The effects of affect-guided interval training on pleasure, enjoyment, and autonomy: A registered report

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Abstract

This registered report tested the effects of a novel exercise protocol, namely affect-guided interval training, on motivationally relevant variables of remembered pleasure, forecasted pleasure, enjoyment, and autonomy. Affect-guided interval training (AIT) consisted of 60-second intervals that alternated between the highest pleasant intensity and lowest pleasant intensity for 20 minutes; this was intended to minimize the potential displeasure of traditional high-intensity interval training. The novel protocol was compared to self-selected exercise intensity (30 minutes) and high-intensity interval training (60-second intervals for 20 minutes). All sessions were, on average, vigorous in intensity (80-89% peak heart rate). Data indicate that the AIT session was experienced as the most pleasant, had the most pleasant slope of affect, was remembered as the most pleasant, resulted in the most positive affective forecasts, and was the most enjoyable. Both the affect-guided interval session and self-selected exercise session resulted in greater autonomy than high-intensity interval training. Several evaluative and motivationally relevant variables, including (a) remembered pleasure, (b) enjoyment, and (c) forecasted pleasure were predicted by (a) experienced pleasure, the (b) pleasure experienced at the end of exercise, and (c) the slope of pleasure experienced throughout the exercise session. Overall, this study suggests that affect-guided interval training is a feasible and positive alternative that can be included as a viable option for exercise programming.

Keywords: affect, high-intensity interval training, autonomy, self-selected exercise

Despite the plethora of benefits associated with an active lifestyle, exercise professionals are faced with the conundrum of physical inactivity. Though estimates vary (Zenko et al., 2019), nationally representative data using accelerometers indicates that a majority of the population is achieving low levels of cardiorespiratory activity (Troiano et al., 2008) and resistance exercise (Bennie et al., 2020). Further, population-levels of cardiorespiratory fitness appear to be declining (Tomkinson et al., 2019). Affective responses during exercise – or the pleasure and displeasure experienced while exercising – have been shown to predict future exercise behavior (Rhodes & Kates, 2015). Thus, supporting hedonic theory (Ekkekakis & Dafermos, 2012), exercisers seem to repeat what makes them feel pleasant, and avoid exercise that makes them feel unpleasant.

Recently, several researchers have joined the search for exercise protocols and experiences that are more pleasant and that will result in greater adherence (e.g., Hutchinson et al., 2020; Jones et al., 2018; Lacharité-Lemieux et al., 2015; Zenko et al., 2016). Several have focused on characteristics of the *pattern* of exercise. For example, several studies have investigated the effects of continuously reducing intensity on experienced pleasure during exercise, remembered pleasure (i.e., recollections of the pleasure or displeasure experienced during the exercise session), enjoyment, and forecasted pleasure (i.e., predictions about the pleasure or displeasure that will be experienced during future exercise sessions).

Zenko et al. (2016) investigated the effects of ramping-down intensity during continuous exercise and found that the slope of pleasure (i.e., the rate and direction of change in affective valence) during exercise explained 35-46% of the variance in remembered and forecasted pleasure. Decreasing intensity resulted in more postexercise pleasure, more enjoyment, more remembered pleasure, and more forecasted pleasure. Hutchinson et al. (2020) largely replicated these effects in a resistance-exercise format. Decreasing load from 75% of one-repetition maximum (1RM) to 65% 1RM and then 55% 1RM resulted in more postexercise pleasure, more enjoyment, and more remembered pleasure than a workload matched for volume but featuring increasing intensity (i.e., 55% 1RM, 65% 1RM, 75% 1RM). Hutchinson et al. (2023) recently replicated and extended these findings over multiple sessions of resistance exercise. Further, the pleasure experienced at the end of exercise explained more variance in postexercise pleasure, enjoyment, and remembered pleasure than the pleasure experienced at the beginning of exercise (Hutchinson et al., 2020; also see Hargreaves & Stych, 2013). These findings may not generalize as well to athletes and sport contexts where accomplishment may be an important mediator of affective evaluations of the overall session (Stuntz et al., 2020).

High-intensity interval training (HIIT) and similar formats (e.g., sprint-interval training; SIT) in which periods of high-intensity exercise are interspersed with periods of low-intensity exercise (or passive rest) have gained more attention (e.g., Box et al., 2020; Eddols et al., 2017; Gibala et al., 2012; Quednow et al., 2015). The search for "time-efficient" exercise protocols is motivated, in part, because lack of time is frequently reported as a barrier to regular exercise (Gillen et al., 2016). Although the ample leisure-time reported by Americans in the American Time Use Survey (United States Bureau of Labor Statistics, 2015) casts doubt on "lack of time" actually being a primary barrier to physical activity, the physiological benefits of this mode of exercise seem well-established (Batacan et al., 2017). However, debate continues about whether HIIT or SIT should be recommended for the promotion of public health (Biddle & Batterham, 2015). Several researchers have investigated the effects of high-intensity intervals on affective responses. This literature is characterized by mixed protocols and mixed results (Alicea et al., 2020; Box et al., 2020; Decker & Ekkekakis, 2017; Fleming et al., 2020; Follador et al., 2018;

Martinez et al., 2015; Roloff et al., 2020; Saanijoki et al., 2015; for review see Stork et al., 2017).

An Interval Protocol Guided by Pleasure

Here, we propose a novel protocol designed to keep certain strengths of HIIT protocols, while reducing the likelihood of experiencing displeasure elicited by high-intensity exercise (Ekkekakis et al., 2011). As with continuous exercise, changes in affective valence (i.e., ratings of pleasure-displeasure) during interval exercise are predicted by changes in oxygen uptake (Roloff et al., 2020). Therefore, although debate continues (see discussion above) the high metabolic demand of HIIT may be considered a weakness from the perspective of maximizing pleasure and exercise adherence as it leads to experiences of lower pleasure (or greater displeasure). Here, we prioritize pleasure over physiological benefits under the assumptions that (a) physiological benefits will not be obtained unless people adhere to exercise, and (b) more pleasant exercise will result in more adherence (Ekkekakis & Dafermos, 2012; Rhodes & Kates, 2015).

On the other hand, while higher intensity may be expected to reduce pleasure (or increase displeasure), it is possible that the changing intensity may be experienced as more interesting and engaging than a constant, unchanging intensity. Continuously decreasing intensity throughout an exercise session represents one strategy for introducing high-intensity exercise (at the beginning of exercise) while creating an overall pleasant exercise experience, at least among people with low cardiorespiratory fitness (Zenko et al., 2016) and sedentary or insufficiently active populations (Hutchinson et al., 2020, 2023).

Intervals could represent another strategy, especially when compared to 40 minutes of continuous exercise in a laboratory setting (e.g., Jung et al., 2014). Laboratory environments are often sterile and boring, and, when studying affective responses, participants are frequently unable to listen to music, or unable to focus attention on other pleasant stimuli (e.g., green exercise; Lahart et al., 2019). It is therefore easy to imagine that monotony of continuous exercise in a laboratory environment can result in less positive experiences.

Further, in nonlaboratory environments, people often choose their own exercise intensity, indicating that self-selected exercise intensity may be more ecologically valid than prescribed intensity. Allowing participants to choose their own intensity may also result in increased autonomy (Ekkekakis, 2009; Vazou-Ekkekakis & Ekkekakis, 2009), and reduced likelihood of experiencing displeasure while still providing physiological benefits (Ekkekakis, 2009). In a randomized controlled trial, Williams and colleagues (2015) either prescribed moderate-intensity exercise or allowed participants to choose their own intensity. The participants who self-selected their own intensity engaged in approximately 26 more minutes of walking per week over 6 months than the participants who were prescribed moderate-intensity exercise.

Therefore, giving participants control over their intensity may enhance autonomy, physiological benefits, and pleasure. This may reduce the physiological benefits compared to prescribed high-intensity exercise (i.e., if participants choose lower intensities), but may be more ecologically valid and more conducive to adherence (Williams et al., 2015). To our knowledge, however, using self-paced exercise or exercise regulated by pleasure (i.e., affect-guided exercise), where participants are tasked with self-selecting intensities that “feel good” (Parfitt et al., 2012) has not been investigated in an interval-training context.

The Present Study

The purpose of this study was to test a novel exercise protocol that combines interval training with affect-guided exercise. This Affect-guided Interval Training (AIT) protocol was designed to maintain the interest of frequently changing intensities, reduce monotony, and contribute to autonomy by allowing participants to regulate their own intensities. Further, the AIT is designed to reduce the likelihood of experiencing displeasure during exercise by providing periods of respite and limiting intensity to the range that is experienced as pleasant. We hypothesized that, compared to high-intensity interval training (HIIT) and self-selected continuous exercise (SELF), AIT would result in a more positive in-task pleasure on average (H1), a more positive in-task slope of pleasure (H2), more remembered pleasure (H3) and forecasted pleasure (H4), greater enjoyment (H5), and greater perceived autonomy (H6).

Methods

After obtaining ethical approval, students from a comprehensive Hispanic-serving university in the United States were recruited for this study. Students were eligible if they were deemed to be ready to become more physically active according to the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+; Warburton et al., 2011). All participants completed a prescreening form and, if eligible, provided contact information so that a researcher could schedule laboratory visits.

Power calculations for a repeated-measures design (3 within-subjects conditions), while anticipating a medium effect size (f = .25), 5% type 1 error rate, 10% type 2 error rate, correlated dependent variables (r = .7), and a violation of sphericity (ε = .7) indicated that at least 29 participants were needed (Faul et al., 2007). To protect against anticipated dropout of 20%, the recruitment goal was 35 people. Participants earned $10.00 for each laboratory visit.

