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UCL

Toward Optimised Exercise Prescription: Exploring Contextual Moderators of Acute Affective Responses to Physical Activity in Young Adults

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1. Introduction

The shift from adolescence to adulthood represents a complex developmental period marked by numerous psychological, social, and practical challenges [1]. Young adults, particularly university students, navigate new responsibilities such as managing interpersonal relationships, meeting academic expectations, living independently for the first time, and coping with financial pressures [2]. These simultaneous demands contribute to elevated stress levels and increased vulnerability to mood disorders, including depression and anxiety [3], which can negatively impact daily functioning, academic performance [4], and overall quality of life [5]. Recently, physical activity (PA) has emerged as a promising, low-cost strategy to mitigate this, enhancing mood and supporting emotional wellbeing [6].

1.1 General Effects of Physical Activity on Wellbeing

PA is defined as “any bodily movement produced by skeletal muscles that results in energy expenditure beyond resting levels", encompassing both structured exercise and general movement [7]. In healthy adults, even single bouts of light-to-moderate PA have been shown to reduce self-reported stress, worry, anger, and confusion, emphasising its role in providing immediate emotional benefits and buffering against later mood declines [8-10]. Over the longer term, regular PA is also associated with increased self-reported happiness and life satisfaction [11, 12].

Clinical populations, specifically those diagnosed with Major Depressive Disorder or Generalised Anxiety Disorder, have experienced medium-to-large reductions in symptom severity following exercise interventions [13-16], with some achieving remission [17]. Further, a longitudinal study has found that PA significantly lowers the risk of future depression, acting as a preventative strategy for mental health [18]. More broadly, PA also reduces the risk of cardiovascular disease, metabolic disorders, and other chronic conditions [19], and has been associated with enhanced cognitive performance, particularly in domains such as attention, working memory, and executive functioning [20], suggesting a broad spectrum of benefits.

1.2 Mechanisms

Current literature posits that affective benefits arising from PA are supported by both biological and psychological mechanisms.

Biologically, exercise stimulates the release of β-endorphins, endogenous peptides released primarily from the anterior pituitary gland and hypothalamus, which bind to μ-opioid receptors in the central nervous system, producing analgesic (pain-reducing) and euphoric (pleasurable) effects. This combination of reduced discomfort and enhanced pleasure is thought to drive the immediate mood improvements reported after PA [21]. Exercise may also attenuate emotional reactivity, reducing activation in the hypothalamic-pituitary-adrenal (HPA) axis, as well as lowering cortisol levels, a hormone linked to stress and the “fight-or-flight” response [22]. In this sense, PA not only alleviates acute stress but also builds long-term resilience against chronic stress exposure—a critical factor in both the onset and maintenance of mood disorders [23].

Psychologically, exercise can function as a cognitive distraction: redirecting attention towards movement coordination, breathing, and external stimuli; and away from ruminative or pessimistic thought patterns that sustain anxious and depressive symptoms [24]. It is also believed to foster a sense of mastery, achievement, and self-efficacy [25], as well as social support, which “comprises emotional, instrumental, or informational support, mainly from family, friends, children, community members, and others" [26], all of which are associated with positive mental health outcomes in clinical and non-clinical studies [27-29].

1.3 Contextual Factors

However, the effects of PA vary greatly depending on the context in which it is performed, and individual psychological factors such as motivation and personality [30, 31]. Understanding these moderators is essential for developing optimised, personalised exercise interventions that enhance emotional wellbeing in young adults.

1.3.1 Exercise Characteristics

While all types of PA can improve mood, the profile of affective change tends to differ: aerobic PA (e.g., cycling, running) tends to elevate high-arousal positive states such as energy and enthusiasm [32], while mind-body exercises (e.g, yoga, tai chi), and resistance practices (e.g., weightlifting) promote low-arousal states like calmness and contentment [33, 34]. Dance represents a hybrid form of PA, integrating aerobic exertion with music and often social engagement. The rhythmic synchronisation of movement with music has been shown to engage the mesolimbic dopaminergic system—particularly the nucleus accumbens and ventral tegmental area—which plays a central role in reward and motivation [35]. Music itself reduces perceived exertion and amplifies positive affect during exercise [36]. Generally, mood improves with increasing exercise intensity, but tends to decline once the ventilatory threshold is exceeded, as predicted by the dual-mode model due to heightened interoceptive discomfort.

1.3.2 The Physical Environment

Physical activity in natural environments, or "green exercise," is associated with improved mental health compared to similar activity indoors or in built urban settings. Attention Restoration Theory (ART) proposes that natural settings facilitate recovery from mental fatigue by engaging effortless, involuntary attention [37], while the Biophilia Hypothesis suggests that humans have an evolved affinity for natural elements, such as plants, water, and animals, which elicits innate stress-reducing and mood-enhancing responses [38]. Duration and frequency of exposure modulate outcomes, and age influences responsiveness, with middle-aged and older adults typically showing reliable improvements, but mixed results were observed in younger populations [39]. This study's investigation of green exercise specifically in young adults is therefore critical to clarify its efficacy.

