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Research article

Does Exercise Modality Matter Affectively? Contrasting Type and Sequence of Moderate-Intensity Continuous Training Versus High-Intensity Interval Training in a Randomized Within-Subject Study

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Abstract

Over the past two decades, affective determinants of exercise behavior have received increasing attention in research on health promotion and prevention. To date, however, little is known about changes in affective exercise determinants during multi-week training programs in insufficiently active individuals. This applies in particular to the currently discussed advantages and disadvantages of high-intensity interval training (HIIT) compared with moderate-intensity continuous training (MICT) with regard to the affective experience of these two training types (e.g., reduced monotony vs. more aversive response during HIIT), which is important for exercise adherence. Referring to the Affect and Health Behavior Framework (AHBF), this within-subject study investigated changes in affective exercise determinants as a function of training type and sequence consisting of MICT and HIIT. Forty insufficiently active healthy adults (M_{age} = 27 ± 6 years; 72% women) underwent two 6-week training periods in a randomized sequence (MICT - HIIT vs. HIIT - MICT) within 15 weeks. Pre-post questionnaires and in-situ measurements, during and after a standardized vigorous-intensity continuous exercise session (VICE), were used to assess affective attitude, intrinsic motivation, in-task affective valence, as well as post-exercise enjoyment. These four affect-related constructs were collected before, between, and after the two training periods. Mixed models revealed a significant effect for training sequence (p = 0.011) - but not for training type (p = 0.045; non-significant after Bonferroni alpha adjustment) - on changes in in-task affective valence in favor of the MICT - HIIT sequence. Moreover, no significant training type or sequence effects were found for the constructs of reflective processing: exercise enjoyment, affective attitude, and intrinsic motivation. Therefore, individual-based training recommendations should consider the effects of variety and training sequence to develop tailored interventions that lead to more positive affective experiences - in particular during exercise - and promote the maintenance of exercise behavior in previously inactive individuals.

Key words: Physical inactivity, exercise intensity, affect, enjoyment, intrinsic motivation.

Introduction

There is strong evidence that regular participation in exercise improves mental and physical health and reduces the risk for non-communicable diseases and all-cause mortality (Warburton and Bredin, 2017). Despite these benefits, high rates of physical inactivity can be observed in Western countries (Guthold et al., 2018). Therefore, from a public health perspective, the identification of determinants of exercise initiation and maintenance is of major importance in order to guide theoretically founded interventions. In this regard, affective determinants of exercise behavior (e.g., acute affective response to exercise, exercise enjoyment, affective attitude towards or intrinsic motivation for exercise) are receiving increasing attention in exercise science (e.g., Williams and Evans, 2014; Conner et al., 2015; Rhodes and Kates, 2015; Williams et al., 2018; Ekkekakis and Brand, 2019; Stevens et al., 2020). A leading conceptual framework for this area of research is provided by the dual-mode theory (DMT; Ekkekakis, 2003), according to which the acute affective response to exercise is differentially influenced by cognitive factors and interoceptive stimuli as a function of exercise intensity (Ekkekakis and Acevedo, 2006). Building on this, the Affective-Reflective Theory (ART; Brand and Ekkekakis, 2018) postulates that a combination of both the automatic affective valuation (type-1 process) and the reflective evaluation (type-2 process) of exercise are decisive for whether an individual either remains in a state of physical inactivity or initiates and maintains exercise.

Against this background, a controversial discussion has taken place concerning the public health potential of high-intensity interval exercise (HIIE) compared with moderate-intensity continuous exercise (MICE) (Biddle and Batterham, 2015). On the one hand, following the tenets of DMT, negative affective responses to high-intensity exercise are emphasized, especially for inactive individuals, which is assumed to limit the successful adoption and maintenance of regular exercise behavior (e.g., Ekkekakis et al., 2005, 2011; Hardcastle et al., 2014; Chu et al., 2021). On the other hand, the benefits of reduced monotony, perceived time-efficiency, and higher subjectively experienced effectiveness of training are highlighted, which can be associated with a more positive reflective evaluation such as positive feelings of pride and accomplishment after completion (e.g., Jung et al., 2014; Gropper et al., 2021; Tavares et al., 2021).