Measures

Descriptive characteristics. In addition to typical demographic variables (age, sex, gender identity), body mass index and body fat percentage were also measured. Self-reported exercise behavior was measured using the short form of the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003). This questionnaire measures leisure-time behavior accumulated in bouts of at least 10 minutes. In other words, the IPAQ assesses deliberate exercise behavior rather than total physical activity behavior. See Craig et al. (2003) for evidence of criterion validity.

In-task measures. *S*everal variables were measured repeatedly during exercise, including affective valence, arousal, and rating of fatigue. Participants responded to in-task measures verbally and by pointing to poster-sized scales that were made available during measurement but removed from view between measurements. In-task ratings of affective valence (i.e., pleasure-displeasure) were measured using the Feeling Scale (FS; Hardy & Rejeski, 1989) and in-task ratings of arousal were measured with the Felt Arousal Scale (FAS; Svebak & Murgatroyd, 1985), which are respectively conceptualized to map onto the valence and arousal dimensions of the circumplex model of affect (Russell, 1980). The FS is a single-item, 11-point scale ranging from +5 (*very good*) to -5 (*very bad*) with verbal anchors at 0 and odd numbers. The FAS is a 6-point scale ranging from 1 (*low arousal*) to 6 (*high arousal*). Together, these measures are theorized to provide excellent domain coverage for the domain of affect as well as strong temporal resolution (Backhouse et al., 2007; Russell, 1980). Perceived fatigue was assessed using the Rating-of-Fatigue Scale (ROF; Micklewright et al., 2017). The ROF scale was used to illustrate changes in fatigue during exercise and mainly for exploratory and descriptive purposes because we did not have any specific hypothesis related to ROF. The ROF ranges from 0 (*not fatigued at all*) to 11 (*total fatigue & exhaustion – nothing left*) and contains five verbal descriptors and diagrams representing progressively increasing fatigue. Instructions for each scale were read to participants prior to each exercise session.

Post-task measures. In addition to the FS, FAS, and ROF, several measures were used only after exercise.

Remembered Pleasure.

Kahneman and Riis (2005) made the distinction between the current "experiencing self" and the past "remembering self". The remembering self may be susceptible to biases and individual differences (e.g., in attitudes toward exercise) and appears to be disproportionately influenced by several characteristics of the previous experience, such as the peak and final moment of exercise (Alaybek et al., 2022; Ariely & Carmon, 2000; Hargreaves & Stych, 2013) or the slope of pleasure experienced during exercise (Zenko et al., 2016; Hutchinson et al., 2020; Hutchinson et al., 2023). In contrast to post-task measures of the experiencing self (FS, FAS, and ROF), which require participants to report on how they feel at the moment of measurement, measures of the remembering self requires participants to retrospectively reflect on how they felt during a previous experience. It is possible that the *memory of an experience* may influence forecasts or predictions of future experience more than the *actual experience.* Memories of an experience are thought to influence anticipated or forecasted affective experiences at the point of decision making (see Slawinska & Davis, 2020). To our knowledge, one study has demonstrated that remembered pleasure is more strongly associated with future exercise behavior than experienced affective responses in laboratory settings (Kwan et al., 2017).

Therefore, remembered pleasure was assessed using the Empirical Valence Scale (EVS, Lishner et al., 2008). Participants responded to the question "How did you feel during the exercise session you just completed?" using a bipolar rating scale ranging from *most unpleasant imaginable* to *most pleasant imaginable,* with empirically spaced verbal anchors throughout the rating scale. Participants were asked to place an "x" anywhere on a horizontal 140 mm line. Two raters measured and scored each response with excellent agreement (intraclass correlation coefficient of 1.0, 95% CI: 1.0, 1.0). The average of the two ratings was used as the final value for remembered pleasure, which was then transformed so that the minimum possible rating (*most unpleasant imaginable*) corresponded to -100, and the maximum possible rating (*most pleasant imaginable*) corresponded to 100; *neutral* corresponded to a rating of 0.

Enjoyment.

Enjoyment was measured using the Physical Activity Enjoyment Scale (PACES; Kenzierski & DeCarlo, 1991), which consists of 18 bipolar items on a 7-point scale (e.g., *I enjoy it* versus *I hate it*). Mean enjoyment was calculated for participants with at least 16 of 18 items completed. Internal consistency in this sample was excellent (Cronbach's $\alpha = .90$ following the HIIT session, .92 following the AIT session, .95 following the SELF session).

Forecasted Pleasure.

Forecasted pleasure was measured by asking participants to predict how they would feel if they were to repeat the exercise session again. Participants responded to the question "If you were to repeat today's exercise session, how do you think you would feel?" by responding to a scale ranging from -3 (*extremely negative*) to +3 (*extremely positive*) with a neutral point at 0 (*neither positive nor negative*). Response options were presented vertically. The use of different measures for in-task ratings of affective valence, remembered pleasure, enjoyment, and forecasted pleasure is intended to reduce common method variance (Podsakoff et al., 2003).

Perceived Autonomy.

Perceived autonomy was assessed using the measure describe by Reeve et al., (2003). A nine-item measure of perceived locus of causality, volition, and perceived choice was adapted to focus on exercise intensity (e.g., “I felt like I was doing what I wanted to be doing”; “During the exercise, I felt free”; and “I felt that I had control to decide which intensity to choose”). Responses will range from 1 (*not at all true*) to 7 (*very much true*). One item (“I felt I was only doing what the researcher wanted me to do”) reduced internal consistency in all measurements and was eliminated from the analyses. The remaining eight items had strong internal consistency (Cronbach’s $\alpha = .81$ for the HIIT session, .82 for the AIT session, and .80 for the SELF session).

Procedures

Participants completed four laboratory visits. Whenever possible, each visit was scheduled seven days apart and at the same time of day to control for possible diurnal variation in affective responses (Richardson et al., 2020; Zenko et al., 2016). All exercise sessions began with a 3-minute warm up at 50 Watts (di Fronso et al., 2020). The order of the three experimental sessions was randomly assigned in a counterbalanced fashion. Participants could observe their workload (Watts) on the display of the cycle ergometer. Perceptual measures were removed from the field of view except during moments of measure administration. Likewise, participant-experimenter interaction was kept to a minimum during exercise, with no verbal encouragement or discussion initiated by the researcher. When participants asked questions or initiated a discussion, the researcher explained that they can have a discussion after the experiment is over. Prior to the first laboratory visit, participants completed the screening form to determine eligibility. Participants provided informed consent prior to data collection.

Orientation visit. Eligible participants attended an orientation visit and provided informed consent. The purpose of the orientation visit was to determine peak power output, peak heart rate, height, weight, and body fat percentage using bioelectrical impedance analysis. Participants were also familiarized with measures used in subsequent sessions, namely the FS, FAS, ROF, EVS, and the measure of Forecasted Pleasure. Measurements performed during this session were used for familiarization purposes only, not as dependent variables of the present study. During this session, participants completed an exercise test to volitional exhaustion using an electronically braked cycle ergometer (Lode, Groningen, Netherlands) and while wearing a chest-strap Heart Rate monitor (Polar, Polar USA). Participants were instructed to exercise until maximal effort and stopped when they indicated that they could not continue or when they could not maintain a cadence of at least 50 rpm on the cycle ergometer. Due to user or equipment error, two participants were unable to have their heartrate measured during this session, meaning that peak heart rate could not be measured for all participants (89.22 ± 6.51% age-predicted maximum heart rate). Peak power output was measured for all participants (165 ± 40 Watts). A cycle ergometer was used for all sessions to prevent confounding effects from changing exercise mode (i.e., switching from walking to running during the interval sessions). A ramped protocol consisting of an increasing intensity of 20 Watts/minute was used during this visit. After volitional exhaustion, participants completed a cool-down for 5 minutes at 20 Watts. The subsequent conditions (described next) were scheduled in a random and counterbalanced order. Participants were permitted to drink water during all sessions.

Affect-guided interval training. Affect-guided interval training (AIT) was used for one of the experimental conditions. In this session, participants were instructed to select the highest intensity that still gives them pleasure (i.e., positive affective valence) for 60 seconds, and then the lowest intensity that still gives them pleasure for 60 seconds. Participants were instructed to alternate between the highest pleasant intensity and the lowest pleasant intensity. This pattern was repeated for 20 minutes, such that participants alternated between 10 higher-intensity “work” intervals and 10 lower-intensity “respite” intervals. During the session, Workload (Watts) and Heart Rate were recorded at the end of each work and respite interval, which corresponded to 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, and 100% completion. The FS, FAS, and ROF were administered at 15%, 20%, 35%, 40%, 55%, 60%, 75%, 80%, 95%, and nearly 100% completion, to ensure that measurements were recorded during-exercise and not conflated with post-exercise measurements. These measurement timings allowed for an identical number of measurements in all conditions and consistency of measurements for both interval-style exercise sessions (i.e., five higher-intensity and five-lower intensity intervals). By using timing based on percentage completion, we were also able to be consistent between 20- and 30-minute exercise sessions. This strategy is consistent with prior research comparing affective and perceptual responses between exercise sessions of different durations (e.g., Thum et al., 2017). The FS, FAS, and ROF were administered 2 minutes before exercise to establish a baseline measure of affective valence, arousal, and fatigue respectively. This measurement schedule ensured that in-task affective valence, in-task arousal, and fatigue were measured during five work intervals and five respite intervals. Post-task affective valence was measured five minutes following exercise, while remembered pleasure, enjoyment, forecasted pleasure, and perceived autonomy were administered 10 minutes following exercise. All 32 participants who began the AIT session were able to complete it.