1.3.3 Social Interaction

Evidence indicates that exercising with others generally produces greater improvements in mood than exercising alone [40]. Participation in team sports, or individual sports performed alongside peers can foster feelings of belonging and shared purpose, which are associated with positive affect [41]. Social Identity Theory further suggests that perceiving oneself as part of a valued group enhances intrinsic motivation and adherence to exercise routines [42]. In contrast, solitary exercise confers affective benefits primarily through mastery, self-efficacy, and satisfaction, though the absence of social reinforcement may limit the magnitude of mood improvement [43].

1.4 Research Aims and Hypotheses

Building on the literature reviewed, this study aims to examine: (1) whether engaging in physical activity produces measurable changes in positive and negative affect, and (2) how these effects vary across contextual factors, namely exercise characteristics (type and intensity), the physical environment (indoor vs. outdoor), and the social environment (exercising alone or with others). It is expected that physical activity will improve mood overall, with greater benefits observed in natural environments, during social exercise, and with distinct patterns of affective change (high-arousal versus low-arousal positive mood) emerging depending on exercise type and intensity.

2. Methods

2.1 Participants

Participants were young adults aged 18–34, consistent with the definition of this age group by the United States Census Bureau [44]. They were recruited from a university population through voluntary participation. All participants provided written informed consent prior to the start of the study, and ethical approval was obtained from the UCL Ethics Committee. At baseline, demographic information was collected, including age, sex, and general physical activity habits.

2.2 Study Design

The study followed a repeated-measures, observational design. Each participant wore a Garmin activity watch for continuous activity tracking throughout the study period of eight weeks. In addition, they completed an electronic mood questionnaire three times daily: upon waking, two hours after waking (immediately following exercise if undertaken, or at rest if not), and immediately before going to bed.

The mood questionnaire consisted of 10 items designed to capture both positive and negative affective states: *happy, sad, calm, nervous, focused, distracted, alert, sleepy, energetic,* and *lethargic*. Each item was rated on a continuous 1–100 scale, with higher values indicating greater intensity of the emotion. This repeated sampling approach provided a high-resolution account of participants' affective fluctuations across the day.

On days when participants exercised, they reported additional contextual details:

- **Exercise type:** cardio, strength-based, stretching, or music-related activity (e.g., dance)
- **Location:** indoors (home or gym) or outdoors (park or other environment)
- **Social context:** exercising alone or with others

Exercise intensity was assessed using the Rate of Perceived Exertion (RPE) scale, a validated subjective measure of effort, immediately following exercise. The modified Borg CR10 scale was employed, ranging from 0 ("rest; no exertion at all") to 10 ("maximal exertion; the hardest effort imaginable"). Anchors were provided at key points (e.g., 3 = "moderate," 5 = "hard," 7 = "very hard") to help participants calibrate their responses [45]. The RPE has been shown to correlate strongly with physiological measures such as heart rate and oxygen uptake, while also capturing subjective effort in naturalistic conditions, especially when administered via Ecological Momentary Assessment as in this study [46].

2.3 Factor Analysis

Exploratory factor analysis (EFA) was performed on all emotion ratings to identify underlying mood constructs, using the *psych* package in R. Data suitability was verified using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity, while principal axis factoring with oblique rotation was applied to account for correlations among factors. For analyses of general effects of physical activity on mood across the day (i.e., independent of contextual moderators), factor scores were combined to produce two composite dependent variables:

- **Positive Mood:** *happy, calm, focused, energetic, alert*
- **Negative Mood:** *sad, nervous, distracted, sleepy, lethargic*

For analyses examining contextual moderators, three more specific latent factors were retained from the EFA:

- **Low-Arousal Positive Mood (Serenity):** *calm, focused*
- **High-Arousal Positive Mood (Drive):** *happy, energetic, alert*
- **Negative Mood (Anxiety):** *sad, nervous, distracted, sleepy, lethargic*

Items with factor loadings greater than 0.40 on a single factor were retained. Factor scores for each participant at each timepoint were computed using the regression method and served as dependent variables in subsequent statistical models.

2.4 Statistical Analyses

All analyses were conducted using R (version 2024.12.0+467). Descriptive statistics were first calculated to summarise participant demographics, exercise behaviours, and baseline mood factor scores. Outliers were inspected, and assumptions of normality and homogeneity of variance were tested.

To evaluate mood changes, repeated-measures ANOVAs and linear mixed-effects models (implemented via the *lme4* package) were employed. Mixed models included random intercepts for participants to account for within-subject variability. Analyses examined differences across the three daily timepoints (waking, post-exercise/2 hours after waking, and bedtime) for each mood factor.

Additionally, mood change scores were computed for each day as the difference between pre- and post-exercise factor scores (Δ = immediately post-exercise – pre-exercise). These change scores were analysed using repeated-measures ANOVAs to assess whether exercise-induced affective responses varied according to contextual factors (exercise type, location, social context, and RPE intensity).

Statistical significance was set at $p < 0.05$, and effect sizes were reported as partial eta squared (η^2) for ANOVAs and standardised regression coefficients (β) for mixed models. Where significant effects were observed, post-hoc pairwise comparisons with Bonferroni corrections were conducted, via the *emmeans* package.