The apparent inconsistency regarding affective response to interval in comparison with continuous

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exercise may be explained by several methodological differences between the studies published to date. These include, among others, participant characteristics (e.g., younger/older, active/inactive, healthy/unhealthy), exercise protocol variables (e.g., work-to-rest ratio, total session duration, and energy expenditure), and the determination of exercise intensities with or without reference to a physiological framework (Decker and Ekkekakis, 2017). Furthermore, building on an increasing number of studies comparing MICE and HIIE, meta-analytical findings suggest that the results of comparisons between the two kinds of exercise modalities also differs depending on the affective measure studied. Existing evidence indicates that compared with MICE, HIIE is associated with more negative acute affective responses and is experienced as less pleasurable but is reported post-exercise to be more enjoyable (Stork et al., 2017; Oliveira et al., 2018; Niven et al., 2021; Tavares et al., 2021). However, based on between-group comparisons, most studies analyzed the acute effects of single MICE and HIIE sessions on affective and enjoyment responses. Therefore, little is known about changes of various affective exercise determinants over multiple exercise sessions (Tavares et al., 2021). Moreover, given the lack of evidence, exercise prescriptions can hardly refer to findings regarding intra-individual comparisons of the two exercise modalities within a structured multi-week training program (i.e., moderate-intensity continuous training [MICT] vs. high-intensity interval training [HIIT]). Considering that both the subjective experience and the reflective evaluation of different exercise regimens take place against the background of individuals' previous exercise experiences and that contrasting different exercise modalities might be crucial for changes of affective exercise determinants (Gropper et al., 2021), studying intra-individual comparisons becomes particularly important.

Thus, the aim of the present within-subject study was to investigate changes in various affective determinants of exercise behavior in insufficiently active individuals depending on the type and sequence of training modes. Hereby, we compared different sequential arrangements of two different exercise protocols (MICT - HIIT vs. HIIT - MICT) in the context of a structured multi-week training program.

Affective determinants of exercise behavior

Following the Affect and Health Behavior Framework (AHBF; Williams and Evans, 2014; Williams et al., 2019; Stevens et al., 2020), the consequences of exercise training on affective determinants of exercise behavior can be divided into the following three categories: (1) *affective response*, which refers to how one feels while performing or immediately after completing the exercise (e.g., core affect [valence and arousal]); (2) *affect processing*, which encompasses cognitive processing of previous or anticipated affective responses to exercise, in the form of automatic (e.g., affective association and implicit attitude) or reflective processing (e.g., affective judgments [affective attitude, exercise enjoyment]); and (3) *affectively charged motivation*, which is a motivational state that includes and/or has a basis in past affective responses to exercise, arising from automatic (e.g., hedonic motivation) as well as reflective (e.g., intrinsic motivation) processing pathways.

In the few previously published studies on affect-related responses to MICT compared with HIIT within a multi-week training program, exercise enjoyment (the second category) has been the most studied affective determinant to date (Heisz et al., 2016; Kong et al., 2016; Vella et al., 2017; Santos et al., 2021). Less frequently, constructs from different categories of the AHBF have been considered in combination. These studies examined changes in affective valence and intrinsic motivation (Gerber et al., 2018) or affective valence, exercise enjoyment, and affective attitude (Santos et al., 2021) in response to MICT versus HIIT.