High-intensity interval training. High-intensity interval training (HIIT) was used for another experimental condition. Participants completed alternating work and recovery intervals consisting of cycling at 90% of the Watts corresponding to their peak power output and 20% of the Watts corresponding to their peak power output, respectively. These workloads were partly based on previous studies (Gillen et al., 2012; Little et al., 2011), although these prior researchers used 90% maximal Heart Rate for work intervals. Other than the change in intensity regulation, the mode, duration of exercise, number of work and recovery intervals, and measurement protocols were identical to the AIT session. Of the 31 participants who began the HIIT session, 27 were able to complete it (four participants requested to stop early after indicating that they could not manage the intensity).

Self-selected continuous exercise. The third and final type of experimental condition consisted of self-selected continuous exercise (SELF). In this session, participants chose whichever intensity they wanted for 30 minutes. The participants were also informed that they can change the intensity at any time, and as frequently or infrequently as they desire. The mode of exercise was identical to the AIT and HIIT sessions. The measurement protocol was also identical, such that in-task measures were administered at 15%, 20%, 35%, 40%, 55%, 60%, 75%, 80%, 95%, and nearly 100% completion, the FS, FAS, and ROF were administered 2 minutes before exercise, and post-task measures were administered identically to the other conditions. This also helped control for participant-experimenter interaction. The duration of this session was longer than the AIT and HIIT sessions because it was anticipated that intensity would be lower, and a longer duration would a more consistent overall workload. These assumptions were tested. All 32 participants who began the SELF session were able to complete it.

Data Analysis

Data were assessed for outliers on relevant variables using Tukey's fences (i.e., 25^{th} percentile – (IQR * 1.5); 75^{th} percentile + (IQR * 1.5)). Then, the weight of outliers was reduced by winsorizing the data such that the outliers matched the nearest non-extreme observed values. Data were also examined to check the assumption of normality and nonparametric alternatives were used to analyze data, if necessary.

Affective valence was rescaled to control for pre-exercise levels of affective valence for each session. Since a few participants were unable to complete the HIIT session, mean affective valence for each session was computed if a minimum of five measurements were completed. Similarly, mean heart rate for each session was calculated for each participant if a minimum of 10 heart rate measurements were completed. Heart rate is reported as a percentage of the observed peak heart rate from the orientation session. Watts are reported as a percentage of the observed peak power output from the orientation session. In few instances, due to equipment or user error, heart rate measurements are unavailable and thus some participants are not included in some analyses using heart rate. In other instances, missing data is due to a missing measurement (e.g., participants not completing to a questionnaire). Data and analyses are available at https://osf.io/gec4u/.

The primary hypotheses were assessed using within-subjects ANOVAs or nonparametric alternatives, using the three exercise sessions (AIT, HIIT, and SELF) as the primary within-subjects variable. Greenhouse-Geisser corrections were applied when violations of the sphericity assumption were present. An experiment-wide false discovery rate of 5% was used to address the multiplicity problem while preserving statistical power for all six confirmatory hypotheses (Benjamini & Hochberg, 1995; Benjamini & Yekutieli, 2005; Keselman et al., 2002). The unadjusted p-values (e.g., after a paired t-test) are reported for all analyses subjected to the experiment-wide false discovery rate of 5%. This was completed using the STATS PADJUST syntax available for SPSS versions 18 or later.

Further, correlations between average in-task pleasure, the slope of pleasure, remembered pleasure, forecasted pleasure, and enjoyment are reported to examine theoretically likely affective predictors of remembered pleasure, forecasted pleasure, and enjoyment. Theoretically, remembered pleasure is likely predicted by experienced pleasure, the pattern of change in pleasure (i.e., the slope of pleasure) and the pleasure experienced at the final moment of the exercise experience (Alaybek et al., 2022). We also examined the correlation between pre-exercise pleasure and remembered pleasure of each exercise session (Hargreaves and Stych, 2013). In addition, for exploratory purposes and following Alaybek et al. (2022), we calculated the correlations between remembered pleasure, forecasted pleasure, and enjoyment and the peak and the peak-end average. These correlation analyses were also subject to the experiment-wide false discovery rate of 5%.

Two slopes of pleasure were calculated in this study. Primarily, an overall slope of pleasure that included that pre-exercise and during-exercise time points (i.e., baseline, 15%, 20%, 35%, 40%, 55%, 60%, 75%, 80%, 95%, 100% exercise completion) and secondarily, a during-exercise slope of pleasure that disregarded pre-exercise affective valence. Both types of slopes were in the same direction in each condition. In terms of magnitude, there was no difference in the types of slopes in the HIIT condition ($d = -.07$, $p = .692$), but the overall slope was significantly more positive than the during-exercise slope in the AIT condition ($d = .54$, $p = .005$), and less negative in the SELF condition ($d = .41$, $p = .028$).

Enjoyment is theorized to be predicted by those variables and remembered pleasure. Forecasted pleasure is theorized to be predicted by those variables and remembered pleasure. This tested the model illustrated by Jones and Zenko (2021), in which affective responses to exercise, biases in memory, and cognitive filters influence remembered utility (i.e., remembered pleasure, enjoyment), which in turn influences predicted utility (i.e., forecasted pleasure). Repeated measures correlations were calculated using the rmcorr and rmcorr-shiny apps (Bakdash & Marusch, 2017; Marusich & Bakdash, 2021), a package and application that allows a researcher to determine common within-individual associations for repeated measures. This is a statistically powerful tool that does not violate the assumption of independence of observations (Bakdash & Marusch, 2017). Confidence intervals were bootstrapped at the 95% confidence level with 500 resamples (seed 33).

Graphs are presented to highlight comparisons between in-task ratings of pleasure, heart rate, and power output between conditions. Post-hoc analyses of heart rate and power output were completed using Bonferroni adjustments and adjusted p-values are reported. Arousal and fatigue were not central to any hypothesis, but responses are displayed below for descriptive purposes.

Results

Participants

Overall, 34 participants completed at least 1 laboratory visit. These included 24 women and 10 men (sex: 24 females, 10 males), aged 22 ± 3 years (range: 18 to 32 years). Based on body mass index, 17 participants had normal weight, 10 participants were overweight, and seven participants had obesity. Regarding body composition, participants had a body fat percentage of 25.12 ± 7.40%. Using the self-report measure, participants indicated that they obtained very high levels of physical activity (316 ± 271 minutes of walking per week, 271 ± 281 minutes of vigorous activity per week, and 106 ± 119 minutes of moderate activity per week). Two participants completed only one laboratory visit to assess peak power output (one dropped out for unrelated health reasons, and one dropped out due to scheduling issues). In addition, one participant did not complete the HIIT session due to scheduling issues.

Descriptive Analysis: Intensity, Workload, Arousal, and Fatigue

Exploratory analyses for descriptive purposes revealed differences in intensity between conditions, measured by percentage of peak heart rate. A 3x20 repeated-measures ANOVA with three conditions (HIIT, AIT, SELF) and 20 time points (5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, and 100% completion) using percentage of peak heart rate as an outcome revealed a main effect of condition, $F(2, 46) = 22.60$, $p < .001$, $\eta p^2 = .496$, $\omega^2 = .164$, a main effect of time, $F(3.303, 75.968) = 78.24$, $p < .001$, $\eta p^2 = .773$, $\omega^2 = .187$, and a condition by time interaction, $F(38, 874) = 8.32$, $p < .001$, $\eta p^2 = .266$, $\omega^2 = .035$. Analysis of marginal means indicated that all sessions were, on average, vigorous (i.e., greater than 76% peak heart rate; Garber et al., 2011) (HIIT: 88.68% peak heart rate, 95% CI: 83.97, 93.39; AIT: 79.63% peak heart rate, 95% CI: 74.91, 84.34; SELF: 80.09% peak heart rate, 95% CI: 75.37, 84.80). See Figure 1. After applying a Bonferroni correction, heart rate was higher in the HIIT condition than the AIT condition (t = 5.97, d = .91, p < .001) and the SELF condition (t = 5.67, d = .87, p < .001). The AIT and SELF conditions were not different (t = -0.30, d = -.05, p > .999).

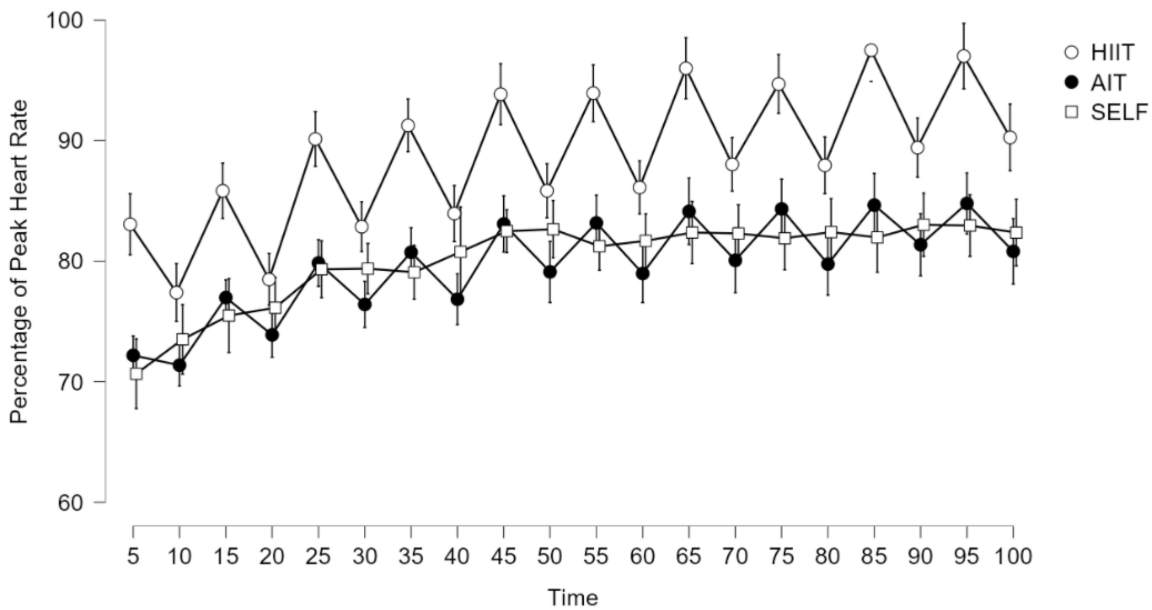

Figure 1. Mean heart rate over time for each condition, as a percentage of peak heart rate. HIIT: High-intensity interval training. AIT: Affect-guided interval training. SELF: Self-selected continuous exercise. 95% confidence intervals are shown.