3. Results

3.1 General Effects of Physical Activity on Mood

3.1.1 Positive Mood

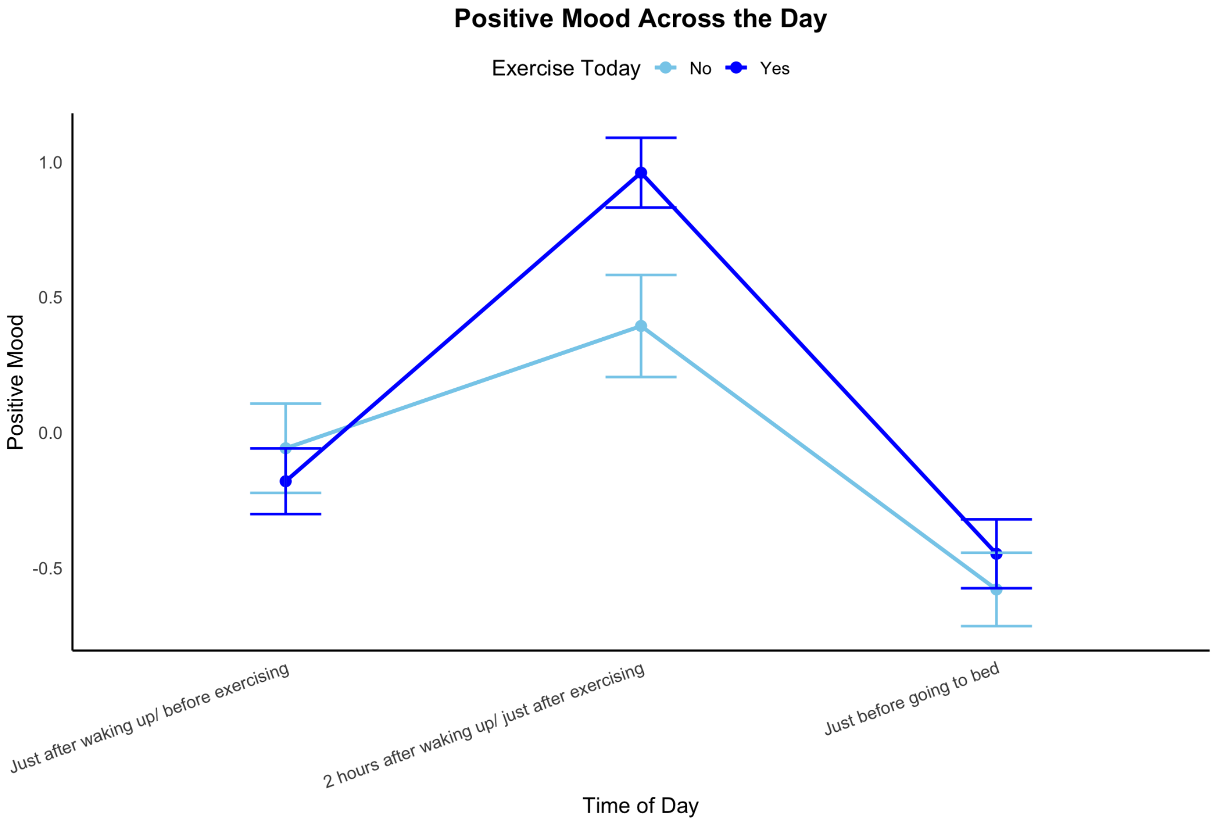

Figure 1. Daily Trajectories of Positive Mood With PA vs Without PA

A mixed-model ANOVA tested the effects of time of day, physical activity participation (PA_today), and their interaction on composite positive mood scores. Results showed a significant main effect of time of day, $F(2, 170.44) = 40.21$, $p < .001$, with positive mood varying across the day. The main effect of PA was marginal, $F(1, 171.70) = 3.00$, $p = .085$, while the time of day × PA interaction was significant, $F(2, 169.77) = 3.18$, $p = .044$.

Pairwise comparisons revealed that positive mood did not differ between exercise and non-exercise days upon waking (exercise: $M = 57.5$, SE = 4.23; no exercise: $M = 58.3$, SE = 4.28; $p = .83$). However, two hours after waking—corresponding to immediately after exercising on PA days—positive mood was significantly higher on exercise days ($M = 69.0$, SE = 4.38) than on non-exercise days ($M = 60.6$, SE = 4.33), $p = .025$. This benefit persisted into the evening, with higher bedtime positive mood on exercise days ($M = 61.4$, SE = 4.37) compared to non-exercise days ($M = 53.5$, SE = 4.31), $p = .033$ (**Figure 1**).

