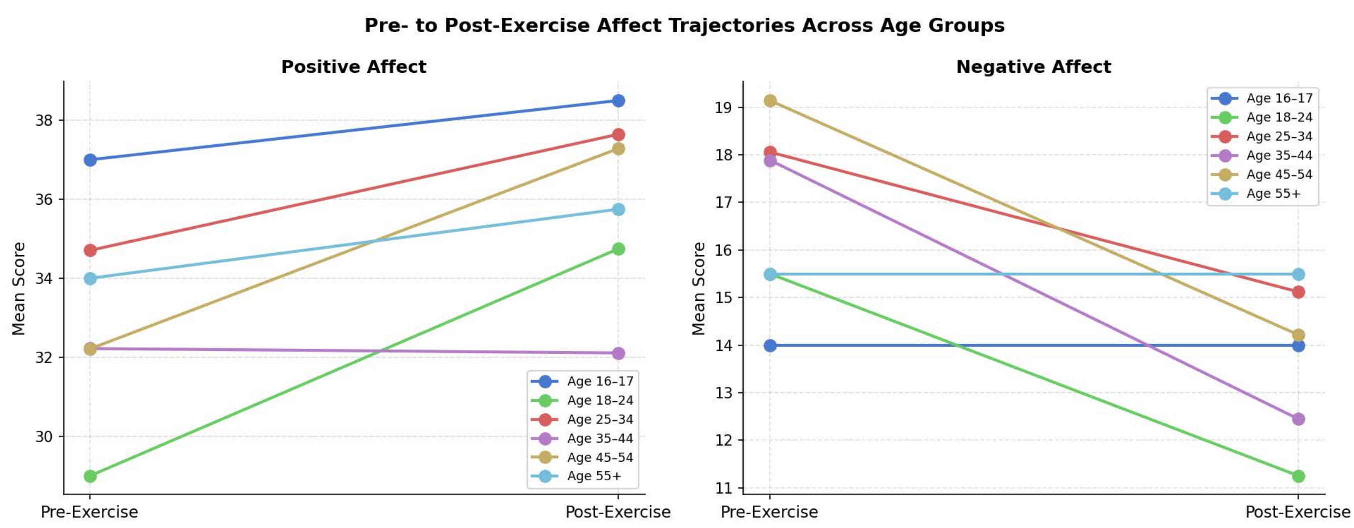

Figure 4. Pre- and post-exercise mean PANAS Positive Affect (left) and Negative Affect (right) trajectories by age group. Note that small sample sizes in the 16–17 (n = 2) and 55+ (n = 4) groups limit the reliability of standard error estimates for those groups. Alternate text: Two side-by-side line plots showing mean PANAS scores at pre-exercise and post-exercise, connected by lines for each of six color-coded age groups (16–17, 18–24, 25–34, 35–44, 45–54, and 55+). The left panel shows positive affect: most age groups show upward-sloping lines from pre- to post-exercise, with the 25–34 and 18–24 groups showing the largest visible increases and the 35–44 group showing a relatively flat trajectory. The right panel shows negative affect: most age groups show downward-sloping lines from pre- to post-exercise, with the 35–44 and 18–24 groups showing the steepest declines and the 16–17 group showing a flat trajectory. The overall visual pattern reflects the result that positive affect increased and negative affect decreased across most age groups, with the 35–44 group displaying the dissociation between affect dimensions described in the text.

Table 1. Pearson Correlations Between RPE and PANAS Scores by Age Group.

Age	n	Pre PA r	Post PA r	ΔPA r	Pre NA r	Post NA r	ΔNA r	Sig. findings
16–17	2	—	—	—	—	—	—	n too small
18–24	4	−.963*†	−.117	+.590	−.802	+.343	+.800	Pre PA*†
25–34	17	+.458	+.405	+.091	+.002	+.208	+.259	None
35–44	9	+.463	+.727*	+.521	−.167	−.282	−.044	Post PA*
45–54	14	−.544*	−.684**	−.150	+.469	+.359	−.326	Pre PA*, Post PA**
55+	4	−.071	−.103	−.128	−.931	−.860	+.056	None (ns)

*Note. † 18–24 result based on n = 4. * p < .05, ** p < .01.*

Discussion

The purpose of this study was to examine the acute effects of a single bout of VR exercise on positive and negative affect, as measured by the PANAS, and to explore whether those effects were related to perceived exertion. The results provide consistent evidence that a single session of VR exercise produces significant improvements in both dimensions of affective state, with positive affect increasing and negative affect decreasing following the exercise bout. These results were observed across the full exercise-group sample regardless of exertion intensity, suggesting that VR exercise may represent an accessible modality for eliciting acute psychological benefits. Exploratory analyses of gender and age subgroups did not reveal significant between-group differences, although those comparisons were limited by small subsamples and should be interpreted with caution.