Similarly, differences between conditions emerged when examining percentage of peak power output. Exploratory analyses for descriptive purposes revealed differences in intensity between conditions, measured by percentage of peak power output. A 3x20 repeated-measures ANOVA with three conditions (HIIT, AIT, SELF) and 20 time points (5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, and 100% completion) using percentage of peak power output as an outcome revealed a main effect of condition, $F(2, 58) = 16.48$, $p < .001$, $\eta p^2 = .362$, $\omega^2 = .183$, a main effect of time, $F(3.360, 97.436) = 285.62$, $p < .001$, $\eta p^2 = .908$, $\omega^2 = .790$, and a condition by time interaction, $F(38, 1102) = 110.01$, $p < .001$, $\eta p^2 = .791$, $\omega^2 = .668$. Examination of Figure 2 indicates that chosen intensity of the SELF condition was much more stable than chosen intensity of the AIT session. The AIT session, in turn, varied as expected but was within a more limited range than the imposed HIIT workloads. After applying a Bonferroni correction, Watts in the HIIT condition were higher than the AIT condition (mean difference: 8.38% peak power output (PPO), $t = 4.53$, $d = .65$, $p < .001$) and the SELF condition (mean difference: 9.85% PPO, $t = 5.32$, $d = .77$, $p < .001$). The AIT and SELF conditions were not different overall (mean difference: 1.48% PPO, $t = 0.80$, $d = .12$, $p > .999$).

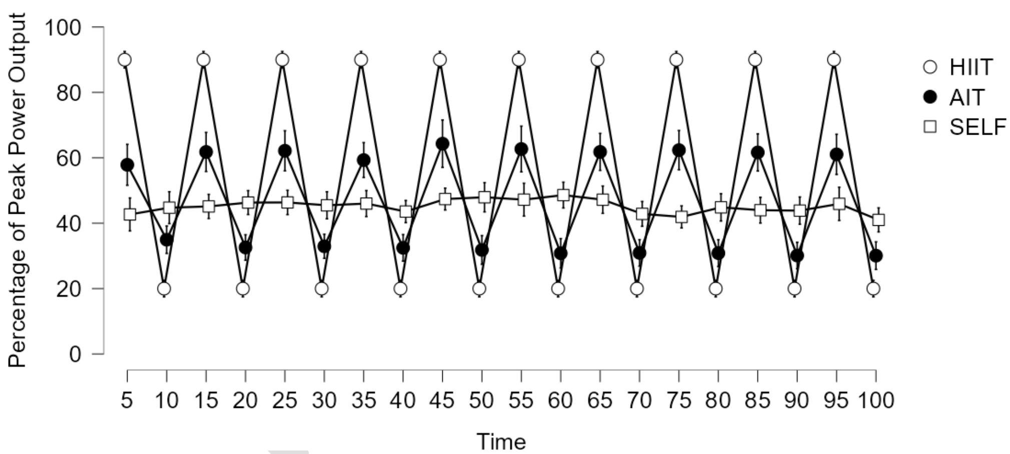

Figure 2. Mean power output over time for each condition, as a percentage of peak power output. HIIT: High-intensity interval training. AIT: Affect-guided interval training. SELF: Self-selected continuous exercise. 95% confidence intervals are shown.

All conditions demonstrated an increase in fatigue (Figure 3) and arousal (Figure 4). There were no differences between conditions for fatigue ($p = .143$, $\eta p^2 = .072$, $\omega^2 = .010$) or arousal ($p = .146$, $\eta p^2 = .071$, $\omega^2 = .009$).

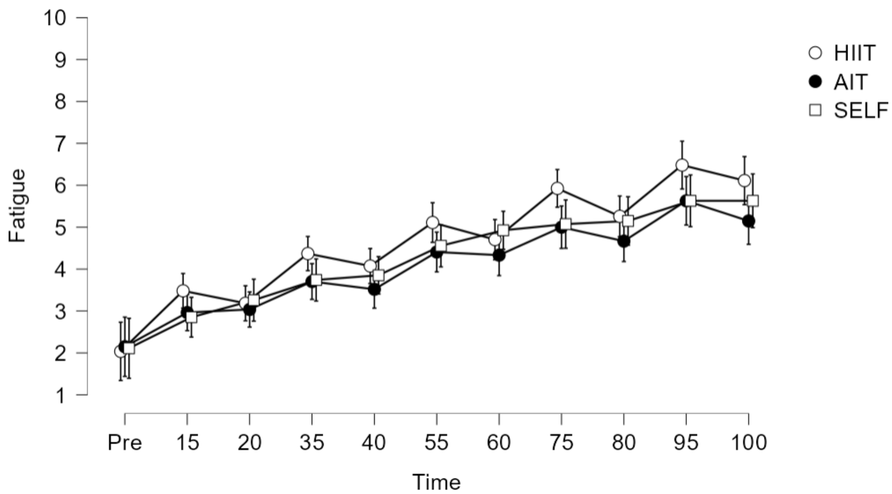

Figure 3. Mean fatigue over time for each condition. HIIT: High-intensity interval training. AIT: Affect-guided interval training. SELF: Self-selected continuous exercise. 95% confidence intervals are shown.

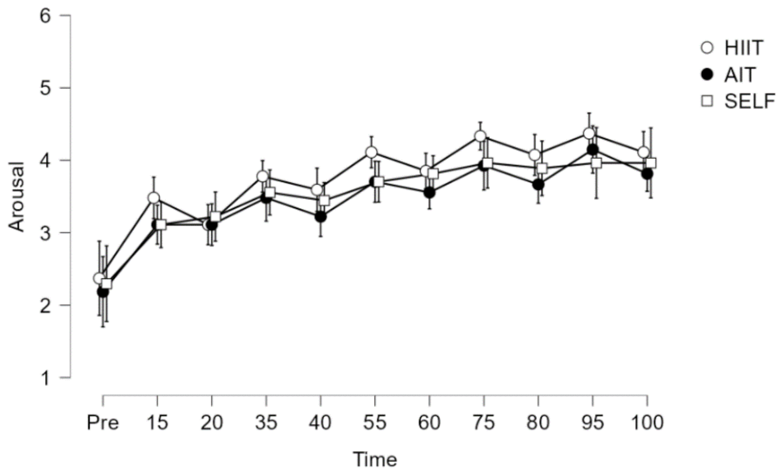

Figure 4. Mean arousal over time for each condition. HIIT: High-intensity interval training. AIT: Affect-guided interval training. SELF: Self-selected continuous exercise. 95% confidence intervals are shown.

Hypothesis 1: Experienced Pleasure

Hypothesis 1 predicted that AIT would result in more positive in-task (experienced) pleasure than HIIT and SELF. This hypothesis was confirmed by a repeated-measures ANOVA controlling for pre-exercise levels of affective valence, measured at baseline (Figure 5). This analysis included a 3x10 repeated-measures ANOVA with three conditions (HIIT, AIT, and SELF) and 10 time points (15%, 20%, 35%, 40%, 55%, 60%, 75%, 80%, 95%, 100% exercise completion) revealed a main effect of condition, $F\ (2, 52) = 10.19$, $p < .001$, $\eta p^2 = .282$, $\omega^2 = .106$, and a condition by time interaction, $F\ (5.98, 155.51) = 3.67$, $p = .002$, $\eta p^2 = .124$, $\omega^2 = .014$ (although the effects of time and the condition by time interaction were not relevant to this hypothesis).

Post-hoc analyses using paired t-tests with an experiment-wide false discovery rate of 5% revealed that the experienced pleasure of the AIT session was more positive than the HIIT condition ($t(29) = 4.75$, $d = .87$, $p < .001$) and the SELF condition ($t(31) = 3.29$, $d = .58$, $p = .003$). The HIIT condition was not significantly different than the SELF condition ($t(29) = -1.22$, $d = -.28$, $p = .137$).

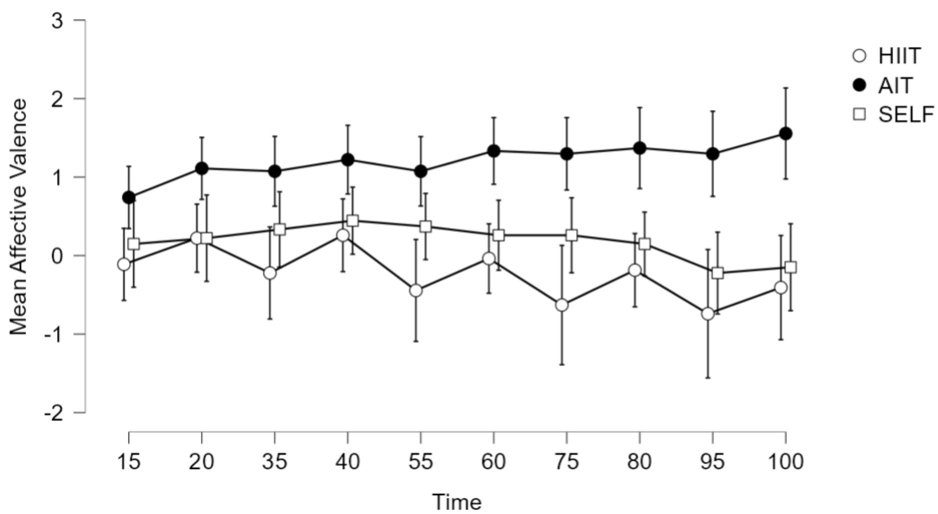

Figure 5. Mean affective valence over time for each condition, controlling for pre-exercise levels of affective valence. HIIT: High-intensity interval training. AIT: Affect-guided interval training. SELF: Self-selected continuous exercise. 95% confidence intervals are shown.