3.1.2 Negative Mood

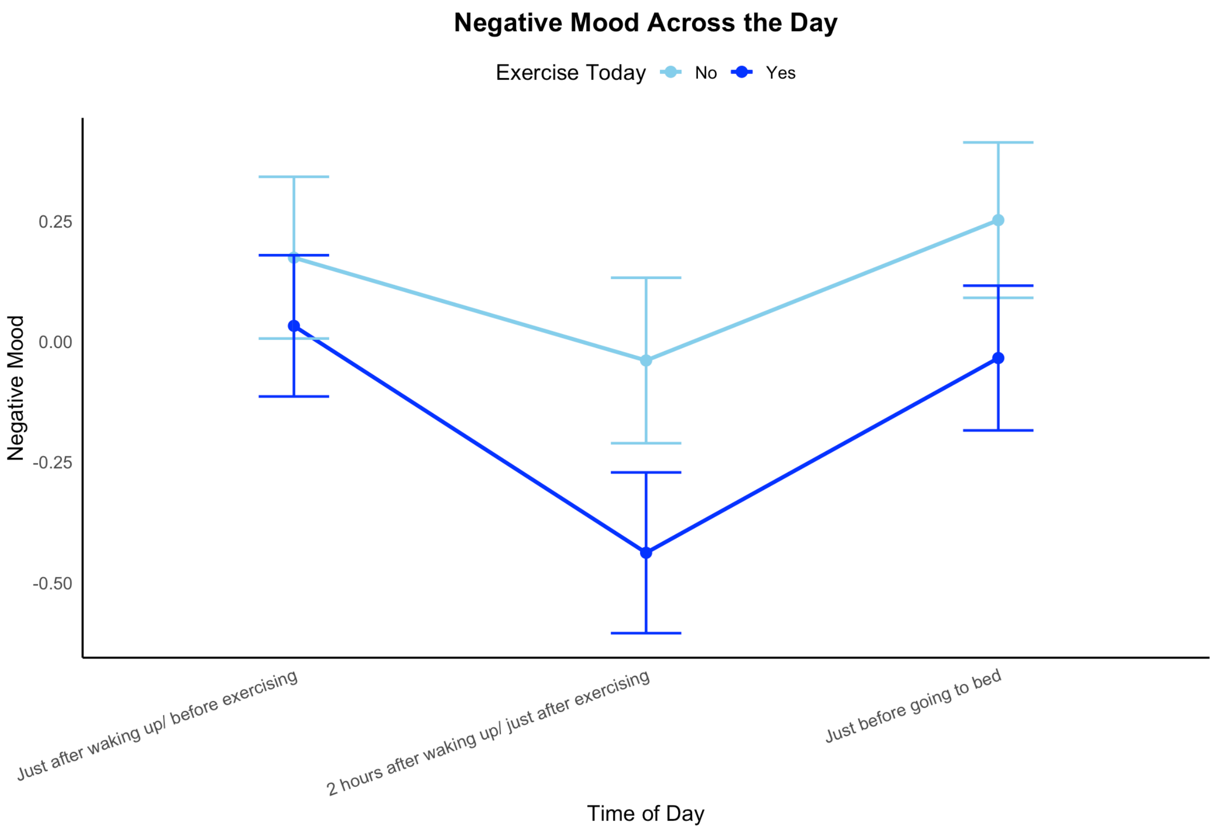

Figure 2. Daily Trajectories of Negative Mood With PA vs Without PA

For composite negative mood, there was a significant main effect of time of day, $F(2, 166.96) = 6.68$, $p = .002$, and a significant main effect of PA, $F(1, 167.76) = 8.04$, $p = .005$. The interaction between time of day and PA was not significant, $F(2, 166.87) = 0.73$, $p = .484$.

Follow-up pairwise comparisons indicated that two hours after waking, negative mood was lower on exercise days ($M = –0.41$, SE = 0.19) relative to non-exercise days ($M = –0.09$, SE = 0.18), $p = .034$. At bedtime, there was a trend toward lower negative mood on exercise days ($M = –0.08$, SE = 0.19) compared to non-exercise days ($M = 0.21$, SE = 0.18), though this did not reach conventional significance ($p = .051$). No differences emerged upon waking ($p = .48$) (**Figure 2**).

3.2 Influence of Physical Activity Context on Mood

3.2.1 Exercise Type

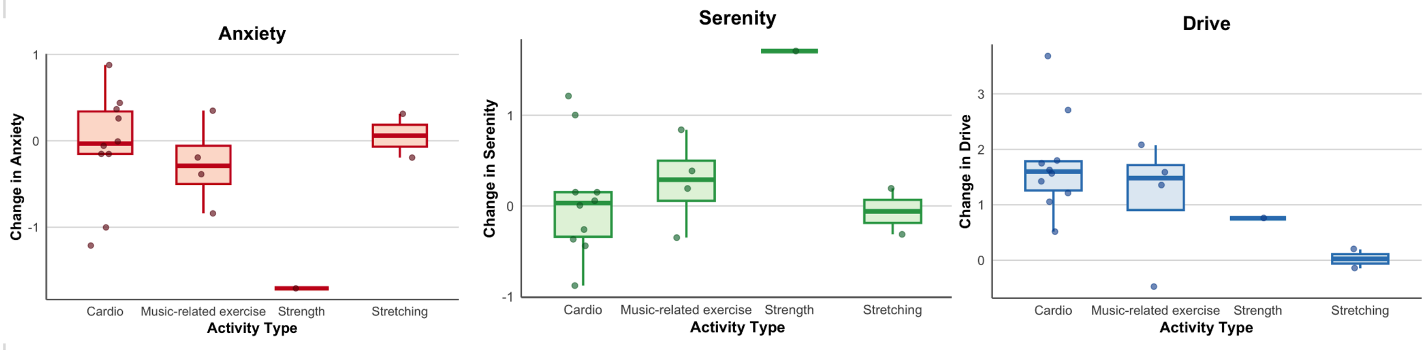

Figure 3. Boxplots of mood change scores (Drive, Serenity, and Anxiety) by exercise type

We next examined whether the type of physical activity (aerobic, dance/music-based, strength, or stretching) differentially influenced mood changes across the three factor-derived dimensions.