Empirical evidence on changes in affective exercise determinants

Regarding *affective attitude* (the second category of the AHBF) the study by Santos et al. (2021) showed a constant pattern of positive change over a 2-week intervention, with participants in MICT reporting a more positive affective attitude than participants in HIIT throughout. With regard to *affectively charged motivation* (the third category of the AHBF), Thøgersen-Ntoumani et al. (2016) showed that *intrinsic motivation* for HIIT and MICT was positively linked to adherence but did not differ between training types in the middle of a 10-week program. Confirmatory evidence is provided by the study of Gerber et al. (2018), in which intrinsic motivation increased significantly from baseline to post-intervention within a 4-week period of either a sprint interval training (SIT) as a specific mode of HIIT, or a time-adjusted MICT without group difference.

In addition to repeated measurements of affective determinants through the application of multi-item questionnaires before, during, or after the intervention period, some studies repeatedly conducted in-situ measurements during and directly after exercise sessions to examine changes in task-related responses over the weeks. Based on the preliminary evidence, HIIT seems to result in greater (Heisz et al., 2016; Kong et al., 2016) or at least similar (Vella et al., 2017; Santos et al., 2021) *exercise enjoyment* (second category of the AHBF) compared with MICT. Moreover, different patterns of change emerged over the course of multi-week training programs. While two studies showed no difference between MICT and HIIT due to a constantly high level (Vella et al., 2017; 8 weeks) or an equally increasing level of exercise enjoyment (Santos et al., 2021; 2 weeks), two other studies found a difference in favor of HIIT due to a constant higher level (Kong et al., 2016; 5 weeks) or a progressive increase in exercise enjoyment over the weeks (Heisz et al., 2016; 6 weeks). Only one of these studies (Santos et al., 2021) and one additional study (Gerber et al., 2018) examined *in-task affective valence* (first category of AHBF). Santos et al. (2021) observed significantly lower peak negative values during exercise in HIIT compared with MICT across all three weeks with no significant change from the first to the last week of the intervention. Gerber et al. (2018) found no difference in affective valence during exercise between the MICT and HIIT groups across all weeks, but a significant decrease from the first to the last week of the intervention in both groups. However, in both studies, no interaction effect (time *x* training type) was observed, suggesting a similar pattern of change for both training conditions.

The preliminary evidence on changes in affect-related exercise determinants in response to a multi-week MICT or HIIT program reveals partly mixed results, with studies showing either no difference or favoring results for one type of training or the other. Importantly, this inconsistency in the findings - in addition to the methodological issues mentioned above - appears to be driven by the particular construct being studied and the survey method used for this purpose (pre-post questionnaires vs. in-situ measurements). Furthermore, the state of research leaves open whether the order of experiencing the two different exercise modalities matters for changes in affective exercise determinants.

Study rationale

This study aims to investigate training type- and sequence-dependent changes in different affect-related exercise determinants over a multi-week training program in insufficiently active adults. On this basis, the study can potentially generate evidence for the influence of different exercise modalities on affective determinants and thus on the maintenance of exercise behavior. Referring to the AHBF (Williams and Evans, 2014; Stevens et al., 2020), we examined three exercise-related categories of affective determinants: affective response to exercise, affect processing, and affectively charged motivation. Following the identified research gap, we first compared responses before and after a training period of either MICT or HIIT. Considering that previous exercise experiences of individuals influence their subjective experience as well as their reflective evaluation of different exercise regimens, in a second step we investigated the influence of the training sequence on changes in affective exercise determinants to contrast the two training types in an intra-individual comparison. For this purpose, the training program was switched following the first training period, resulting in two training sequences with reversed orders of training types (i.e., MICT - HIIT vs. HIIT - MICT).

In order to capture changes in affect-related exercise determinants over the intervention period, we used the classical approach of pre-post questionnaires particularly for *affective attitude* and *intrinsic motivation*. Additionally, we applied an innovative approach to compare changes in affective response to exercise in a more general manner and independent of the training regimen itself. Thus, the rationale was to go beyond task-specific responses to specific sessions with different exercise protocols (MICT/HIIT) by repeatedly recording changes in affective response to a standardized exercise session, which differs from the two types of training. For this purpose, we conducted in-situ measurements of *affective valence* and e*xercise enjoyment* during and after a standardized vigorous-intensity continuous exercise session (VICE), respectively. This exercise intensity was chosen because the greatest variability in affect-related responses has been observed in this vigorous domain, especially in insufficiently active individuals (Ekkekakis et al., 2005, 2011).