Hypothesis 2: Slope of Pleasure

Individual slopes of pleasure were calculated for each participant in each session using the least squares method to calculate the line of best fit (Steffens & Guastavino, 2015), using baseline and during-exercise affective valence to capture the overall exercise experience (overall slope of pleasure). Hypothesis 2 predicted that the AIT would result in more positive overall slopes of pleasure than the HIIT and SELF sessions. A repeated-measures ANOVA with three conditions (HIIT, AIT, SELF) and the slope of pleasure as an outcome confirmed this hypothesis and indicated a main effect of condition, $F\ (1.662, 49.870) = 12.15$, $p < .001$, $\eta^2 = .288$, $\omega^2 = .097$.

Post-hoc analyses using paired t-tests or Wilcoxon-signed rank tests and an experiment-wide false discovery rate of 5% indicated that the AIT condition resulted in a more positive slope than the HIIT condition ($t(30) = 5.50$, $d = .99$, $p < .001$) and the SELF condition ($W = 403$), $d = .63$, $p = .002$). There was no difference between the SELF and HIIT conditions ($t(30) = 1.73$, $d = .31$, $p = .094$).

Hypothesis 3: Remembered Pleasure

Hypothesis 3 predicted that AIT would result in greater remembered pleasure than HIIT and SELF. A repeated-measures ANOVA with three conditions (HIIT, AIT, and SELF) confirmed this hypothesis and indicated a main effect of condition, $F\ (2, 60) = 10.79$, $p < .001$, $\eta^2 = .264$, $\omega^2 = .096$. The remembered pleasure of the AIT session was 54.31 ± 19.27 units. The remembered pleasure of the SELF condition was 35.28 ± 31.90 units. The remembered pleasure of the HIIT session was 29.56 ± 38.52 units.

Post-hoc analyses using paired t-tests and an experiment-wide false discovery rate of 5% indicated that the remembered pleasure of the AIT was more pleasant than the HIIT condition ($t(30) = 4.08$, $d = .73$, $p < .001$) and the SELF condition ($t(31) = 3.96$, $d = .70$, $p < .001$). There was no difference between the SELF and HIIT condition ($t(30) = 1.03$, $d = .19$, $p = .311$). Overall, approximately 67% of participants remembered the AIT session as more pleasant than the HIIT session (Figure 6).

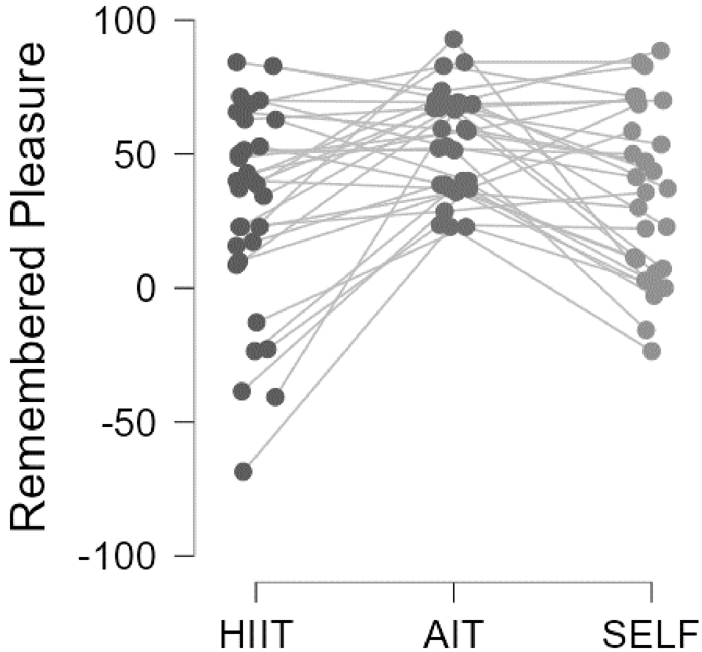

Figure 6. Remembered pleasure for each condition by participant. HIIT: High-intensity interval training. AIT: Affect-guided interval training. SELF: Self-selected continuous exercise. Standard errors are shown.

Hypothesis 4: Forecasted Pleasure

Hypothesis 4 predicted that the AIT session would result in greater forecasted pleasure than the HIIT and SELF conditions. Shapiro-Wilk tests revealed significant deviations from normality in the measure of forecasted pleasure for all three conditions, and so a nonparametric analysis was used. A nonparametric Friedman test of differences among repeated measures revealed a Chi-squared value of 10.889, which was statistically significant ($p = .004$).

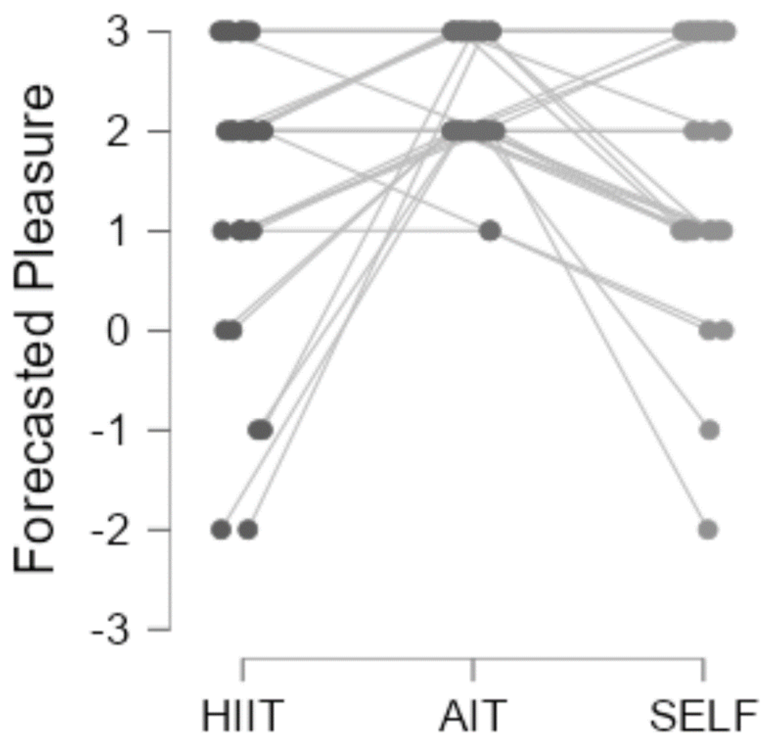

Figure 7. Forecasted pleasure for each condition by participant. HIIT: High-intensity interval training. AIT: Affect-guided interval training. SELF: Self-selected continuous exercise. Standard errors are shown.

Post-hoc analyses using paired t-tests or Wilcoxon-signed rank tests and an experiment-wide false discovery rate of 5% indicated that the AIT condition resulted in greater forecasted pleasure than the HIIT condition (W = 125, d = .84, p = .003). and the SELF condition (W = 169, d = .78, p = .002). There was no difference between the HIIT and SELF conditions (t(30) = -0.57, d = -.10, p = .572).

Hypothesis 5: Enjoyment

Hypothesis 5 predicted that the AIT session would be more enjoyable than HIIT and SELF. Because enjoyment deviated significantly from normality in one condition, a nonparametric analysis was used. A nonparametric Friedman test of differences among repeated measures revealed a Chi-squared value of 6.467, which was statistically significant ($p = .039$).

Post-hoc analyses using paired t-tests and an experiment-wide false discovery rate of 5% indicated that the AIT condition resulted in a more enjoyment than the HIIT condition ($t(29) = 2.93$), $d = .54$, $p = .007$) and the SELF condition ($t(30) = 2.84$, $d = .51$, $p = .008$). There was no difference between the SELF and HIIT conditions ($t(30) = 0.99$, $d = .18$, $p = .329$).

Hypothesis 6: Autonomy

Hypothesis 6 predicted that the AIT condition would result in more perceived autonomy than the HIIT and SELF conditions. This was partly confirmed. Because autonomy deviated significantly form normality in one condition, a nonparametric analysis was used. A nonparametric Friedman test of differences among repeated measures revealed a Chi-squared value of 33.217, which was statistically significant ($p < .001$).

Post-hoc analyses using paired t-tests and an experiment-wide false discovery rate of 5% indicated that the AIT condition resulted in a more autonomy than the HIIT condition ($t(30) = 4.97$, $d = .89$, $p < .001$). The SELF condition resulted in greater autonomy than the HIIT condition ($t(30) = 6.86$, $d = 1.23$, $p < .001$). The SELF condition also resulted in more autonomy than the AIT condition ($t(31) = 2.24$, $d = .40$, $p = .032$), which we did not hypothesize in advance.

Predictors of Remembered Pleasure, Forecasted Pleasure, and Enjoyment

Correlation analyses were conducted to determine the relations between mean experienced pleasure (not controlling for baseline), slopes of pleasure, pleasure experienced at the end of each session (affective valence at 100% completion), remembered pleasure, forecasted pleasure, and enjoyment. This was done to examine theoretically likely predictors of remembered pleasure, forecasted pleasure, and enjoyment. The following exploratory analyses were also subject to the experiment-wide false discovery rate of 5%.