For Drive (high-arousal positive mood), a one-way between-subjects ANOVA showed no significant main effect of exercise type, $F(3, 14) = 2.41$, $p = 0.11$, though the pattern suggested a possible trend toward variation across activity categories. Upon visual inspection of the data, cardio and music-related exercise were associated with the largest increases in Drive, while stretching showed minimal change.

For Serenity (low-arousal positive mood), the effect of exercise type also did not reach statistical significance, $F(3, 13) = 2.51$, $p = 0.10$. Similar to Drive, there was some indication of differences, though these did not exceed the threshold for significance. Boxplots indicated that music-related exercise produced the greatest increases in Serenity, whereas cardio was more variable and stretching tended to show little to no increase.

For Anxiety (negative mood), no significant differences across exercise types were observed, $F(3, 13) = 2.51$, $p = 0.10$. Descriptively, strength training appeared to produce the most consistent reduction in Anxiety.

Taken together, while descriptive trends hinted that different activity types may produce distinct mood profiles, particularly in relation to low- and high-arousal positive affect, the analyses did not reveal statistically significant effects. These results are displayed in **Figure 3**, which illustrates mood change scores by exercise type for each of the three mood dimensions.

3.2.2 Intensity

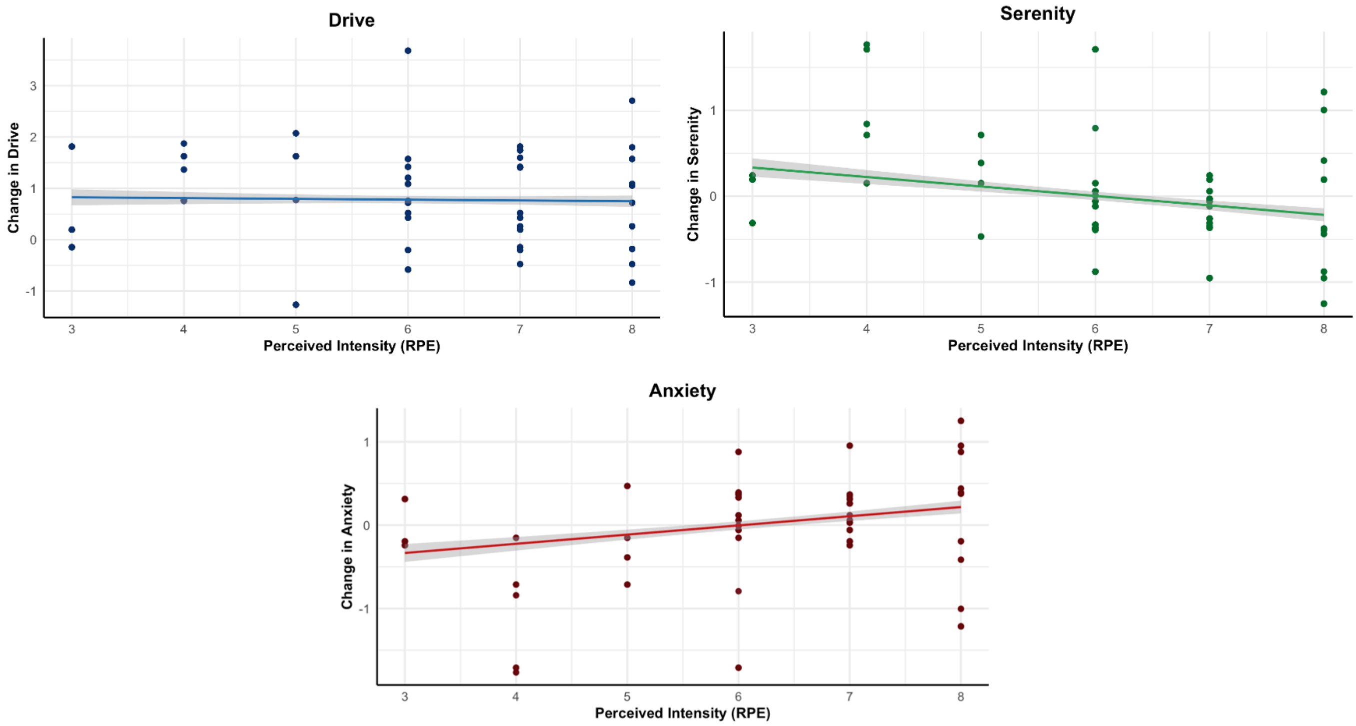

Figure 4. Mood change scores (Drive, Serenity, and Anxiety) by RPE

To examine how changes in mood were associated with participants' perceived exercise intensity, measured using the Rate of Perceived Exertion (RPE) scale, where scores range from 1 (low intensity) to 10 (high intensity). Linear regression analyses indicated that perceived intensity was not significantly related to changes in Drive ($\beta = -0.015$, $p = 0.498$). In contrast, higher perceived intensity was significantly linked to reductions in Serenity ($\beta = -0.110$, $p < 0.001$) and greater increases in Anxiety ($\beta = 0.110$, $p < 0.001$). These models accounted for approximately 7.6% of the variance in both Serenity and Anxiety change scores, with results displayed in **Figure 4**.