Based on the preliminary evidence presented above (Thøgersen-Ntoumani et al., 2016; Gerber et al., 2018; Santos et al., 2021), we hypothesized that participants' *affective attitude* and *affectively charged motivational responses* will show a similar pattern of positive change after the first period of HIIT or MICT. Regarding *affective and enjoyment responses* to exercise training programs, evidence indicates that compared with MICT, HIIT is experienced as less pleasurable but is reported post-exercise to be more enjoyable (Heisz et al., 2016; Kong et al., 2016; Vella et al., 2017; Gerber et al., 2018; Santos et al., 2021). However, to our knowledge, there have been no studies to date that have examined the change of in-task affect-related responses to a standardized VICE session as a result of different types of training. Therefore, the transferability of these findings to changes in a within-subject comparison with different training sequences (MICT - HIIT vs. HIIT - MICT) was investigated on an exploratory basis.

Methods

Study design

This study was part of the "Individual Response to Physical Activity" (iReAct) project, which is an interdisciplinary research network that investigates physiological and psychological responses to exercise at the individual level. The study protocol was approved by the Ethics Committee of the Medical Faculty, University of Tübingen (# 882/2017BO1). Information pertaining the current study is presented below. Further details on the registered trial (German Clinical Trials Register, # DRKS00017446) can be found elsewhere (Thiel et al., 2020).

The study used a 15-week, two-period sequential training intervention design in order to compare adaptive responses to two types of endurance training (MICT vs. HIIT) and their different sequential order (MICT - HIIT vs. HIIT - MICT). This means that participants started with either MICT or HIIT and then switched respectively to HIIT or MICT. The training programs were designed for a duration of six weeks each, so that – on the one side – physiological adaptations could occur. On the other side and from the psychological point of view of this study, this training period allows to study changes in affective exercise determinants based on subjective experiences and evaluations of the training program. In contrast to the wash-out period in clinical trials (e.g., Lim and In, 2021), we deliberately opted for a continuous sequence to allow evaluation of the training experience in direct comparison (i.e., within-person differences). After a baseline assessment, participants were randomly assigned to either the MICT - HIIT or the HIIT - MICT group. Randomization was computer-generated (nQuery 7.0) with a 1:1 allocation ratio to each sequence using mixed block sizes and two binary stratification factors: sex and maximal oxygen uptake ($\dot{V}O_2$max).

For the purpose of this paper, we focused on changes in affect-related exercise determinants, which were collected in comprehensive assessments at baseline, between