Remembered pleasure was not correlated with pre-exercise affective valence, $r_{rm}(62) = 0.05$, 95% CI [-0.232, 0.299], $p = 0.679$. Remembered pleasure was correlated with pleasure experienced at the end of exercise, $r_{rm}(61) = 0.67$, 95% CI [0.513, 0.783], $p < 0.001$ and the overall mean experienced pleasure, $r_{rm}(61) = 0.57$, 95% CI [0.394, 0.727], $p < 0.001$ (see Figure 8). Remembered pleasure was also correlated with the overall slope of pleasure, $r_{rm}(62) = 0.60$, 95% CI [0.455, 0.727], $p < 0.001$; and the slope of pleasure determined using only during-exercise affective responses (i.e., not considering pre-exercise affective valence), $r_{rm}(60) = 0.64$, 95% CI [0.483, 0.786], $p < 0.001$. Remembered pleasure was correlated with the peak, $r_{rm}(62) = 0.40$, 95% CI [0.123, 0.62], $p = 0.001$, and the peak-end average, $r_{rm}(62) = 0.62$, 95% CI [0.436, 0.76], $p < 0.001$.

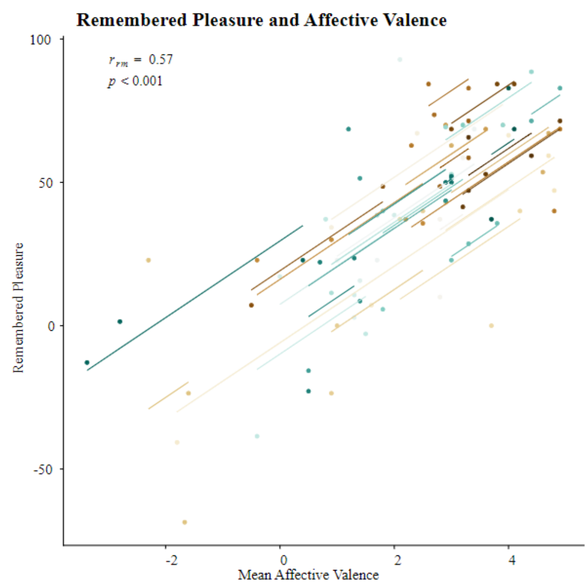

Figure 8. Rmcorr plot showing the relation between mean affective valence and remembered pleasure using repeated measures. Each line corresponds to a different participant's data.

Enjoyment was correlated with affect experienced at the end of exercise, $r_{rm}(60) = 0.45$, 95% CI [0.255, 0.641], $p < 0.001$; mean experienced pleasure, $r_{rm}(60) = 0.46$, 95% CI [0.277, 0.631], $p < 0.001$; the overall slope of pleasure, $r_{rm}(61) = 0.44$, 95% CI [0.23, 0.656], $p < 0.001$; the slope of pleasure during exercise, $r_{rm}(59) = 0.34$, 95% CI [0.06, 0.574], $p = 0.007$; and remembered pleasure, $r_{rm}(61) = 0.51$, 95% CI [0.301, 0.703], $p < 0.001$. Enjoyment was also associated with the peak, $r_{rm}(61) = 0.46$, 95% CI [0.252, 0.678], $p < 0.001$, and the peak-end average, $r_{rm}(61) = 0.50$, 95% CI [0.309, 0.645], $p < 0.001$.

Forecasted pleasure was correlated with affect experienced at the end of exercise, $r_{rm}(61) = 0.51$, 95% CI [0.282, 0.695], $p < 0.001$; overall mean experienced pleasure, $r_{rm}(61) = 0.48$, 95% CI [0.237, 0.675], $p < 0.001$; the overall slope of pleasure, $r_{rm}(62) = 0.43$, 95% CI [0.211, 0.592], $p < 0.001$; the slope of pleasure using during-exercise affective responses, $r_{rm}(60) = 0.45$, 95% CI [0.166, 0.665], $p < 0.001$; and remembered pleasure, $r_{rm}(62) = 0.62$, 95% CI [0.362, 0.788], $p < 0.001$.

Forecasted pleasure was also related to the peak, $r_{rm}(62) = 0.46$, 95% CI [0.185, 0.709], $p < 0.001$, and the peak-end average, $r_{rm}(62) = 0.54$, 95% CI [0.303, 0.719], $p < 0.001$. Enjoyment of the exercise session was strongly associated with forecasted pleasure of a repeated session, $r_{rm}(61) = 0.78$, 95% CI [0.642, 0.874], $p < 0.001$.

Discussion

The primary purpose of this registered report was to test a novel exercise protocol, namely Affect-guided interval training (AIT). AIT allows participants to alternate between the highest pleasant and lowest pleasant intensities, which are expected to vary between participants. AIT is expected to put the exercisers in control and allow them to avoid feelings of displeasure, while still providing a meaningful physiological stimulus. This study compared 20 minutes AIT to traditional high-intensity interval training (HIIT), which alternated between 90% and 20% of peak power output for 20 minutes, and 30 minutes of self-selected continuous exercise (SELF), where participants were informed that they could change intensity whenever they pleased but, in contrast to AIT, were not explicitly instructed to alternate between the highest pleasant and lowest pleasant intensities.

In this study, all sessions were, on average, vigorous (i.e., > 76% peak measured heart rate; Garber et al. 2011). The AIT session ranged from 71.37 ± 8.70% to 84.79 ± 11.60% peak heart rate. The HIIT session ranged from 77.93 ± 9.15% to 97.50 ± 5.25% peak heart rate. The SELF session ranged from 70.66 ± 9.57% to 83.02 ± 12.09% peak heart rate. This suggests that all exercise sessions tested could provide health-enhancing effects and meaningful physiological changes, consistent with physical activity guidelines. Interestingly, but not surprisingly, the AIT session resulted in changes in intensity (from highest pleasant intensity to lowest pleasant intensity), but the peaks and valleys were not as extreme as the HIIT session, which ranged from

90% of peak power output to 20% of peak power output, with no consideration for psychological responses (See Figure 2). This suggests that the "pleasant range" of exercise intensities might be narrower than the range imposed by high-intensity interval training.

In-task Affective Responses

Our hypotheses regarding in-task affective responses were confirmed. The AIT was experienced as more pleasant than the HIIT session (Hypothesis 1), with a large effect size (d = .87), as well as the SELF session, with a medium effect size (d = .58). Further, confirming Hypothesis 2, the overall slope of pleasure in the AIT was more positive than the overall slope of pleasure in the HIIT condition, again with large effects (d = .99) and the SELF condition, again with a more medium effect size (d = .63).

Intensity and pleasure are known to be linked, with people generally experiencing less pleasure as intensity increases beyond the ventilatory threshold (Ekkekakis et al., 2011). Because the intensity of AIT and HIIT were different, it is possible that different intensities and workloads partially explain the differences in affective outcomes, and not entirely attributable to the type of exercise prescription and affect-guided exercise. Interestingly, the heart rate and percentage of peak power output (Watts) during the AIT and SELF conditions were not different from each other, but the AIT still resulted in more experienced pleasure, more remembered pleasure, more forecasted pleasure, and more enjoyment. Therefore, it is unlikely that differences in affective responses between conditions were entirely due to differences in intensity and workload. The differences could be due to several factors that warrant further investigation. First, the AIT session was 10 minutes shorter, and participants were aware of how long the exercise session would be; this could have had an impact on the overall affective experience via anticipated affective responses (e.g., Davis & Stenling, 2020). Second, although participants were in control of their intensity in both the AIT and SELF sessions, they were only explicitly instructed to vary intensity between the highest pleasant intensity and lowest pleasant intensity in the AIT session. Thus, only the AIT session resulted in deliberate changes in intensity each minute during exercise, always with a focus on pleasant affective responses. There may be something unique about providing varying intensities and periods of respite during exercise that are inherently pleasant.

The SELF condition was, on average, vigorous. This was an unexpected result, and it was predicted that exercisers would choose a lower intensity over 30 minutes compared to a 20-minute exercise session. Although the SELF condition was 10 minutes longer, and vigorous, it was not experienced as less pleasant than the HIIT session. The SELF condition was also not less enjoyable than HIIT, despite being 50% longer. It is possible that participants in the SELF condition were able to regulate intensity and avoid displeasure, even if not explicitly instructed to choose a pleasant intensity. Although vigorous, there was still a large difference in intensity in the HIIT condition compared to the SELF condition ($d = .87$). This suggests a limit in the intensity that participants were willing to impose on themselves. This is in line with a review by Ekkekakis (2009), who noted that most individuals choose intensities that are physiologically beneficial and do not result in declines in pleasure. Therefore, it is possible that both self-selected exercise sessions here (AIT and SELF) allowed participants to choose individually appropriate intensities (and vigorous intensity overall), without crossing a threshold that would reduce pleasure and enjoyment.

Although all conditions were vigorous, and the 20-minute AIT session was experienced as most pleasant, but the 30-minute SELF condition was not experienced or remembered as less pleasant than the much more intense, but shorter HIIT condition. This also highlights the possibility that an exercise session that is 50% longer (i.e., SELF vs. HIIT, 30 minutes vs. 20 minutes) may not be perceived as inferior, less pleasant, or more unpleasant, if the exerciser can regulate their own intensity level. This also suggests the possibility of duration neglect (Fredrickson & Kahneman, 1993); perhaps participants are less sensitive to the duration of exercise than they are to the intensity of exercise. In this study, participants were informed that the SELF condition would be 30 minutes, and they were aware that the other sessions were 20 minutes. Despite this, there were also no differences in forecasted pleasure between HIIT and SELF (discussed below), suggesting that the prospect of a longer exercise session is not inherently predicted to be less pleasant. This idea warrants further investigation.