3.2.3 Physical Environment

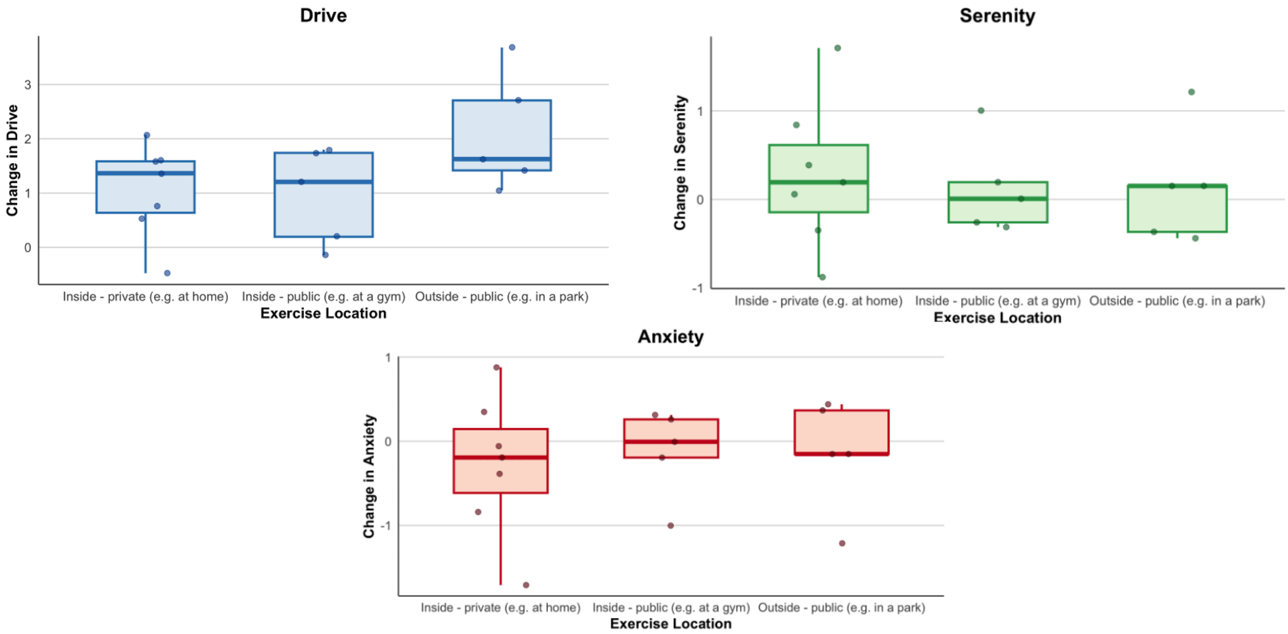

Figure 5. Boxplots of mood change scores (Drive, Serenity, and Anxiety) by exercise location

To explore whether the physical environment of activity influenced mood, we compared outcomes across three exercise locations: exercising inside at home (private), inside at a gym (public), and outside in a park (public, green space).

For Drive, a one-way between-subjects ANOVA revealed a marginal effect of location, $F(2, 15) = 2.70$, $p = .099$. While not statistically significant, descriptive patterns suggested that outdoor exercise in a park was associated with the largest increases in Drive, followed by public gym exercise, with home-based activity showing the smallest gains.

For Serenity, there was no effect of exercise location, $F(2, 15) = 0.06$, $p = .95$. Changes in Serenity were minimal and comparable across locations.

For Anxiety, the analysis similarly showed no effect of location, $F(2, 15) = 0.06$, $p = .95$, with all locations producing little change in negative mood on average.

These results suggest that while Serenity and Anxiety were unaffected by the setting, outdoor activity in green space may confer a relative advantage for enhancing Drive, though this trend did not reach statistical significance. These results are displayed in **Figure 5**, which illustrates mood change scores by exercise location for each of the three mood dimensions.