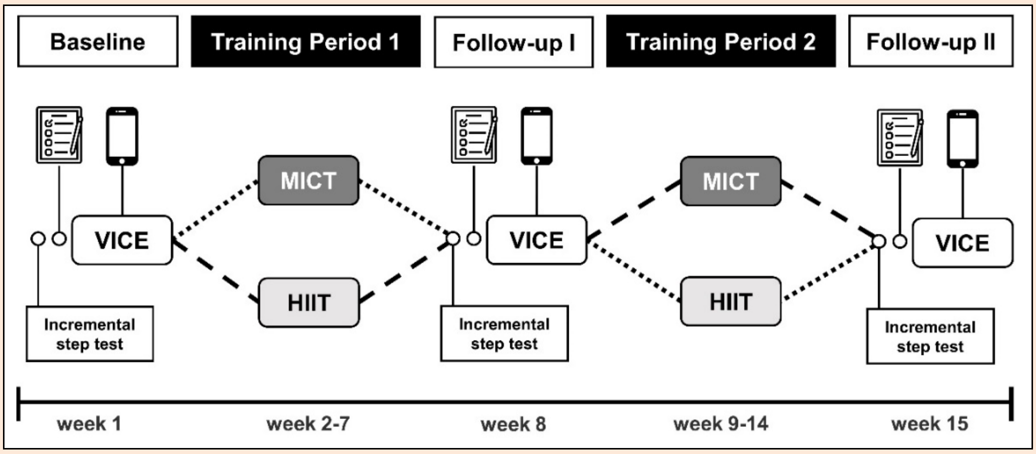

Figure 1. Overview of the within-subject design. Participants underwent two training periods, starting with either high-intensity interval training (HIIT) or moderate-intensity continuous training (MICT) and switched groups for the second period. This results in two sequences: MICT–HIIT (dotted line) and HIIT–MICT (dashed line). Comprehensive assessments were conducted at baseline, follow-up I, and follow-up II, including an incremental step test, paper-pencil questionnaires, and in-situ assessments via smartphone during a standardized vigorous-intensity continuous exercise (VICE) session.

the two training periods (follow-up I), and after the completion of the second training period (follow-up II). A detailed overview of the within-subject design can be found in Figure 1.

Recruitment and eligibility

Participants (men and women between 20 and 40 years of age) were recruited in six consecutive waves over a 2-year period (March 2018 to March 2020), primarily using the University of Tübingen and the University Hospital of Tübingen mailing lists. Interested individuals were asked to fill out the validated German version of the European Health Interview Survey - Physical Activity Questionnaire (EHIS - PAQ; Finger et al., 2015) to assess their physical activity levels. For participation in the study, participants had to be insufficiently active at the time of recruitment that is, not meeting the World Health Organization recommendations for moderate physical activity of at least 150 minutes per week. In addition, participants had to report less than 60 minutes per week of leisure-time exercise (including sports participation, aerobic activities, muscle strengthening) and no regular exercise engagement during the last six months.

To ensure that participants could complete the assessments and training intervention without risk and to avoid large heterogeneity in view of specific diseases or medication (e.g., severe previous illness), we opted for inactive, but healthy adults. For detailed inclusion and exclusion criteria, please refer to the study protocol (Thiel et al., 2020). Eligibility was checked during a telephone screening, as well as a medical screening prior to final enrollment in the study. Participants were provided with detailed information regarding the study procedure and associated risks prior to giving written informed consent.

Sample size

The original power calculation for the whole interdisciplinary research project is described in the study protocol (Thiel et al., 2020) and was based on the primary endpoint regarding physiological adaptations ($\dot{V}O_2max$). The targeted sample size was 60 subjects considering two degrees of freedom spent on the strata age and sex, resulting in effect sizes (difference of means divided by standard deviation) of 74.9% (type 1 error 0.05, two-sided, power 0.8, nQuery 7.0). As the calculated sample size was not reached, we further discuss this issue with respect to the present part of the study in the limitations section.

Measures

Questionnaires

Affective attitude. To measure affective attitude toward exercise, we applied a questionnaire developed by Crites et al. (1994), whose German-language version was validated by Brand (2006). This instrument comprises four items based on the phrase "When I think about exercising, I feel…" Answers follow semantic differentials on a bipolar rating scale ranging from 1 (not relaxed/ not satisfied/ not happy/ not uncomfortable) to 7 (extremely relaxed/ extremely satisfied/ extremely happy/ extremely uncomfortable). The internal consistency of the items was acceptable (Cronbach's $\alpha = .76$), after previously reversing the fourth item (uncomfortable). Thus, the mean of the four items was used as the individuals' affective attitude.

Intrinsic motivation. We used a validated German-language instrument for measuring the self-concordance of sport- and exercise-related goals (SSK-Scale; Seelig and Fuchs, 2006), considering only the 3-item subscale for the intrinsic mode of motivation as an indicator of affectively charged motivation. The internal consistency of this scale was good (Cronbach's $\alpha = .89$), so we used the mean of the three items as the individuals' intrinsic motivation.