Remembered Pleasure

Hypothesis 3 predicted that the remembered pleasure of the AIT session would be highest. This was confirmed. The remembered pleasure of the AIT session was greater than the HIIT session, with large effects (d = .73) and the SELF condition, again with large effects (d = .70). Despite being 50% longer, and also vigorous, the SELF condition was not remembered as less pleasant than HIIT (d = .19). In this within-subjects design, about 67% of participants reported higher remembered pleasure following the AIT session compared to the HIIT condition. Whereas approximately 19% of participants remembered the HIIT session to be unpleasant (i.e., more negative than neutral), 9% of participants remembered the SELF session to be unpleasant. In contrast, every participant remembered the AIT session to be pleasant (remembered pleasure ratings ranged from 23 units to 93 units).

Regarding raw values of remembered pleasure, there was a range from 29.56 units (on average) following the HIIT session, to 35.27 units following the SELF session, to 54.31 units following the AIT session. These correspond to approximately mildly pleasant (24 units) to moderately-strongly pleasant (38 to 70) on the Empirical Valence Scale (Lishner et al., 2008). Regarding behavioral implications, Kwan et al. (2017) have demonstrated that remembered pleasure of a laboratory exercise experience is associated with subsequent exercise behavior, whereas Hargreaves and Stych (2013) observed nonsignificant associations between retrospective evaluations and exercise behavior. Theoretically, remembered pleasure and core affective experiences are linked to forecasted pleasure and attraction toward exercise, which is associated with exercise behavior (Ekkekakis et al., 2021; Nieves & Zenko, 2023). Future investigators, ideally with longitudinal designs, should work to determine how many units on the Empirical Valence Scale correspond to meaningful differences or changes in behavior. That is, are 10 units associated with 10 minutes of physical activity per week, or 30, or more, or fewer? It is also noteworthy to observe that remembered pleasure was, on average, positive for all sessions. It is possible that results may differ and that larger differences between conditions would emerge in a different sample (e.g., older, more sedentary, clinical).

Forecasted Pleasure

Hypothesis 4 predicted that AIT would be forecasted as most pleasant. This was confirmed; the AIT was forecasted to be more pleasant than the HIIT condition ($d = .84$) and the SELF condition ($d = .78$), and again there was no difference between the HIIT and SELF condition ($d = .10$). Like with remembered pleasure, future investigators should work to determine how much difference in forecasted pleasure results in meaningful difference in behavior. For now, at least theoretically, exercise sessions that are predicted to be more pleasant are more likely to be repeated (Ekkekakis & Dafermos, 2012; Hutchinson et al., 2023; Jones & Zenko, 2021; Slawinska & Davis, 2020), although empirical evidence linking forecasted or anticipated affect to future physical activity behavior is mixed, with only a few studies available to date (Feil et al., 2023). In addition, future investigators should work to understand how to enhance more complex anticipated emotions (Feil et al., 2022, 2023).

Enjoyment

Hypothesis 5 predicted that AIT would be more enjoyable than HIIT and SELF. This was also confirmed; the AIT was more enjoyable than HIIT (d = .54) and SELF (d = .51). However, as with forecasted pleasure, remembered pleasure, the slope of pleasure, and experienced pleasure, there was no difference between the HIIT session and the longer SELF session (d = .18). We believe it is uncontroversial to suggest that exercise should be enjoyable whenever possible, as activities that are enjoyable are more likely to be repeated. Indeed, Lewis et al. (2016) provided data indicating that enjoyment of physical activity is a more powerful predictor of future behavior than self-efficacy.

Autonomy

Hypothesis 6 predicted that the AIT session would result in higher levels of autonomy than the HIIT and SELF condition. This was only partly confirmed. Although AIT resulted in more autonomy than the HIIT condition (d = .89), there was also a large difference in autonomy of SELF vs. HIIT (d = 1.23). Further, the SELF condition resulted in more autonomy than the AIT condition (d = .40). This suggests that, perhaps, allowing participants to choose the highest pleasant and lowest pleasant intensities enhanced autonomy relative to imposing intensities, but reduced autonomy relative to allowing them to simply choose their own intensity with no instructions on increasing or decreasing intensity. Although somewhat mixed (Teixeira et al., 2012), there seems to be a generally positive association between autonomy and exercise behavior (Nieves & Zenko, 2023).

In this study, allowing participants to choose their own intensity, or allowing them to choose the highest and lowest pleasant intensities, enhanced autonomy relative to imposing intensity. This extends previous research focused on matched intensities (e.g., Vazou-Ekkekakis & Ekkekakis, 2009). Although the chosen intensities in the current study were different than the imposed condition, the percentage of peak heart rate observed for the AIT and SELF conditions were not different. It is important to highlight that the AIT and SELF conditions both included vigorous exercise and lasted for 20 to 30 minutes, while still enhancing autonomy relative to HIIT. This complements previous research that has indicated self-paced HIIT can enhance cardiorespiratory fitness and other outcomes (Connolly et al., 2017; Solyu et al., 2021).

Arguably, these findings suggest that we can simplify exercise prescription by removing the need to be rigid and focused on indicators of intensity (e.g., prescribing based on a percentage of heart rate, or a percentage of maximal oxygen consumption). Allowing participants to choose their own intensity and emphasizing intensities that are pleasant or "feel good" has been recommended previously (e.g., Ladwig et al., 2017) and shown to result in physiological and psychological benefits (Carter et al., 2022; Parfitt et al., 2012). These results suggest that allowing people to choose their own intensity increases autonomy, and allowing people to choose their own intensity with an emphasis on pleasure enhances experienced pleasure, the slope of pleasure, remembered pleasure, forecasted pleasure, and enjoyment. Further, allowing participants to choose their own intensity and emphasizing pleasure may enhance completion and adherence to the exercise programming. In this study, all 32 participants who began the AIT and SELF conditions were able to complete the 20- or 30-minute sessions. However, about 13% of the participants (4 of 31) who began the HIIT session were unable to complete it; each of these participants indicated that they could not manage the intensity.

Predictors of Remembered Pleasure, Forecasted Pleasure, and Enjoyment

Further, this study examined predictors of remembered pleasure, forecasted pleasure, and enjoyment. While these differed between conditions, as discussed above, it is also important to recognize potential individual differences or characteristics of an exercise experience that enhance remembered pleasure, forecasted pleasure, and enjoyment.

Remembered pleasure.

In the current study, remembered pleasure was not associated with pre-exercise affective valence, which is different from the findings of Hargreaves and Stych (2013). In that study, pre-exercise pleasure was correlated with retrospective evaluations in participants who exercised at or above the ventilatory threshold (Hargreaves and Stych, 2013).

Remembered pleasure was predicted by in-task ratings of affective valence. This suggests that about 32% of the variance in remembered pleasure was explained by mean experienced pleasure. These results are consistent with a study by Hutchinson et al. (2020), who found that pleasure experienced during exercise was associated with remembered pleasure, both shortly after and 24 hours after exercise. In addition, when considering the overall experience, the slope of pleasure during exercise explained 36% of the variance in remembered pleasure. The relations between the slope of pleasure and remembered pleasure were similar when considering only affective responses measured during exercise (not pre-exercise affective valence); this slope explained 41% of the variance in remembered pleasure.

These results conceptually replicate prior research findings by Hutchinson et al. (2020, 2023) and Zenko et al. (2016). In these studies, researchers experimentally manipulated the slope of pleasure during exercise by manipulating exercise intensity or resistance training load and found that improving affective responses during exercise impacted remembered pleasure. In this current study, although the AIT session resulted in more positive slopes compared to HIIT and SELF, reflecting an increasingly positive experience, this was not due to instructions to progressively decrease intensity.

Affective responses at the end of the sessions (i.e., final measured response during exercise) predicted 45% of the variance in remembered pleasure, while the peak explained 16% of the variance and the peak-end average explained 38% of the variance. This is consistent with previous researchers who found that affective responses experienced at the peak (Hargreaves and Stych, 2013) and end (Hargreaves and Stych, 2013; Hutchinson et al., 2020, 2023) of the session were related to remembered pleasure or retrospective evaluations. In the context of high-intensity interval exercise, one study (to our knowledge) examined the effect of creating a longer high-intensity interval session that would be less intense at the end. However, this did not change psychological responses at the end of the exercise, suggesting that the end was not sufficiently altered between the short and long exercise sessions (Alves et al., 2021). Recently, Fessler et al. (2023) performed an early phase study which included an additional nine minutes of exercise at a lower intensity over multiple sessions. This resulted in more positive affective attitudes toward exercise.

Taken together, the relations between experienced pleasure, the slope of pleasure, the peak of pleasure, and the final moment affect during exercise and remembered pleasure observed in the current study conceptually replicate and extend previous research in exercise psychology (Hargreaves & Stych, 2013; Hutchinson et al., 2020, 2023; Zenko et al., 2016). In the broader literature, Alaybek et al. (2022) conducted a meta-analysis to determine the influence of the peak, end, peak-end, trend, and other characteristics of an experience on retrospective evaluations. Overall, the peaks the end of an experience had a robust effect on the retrospective evaluations, comparable to the overall average, while the effect of the trend was considerably weaker (Alaybek et al., 2022). Future researchers should work to determine other influences of remembered pleasure, beyond the affect experienced during exercise. In addition, future researchers should investigate other ways to enhance remembered pleasure.

Enjoyment and Forecasted Pleasure.