3.2.4 Social Interaction

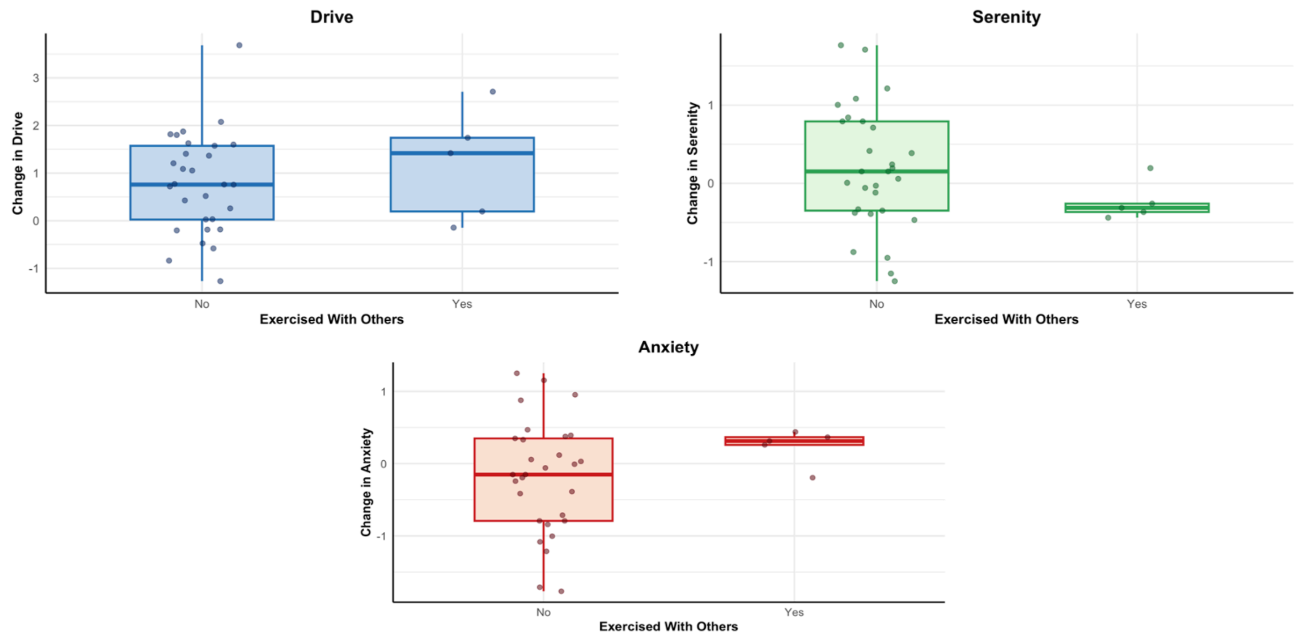

Figure 6. Boxplots of mood change scores (Drive, Serenity, and Anxiety) by social context

Social interaction was operationalised as whether participants exercised alone or with others, and its influence on post-exercise mood was assessed. For Drive, no significant effect of social context was observed, $F(1, 32) = 0.60$, $p = .445$. Similarly, Serenity and Anxiety did not differ significantly between solo and group exercise, $F(1, 32) = 1.36$, $p = .253$ for both.

Visually, the boxplots show that for Drive and Anxiety—both higher-arousal mood dimensions—participants who exercised with others had slightly greater median increases compared to those who exercised alone. For Serenity, by contrast, the median change was marginally higher for those who exercised alone, though the two groups remained very similar.

Overall, within this sample, the presence of others during physical activity did not significantly alter mood outcomes (**Figure 6**), suggesting that social interaction may not be a major determinant of acute affective responses in this context.

4. Discussion

Our analyses confirmed that physical activity exerted the expected broad affective benefits across the day. Compared to non-exercise days, participants reported higher positive mood and lower negative mood, both immediately after activity and before bedtime, reinforcing a well-documented body of evidence underscoring PA's ability to reliably improve mental health trajectories in the young adult population.

4.1 Key Determinants: Exercise Type and Intensity

Among contextual variables, exercise intensity emerged as the most robust predictor of mood change. Higher ratings of perceived exertion were associated with significant reductions in Serenity and increases in Anxiety, while Drive did not change. This represents a notable discrepancy: given its high-arousal nature, one might expect Drive to increase with exertion. Instead, our findings suggest that overly intense activity may undermine calmness without providing the energising benefits commonly attributed to high arousal. This divergence points to the importance of intensity calibration in exercise prescriptions.

Our findings align with clinical trial evidence favouring moderate-intensity activity. For example, a 12-week randomised controlled trial demonstrated that moderate continuous training (MCT) was more effective in improving mood than high-intensity interval training (HIIT), providing external validation of our results [47]. More broadly, meta-analyses consistently report that affective benefits peak at moderate intensity, with higher intensities more likely to induce fatigue or distress [48]. These results highlight intensity as a critical target in designing interventions—moderate activity may be optimal for maximising calmness while minimising anxious arousal.

Although not statistically significant, descriptive patterns across exercise types aligned with clinical evidence and provide valuable practical insights. Aerobic and music/dance-based activities tended to boost Drive, while strength training was most consistently associated with reductions in Anxiety [49]. These profiles resonate with clinical studies showing that aerobic exercise and dance therapy are effective adjunctive treatments for depression, improving vitality, alertness, and mood when combined with psychotherapy or medication [50].