Overall affective response to VR exercise

The primary finding of this study- that a single bout of VR exercise significantly improved both positive and negative affect- is consistent with the broader exercise-affect literature. Meta-analytic evidence consistently demonstrates that acute exercise produces reliable improvements in positive affect and reductions in negative affect, with effect sizes typically in the small-to-medium range.[18] The present study yielded a medium effect for positive affect (Cohen's d=0.51) and a medium-to-large effect for negative affect (Cohen's d=-0.78), both of which align with or exceed the magnitude of effects typically observed following conventional exercise modalities. That the effect on negative affect was somewhat larger than the effect on positive affect is also consistent with prior findings and may reflect the proposition that exercise is particularly effective at alleviating emotional states, perhaps through mechanisms related to distraction, physiological arousal reduction, or endocannabinoid release.[19,20] The immersive, game-like quality of VR exercise may amplify these affective benefits relative to conventional exercise by adding an attentional and hedonic dimension to physical activity. The attentional dissociation hypothesis holds that exercise contexts that redirect attention away from effort-related sensations- such as immersive VR environments- are associated with more positive affective responses.[21,22] The present findings are consistent with this framework, as participants reported meaningful affective improvements at a mean RPE of only 4.52 on a 1-10 scale, suggesting that positive affective change was achieved at moderate perceived exertion levels. This supports earlier experimental work demonstrating that VR environments can enhance mood states and reduce perceived discomfort during exercise relative to traditional conditions.[23]

The role of perceived exertion

A secondary aim of this study was to examine whether the intensity of perceived exertion moderated the affective response to VR exercise. Neither the group-level comparison (low vs. high RPE) nor continuous correlational analyses revealed significant associations between RPE and affect change scores. Both low-RPE (RPE <6) and high-RPE (RPE ≥6) participants demonstrated significant pre-to-post improvements in positive and negative affect, and the magnitude of affective change did not differ significantly between the groups. These findings are noteworthy because they suggest that the affective benefits of VR exercise are not contingent upon achieving a particular exertion threshold, which has practical implications for exercise prescription. This decoupling of exertion from affective outcome is somewhat inconsistent with the dual-mode model,[24] which predicts that affective responses to exercise become increasingly negative as intensity rises above ventilatory threshold, when interoceptive signals of physiological strain begin to override cognitive-attentional processes. However, the present sample exercised predominantly at low-to-moderate intensities (mean RPE of approximately 4.52), a range in which the dual-mode model generally predicts positive affective responses. It is therefore possible that participants in the high-RPE group did not consistently exercise above their ventilatory thresholds, limiting the ability to fully test this theoretical prediction. Alternatively, VR's strong attentional demands may have effectively suppressed interoceptive discomfort cues even at higher exertion levels, contributing to uniformly positive affect outcomes across the RPE spectrum. Future research employing objective measures of exercise intensity (e.g, heart rate, VO_2) alongside RPE would help clarify the intensity-affect relationship in VR exercise contexts.

Exploratory subgroup analyses

Descriptive comparisons of gender and age subgroups did not reveal any statistically significant between-group differences on PANAS measures, RPE, or affect change scores, and effect sizes for these comparisons were uniformly small. Within the gender subsamples, women showed significant pre-to-post improvements in both positive and negative affect, and men showed a significant reduction in negative affect and a trending (non-significant) increase in positive affect, a pattern most plausibly attributable to the smaller male subsample (n=18) rather than a true differential response. Within the age subsamples, the 25–34 and 45–54 groups showed significant within-group improvements on both PANAS subscales, while several smaller groups (16–17, n=2; 18–24, n=4; 55+, n=4) were underpowered to detect within-group change. These observations are exploratory and hypothesis-generating; given the unequal and in some cases very small subgroup samples, they should not be interpreted as evidence either for or against demographic moderation of VR exercise effects on affect. Larger and more balanced samples would be needed to evaluate any such moderation rigorously.

Future directions: objective measurement of exercise intensity

A key limitation of the present study is its reliance on a single post-exercise rating of perceived exertion (RPE) as the sole index of exercise intensity. While RPE is a validated and widely used measure, it provides only a retrospective, subjective summary of the entire session and may be influenced by attentional, motivational, and contextual factors that are themselves altered by the immersive VR environment. The strong attentional demands of VR have been proposed to attenuate interoceptive awareness, raising the possibility that participants in the present study underreported the physiological strain they actually experienced. This concern is particularly relevant for testing predictions from the dual-mode model, which links affective valence to intensity relative to the ventilatory threshold; without an objective anchor, it is difficult to determine whether high-RPE participants in this sample were truly exercising above their ventilatory thresholds. Future studies should therefore incorporate continuous heart rate monitoring as the primary index of exercise intensity, either in place of or alongside RPE. Wearable optical heart rate sensors and chest-strap monitors are inexpensive, well tolerated, and compatible with VR headsets, and they yield continuous, second-by-second data that can be summarized as mean heart rate, time in defined heart rate zones, or percentage of age-predicted or measured maximum heart rate (%HR_{max}). These metrics would allow investigators to (1) verify that participants assigned to high- and low-intensity conditions are physiologically distinct, (2) examine dose–response relationships between exercise intensity and affect using a continuous predictor rather than a single dichotomized RPE cutoff, and (3) directly test whether VR attenuates the perception of physiological strain by comparing the RPE–heart rate relationship across VR and non-VR exercise modalities. Where feasible, the addition of an individualized ventilatory threshold assessment (or a heart rate proxy such as the heart rate at which talking becomes difficult) would further sharpen tests of the dual-mode model by anchoring intensity to each participant's physiology rather than to an absolute threshold. Pairing these objective intensity measures with the affective outcomes used here would substantially strengthen causal inference about how VR exercise influences acute affect.

The findings of this study provide evidence that a single bout of VR exercise produces significant acute improvements in both positive and negative affect in a community sample of adults and adolescents. These improvements were observed across varying levels of perceived exertion, and exploratory subgroup analyses by gender and age did not reveal between-group differences, although those comparisons were limited by small and unequal subsamples and should be interpreted with caution. Collectively, this study contributes to a growing body of evidence supporting the psychological utility of VR-based physical activity. Future research should incorporate additional control conditions, objective intensity measures, larger and more balanced demographic samples, and longitudinal designs to build a more complete understanding of how VR exercise influences psychological wellbeing over time.

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