As expected, enjoyment was related to affective responses to exercise and other retrospective and prospective evaluations of exercise. Mean affective responses during exercise explained 21% of the variance in enjoyment, while affective responses at the end of exercise explained 20% of the variance in enjoyment. The slopes of pleasure explained between 12% and 19% of the variance in enjoyment. The peak was comparable and shared 21% of the variance with enjoyment, while the peak-end average shared 25% variance. Enjoyment and remembered pleasure were also strongly associated, sharing 26% variance.

Forecasted pleasure was associated with experienced pleasure. Mean affective valence during exercise explained 23% of the variance in forecasted pleasure. The affect experienced at the end of exercise explained 26% of the variance in forecasted pleasure. Further, the slopes of pleasure explained 18% to 20% of the variance in forecasted pleasure. The peak of pleasure explained 21% of the variance in forecasted pleasure, while the peak-end average shared 29% variance with forecasted pleasure. Finally, remembered pleasure explained 38% of the variance in forecasted pleasure, while enjoyment explained 61% of the variance in forecasted pleasure. Overall, these findings are consistent with prior research (Hutchinson et al., 2023; Zenko et al., 2016). Interestingly, forecasted pleasure or anticipated affective states also seem to be predictive of global retrospective evaluations following exercise (Davis & Stenling, 2020).

These data indicate that, as theoretically predicted, the various retrospective evaluations are related but distinct. For example, although correlated [$r_{rm}(61) = 0.51$], remembered pleasure shared approximately 26% of the variance with enjoyment, leaving the majority of variance unique and explained by other factors (perhaps different types of cognitive appraisals, different levels of influence from the exercise experience, etc.). Similarly, remembered pleasure and forecasted pleasure were related [$r_{rm}(62) = 0.62$], sharing more than 38% variance, while leaving the majority of variance unshared. Forecasted pleasure and enjoyment were more strongly related, sharing the majority of variance (61%). Further, compared to enjoyment and forecasted pleasure, remembered pleasure was more strongly related to aspects of the exercise experience such as mean experienced pleasure (32% shared variance), pleasure experienced at the end of exercise (45% shared variance), and the slope of pleasure (36% shared variance). Future investigations should further examine the shared relations and influences of these constructs and determine how these constructs are related to engagement and adherence to exercise programs.

Importantly, the measures of remembered pleasure and forecasted pleasure were distinct. The measure of remembered pleasure consisted of a horizontal visual analog scale, ranging from *most unpleasant imaginable* to *most pleasant imaginable*, and required participants to draw an "x" to indicate their response. The measure of forecasted pleasure was a vertically oriented seven-point scale ranging from *very unpleasant* to *very pleasant*. This suggests that the correlation was not inflated due to common method bias (Podsakoff et al., 2003). It is also possible that the forecasted pleasure would be more strongly related to remembered pleasure, the slope of pleasure, and enjoyment if the response scale was more granular (Pearse et al., 2011). The measure used in the current study was ad-hoc with face validity and intended to be distinct. However, future researchers may consider larger (e.g., 21-point) scales that would allow for greater response variability (Pearse, 2011).

Strengths and Limitations

This study had several strengths. It was a registered report, with the six primary hypotheses, methods, sample size justification, and data analysis plan all specified and peer-reviewed prior to data collection. Data collection took place in a controlled laboratory environment, with consistent timing of measurements across conditions. Valid and reliable measurement approaches were used to assess affective responses during exercise and outcome variables. We also compared three realistic exercise programming options, namely affect-guided interval training (for 20 minutes), high-intensity interval training (for 20 minutes), and self-selected exercise intensity (for 30 minutes). In the HIIT session, intensity was based on peak power output, assessed during the first laboratory visit. In the AIT and SELF sessions, intensity was ultimately decided by the participant, and this allowed us to observe that participants chose moderate-to-vigorous exercise intensities. The novel exercise paradigm introduced here, the AIT, is therefore able to be applied in further research.

On the other hand, this study did include several weaknesses. The sample consisted of students without known health conditions or medical issues. The sample was also fairly young, at 22 years of age, on average. All but five participants were between 18 and 24 years old. Therefore, the generalizability of these findings to other samples may be limited. In addition, the test of peak power output included stages that increased by 20 Watts per minute. This allowed peak power output to only be sensitive to 20-Watt increments (e.g., 130 Watts, 150 Watts, 170 Watts). It is possible that a smaller increment or ramped protocol would allow a more precise estimate of peak power output, and therefore a more precise prescription of intensity for HIIT. It is also possible that intensity was underestimated; peak measured heart rate averaged 89 ± 7% age-predicted maximum heart rate (range: 75% to 99%). It is possible that the cycling modality did not allow participants to achieve their true maximum heart rate. Further, future investigators should consider determining each participant's ventilatory threshold then (a) setting the HIIT intervals in relation to the ventilatory threshold, and (b) comparing the self-selected intensities of AIT and SELF to the ventilatory threshold, given its importance for understanding affective responses to exercise (Ekkekakis et al., 2011).

Further, many analyses were performed and reported in this study. Specifically, this study included six omnibus confirmatory hypothesis tests (Hypotheses 1 through 6), and each had three post-hoc comparisons (AIT vs. HIIT, AIT vs. SELF, HIIT vs. SELF). The power analysis was performed for the repeated-measures design with three within-subject conditions (AIT, HIIT, and SELF) and this analytical approach was applied for each of the six confirmatory hypotheses. To limit the likelihood of a Type 1 error, these analyses were subject to the experiment-wide false discovery rate of 5%. Further, there were 22 correlation analyses performed. Although these correlation analyses were described in the Stage 1 manuscript, these analyses were framed as exploratory. These analyses were also tested using the experiment-wide false discovery rate of 5% to address the multiplicity problem and limit Type 1 error, while preserving statistical power. Despite the efforts to limit Type 1 error rate, we acknowledge that more analyses were performed in this study than the number of participants. Although we intended to achieve adequate statistical power (90%) without exposing an unnecessary number of participants to the risks of exercise, including high-intensity exercise, future studies should examine these outcomes with larger sample sizes. To be conservative, and in response to reviewer comments, we note that applying a Bonferroni correction to all 18 confirmatory post-hoc analyses (rather than 3 at a time following each confirmatory hypothesis) reduces the alpha level for each comparison to .0027 (i.e., .05/18 = .0027). With this new, more conservative approach, AIT was still experienced as more pleasant than HIIT ($p < .001$), resulted in more positive slopes of pleasures than HIIT and SELF ($p < .001$, $p = .002$, respectively), resulted in more remembered pleasure than HIIT and SELF ($ps < .001$), was forecasted as more pleasant than SELF ($p = .002$), and resulted more autonomy than HIIT ($p < .001$). SELF also resulted in greater autonomy than HIIT ($p < .001$). It is important to note for transparency purposes that these additional post-hoc analyses are new to this Stage 2 manuscript, as the original Stage 1 manuscript included the series of within-subject ANOVAs and the false discovery rate of 5%. The original power analysis included an alpha level of .05, not .0027 as reported here.

In addition, there may have been some demand or expectancy effects. In this study, participants in the affect-guided interval training were reminded to choose the highest pleasant intensity and the lowest pleasant intensity. Based on this, it is perhaps not surprising that this condition resulted in more experienced pleasure. There are several potential mechanisms for these findings. Participants may have truly felt more pleasant, perhaps due to greater control and autonomy. It is also possible that they liked switching between different, pleasant intensities, and needed the reminder to emphasize pleasure. It is also possible that participants felt pressured to respond in certain ways. However, the results are not likely fully explained by demand effects. Participants were not prompted to have more remembered pleasure, forecasted pleasure, or enjoyment following the AIT condition, yet these outcomes were also impacted by condition.

We attempted to control for demand effects and biased samples by noting on the informed consent document that the “purposes of this research project are to better understand the psychological and physiological responses of exercise. Ultimately, it is hoped that this project will inform researchers and practitioners of new methods that can promote exercise adherence.” Similarly, recruitment materials mentioned a “research study that will investigate the psychological and physiological effects of exercising”. Therefore, there was no explicit mention of the affective-guided interval training session being favored in our hypotheses. Future investigators should attempt to control for this potential confound more thoroughly by comparing AIT to self-selected interval training without an emphasis on pleasure (e.g., “choose the highest intensity you want; choose the lowest intensity you want”). Researchers could also attempt to understand the mechanisms for these effects by asking participants open-ended questions about their responses and for explanations about their evaluative ratings. Additionally, future investigators should also test whether people adhere to programming based on AIT more than HIIT or traditional exercise prescriptions (e.g., “moderate-to-vigorous intensities”). Using outcomes that do not rely on self-report, such as device-based assessment, would minimize any potential demand effects. After all, adherence to lifelong physical activity is the variable of primary interest.

A final limitation was that SELF was anticipated to result in lower exercise intensity than HIIT, because it was 50% longer. Although it did result in lower exercise intensity, the overall intensity was still vigorous. Therefore, the differences observed between SELF and AIT may diminish if lower intensities (e.g., moderate) or more comparable durations (e.g., 20 minutes) are used.

Conclusions

This study demonstrated that AIT resulted in a moderate-to-vigorous exercise for 20 minutes, with vigorous intensity overall. The AIT session was experienced as more pleasant, remembered as more pleasant, forecasted to be more pleasant if repeated again, and perceived as more enjoyable than HIIT and SELF conditions. Perceived autonomy was higher following both SELF and AIT compared to HIIT. Characteristics of the exercise session, including average level of pleasure, pleasure at the final moment of the exercise experience, and the slope of pleasure meaningfully predicted remembered pleasure. These data suggest that AIT is a feasible alternative to HIIT and SELF and may be useful to enhancing the experience of – and ultimately adherence to – regular exercise behavior. Future research should investigate the effects of using AIT in a longitudinal study to determine long-term effects on exercise behavior.

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