In contrast, clinical recommendations for anxiety disorders often highlight yoga and stretching, which have been shown to increase GABA levels and reduce anxious arousal [51]. Similarly, nature-based activities such as walking in green spaces are frequently associated with enhanced calmness and reduced stress [52]. Interestingly, our data suggested a different profile: strength training rather than yoga or green exercise was most effective for reducing Anxiety. This discrepancy may reflect the distinction between state anxiety (short-term anxious arousal), which PA has been more effective in reducing than trait anxiety (enduring anxious tendencies) [53], corresponding more closely to the acute outcomes we measured. By contrast, the benefits of green exercise may operate through neuroprotective mechanisms that accumulate over longer periods [54], making them less visible in immediate affective change scores. Thus, despite null findings, the observed trends remain consistent with the therapeutic logic of matching exercise type to affective targets.

4.2 Broader Contextual Considerations

Beyond type and intensity, other contextual factors not directly measured in our study likely shape affective outcomes. Duration is an important consideration: evidence indicates that sessions of 10–30 minutes at moderate intensity produce the largest acute improvements in affect [55]

Motivation also plays a critical role. According to self-determination theory, intrinsically motivated exercise—pursued for enjoyment, mastery, or personal value—leads to more positive affective responses than extrinsically motivated activity. For instance, those motivated by social connection may benefit more from music-based or group-based activity, whereas those driven by personal mastery may respond better to strength training or structured goals [56].

Instructor style further interacts with these dynamics. Autonomy-supportive leadership—characterised by offering choices, meaningful rationales, and minimising pressure—has been shown to increase enjoyment, intrinsic motivation, and positive affect during exercise [57]. Conversely, controlling or competitive environments may amplify anxiety, particularly for individuals already sensitive to evaluative pressure. Although not measured here, such interpersonal dimensions are likely critical in translating contextual factors into consistent mood benefits.

4.3 Clinical Relevance

Synthesising our results with the broader literature, Table 1 below illustrates how different combinations of activity characteristics and contexts may target the specific affective needs associated with common mental health conditions. This acknowledges that major depressive disorder (MDD) is often characterised by blunted Drive, while generalised anxiety disorder (GAD) is marked by heightened arousal and reduced Serenity [58]. These findings are not definitive, but rather serve as a clinically informed synthesis of emerging evidence, demonstrating how contextual tailoring can translate exercise into a more precise therapeutic tool.

Mental Health Target	Recommended Exercise Type	Intensity	Duration	Environment	Social / Instructor Context	Expected Affective Outcome	Supporting Literature
Major Depressive Disorder (MDD) • **Low Drive** (high-arousal positive mood)	• Aerobic • Dance/ music-based physical activity	• Moderate	• 20-30 min	• Outdoor environment (green space)	• Group-based • Autonomy-supportive	↑ Drive ↑ Serenity	• Zhang et al., 2023 • Noetel et al., 2024
Generalised Anxiety Disorder (GAD) • **Low Serenity** (low-arousal positive mood) • **High Anxiety**	• Strength training • • Stretching	• Low-moderate	• 20-30 min	• Private setting • Calm green space	• Solo, small non-competitive group	↑ Serenity ↓ Anxiety,	• Wicks et al., 2022 • Bramwell et al., 2023

Table 1. Suggested Exercise Characteristics and Contexts for Optimal Mental Health Benefit

4.4 Limitations

This study has several limitations that must be acknowledged:

1. **Sample Size and Statistical Power:** The small sample size limited statistical power, increasing the likelihood of Type II errors and constraining our ability to include covariates such as gender, socioeconomic status, or baseline fitness.
2. **Self-Reported Mood Outcomes:** Mood outcomes were based exclusively on self-report, which may be subject to bias. Future research should incorporate physiological or neural measures, such as heart rate variability or cortisol, to provide convergent evidence for changes in arousal or perceptions of exercise intensity.
3. **Lack of Standardisation in Physical Activity:** PA sessions were not standardised, and variability within categories (e.g., different forms of aerobic activity) may have diluted effects. Providing a structured PA protocol in future studies could mitigate this.
4. **Acute Measurement Focus:** The use of change scores captured only acute effects, potentially overlooking delayed or buffering impacts of activity later in the day. Longitudinal designs would help clarify whether certain exercise contexts yield sustained benefits.
5. **Measurement Granularity of Social Interaction:** Categorising activity simply as “alone” or “with others” overlooks important aspects of the interaction that could influence mood (e.g., whether it was cooperative or competitive, meaningful or incidental, supportive or evaluative).

4.5 Future Research Directions

A promising direction for future research involves conducting factorial randomised controlled trials (RCTs) that systematically manipulate combinations of exercise type, intensity, duration, environment, social context, and motivational framing. Such designs would allow researchers to examine the interplay between multiple contextual factors, identifying whether certain characteristics amplify or dilute the effects of others on acute affective responses.

In parallel, clinical interventions could be designed to test the “optimal” combinations of exercise characteristics suggested in Table 1 within populations diagnosed with Major Depressive Disorder (MDD) or Generalised Anxiety Disorder (GAD). These studies could employ the factor-derived mood scores as proximal outcomes to capture immediate affective changes, while standardised clinical scales (e.g., the Beck Depression Inventory or the State-Trait Anxiety Inventory) would serve as distal outcomes, enabling evaluation of longer-term therapeutic benefits.

Together, these approaches would provide rigorous evidence to refine prescriptive exercise recommendations for mental health interventions.

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