In-situ assessments

In-task affective valence. Core affective valence was measured every ten minutes during the standardized VICE session using the validated German version of the Feeling Scale (FS; Hardy and Rejeski, 1989; Maibach et al., 2020). The FS is a single-item, 11-point bipolar rating scale, ranging from -5 (very bad) through 0 (neutral) to +5 (very good) developed for the assessment of affective response along a displeasure-pleasure continuum. The in-task value was calculated as the average FS-rating between minute 20 and minute 50. The first FS-rating after minute 10 was not considered, since warm-up did not represent the targeted exercise at vigorous intensity.

Post-exercise enjoyment. Exercise enjoyment was assessed right after termination of the standardized VICE session. Referring to the single-item exercise enjoyment scale (EES; Stanley and Cumming, 2010), participants were asked to indicate how much they enjoyed the exercise session. Answers could be given on an analogue scale ranging from not at all (0) through neutral (50) to very much (100).

Study procedures

Standardization of exercise intensity

In laboratory visits at baseline, follow-up I, and follow-up II (see Figure 1), participants undertook an incremental step test to volitional exhaustion on a cycle ergometer (Ergoselect 200; Ergoline GmbH, Bitz, Germany) for determination of the $\dot{V}O_2max$, peak power output (PO_{peak}), and lactate thresholds (first lactate turning point [LTP1] and second lactate turning point [LTP2]). The test began with a 2-min resting period on the bike, followed by 25-watt (W) step increments every three minutes, starting at 50 W for males and at 25 W for females, until task failure. Capillary blood lactate concentration ([La−]) was analyzed (Biosen S-Line; EKF, Cardiff, UK) by collecting capillary blood samples (20 µL) from the right earlobe before starting the test, during the last 20 seconds of each stage, and immediately after volitional exhaustion. Heart rate (HR) and electrocardiogram (ECG) were constantly monitored throughout the test (12-channel PC ECG; custo med GmbH, Ottobrunn, Germany). Breath-by-breath pulmonary gas exchange and ventilation ($\dot{V}E$) were measured using a metabolic cart (MetaLyzer; CORTEX Biophysics, Leipzig, Germany). Further details on the laboratory setup and data processing can be found elsewhere (Mattioni Maturana et al., 2021).

Exercise training intervention

Over a period of 15 weeks, participants underwent two training periods, starting with either HIIT or MICT and switching groups for the second period (see Figure 1). Each training period lasted six weeks and consisted of three weekly training sessions (on average). Minimum adherence was set at 15 out of 18 prescribed sessions in each training period. The training programs were designed with the goal that both exercise interventions would be matched for energy expenditure (Andreato, 2020).

Exercise protocols. MICT was prescribed as 60 minutes of continuous cycling at the power output (PO) corresponding to 90% of LTP1. Such exercise intensity was prescribed for participants to cycle within the moderate-intensity domain (Binder et al. 2008; Hofmann and Tschakert, 2017). HIIT started with a 10-min warm-up at a PO corresponding to 70% of HR_{max}, followed by 4x4-min intervals at a PO corresponding to 90% HR_{max} with a 4-min active resting period at 30 W between each interval. After the last interval, a 5-min cool-down period was performed at 30 W, totalizing 43 minutes of exercise. Such exercise intensities were chosen to ensure that participants would be within the severe-intensity domain during the load intervals (i.e., all the exercise intensities were above LTP2), allowing participants to reach 70% HR_{max} during the recovery periods.

Training monitoring. All exercise sessions were performed on calibrated cycle ergometers (ec5000; custo med GmbH, Ottobrunn, Germany) and supervised by trained personnel. During every session, participants' HR and ECG were constantly monitored (3-channel ECG; custo med GmbH, Ottobrunn, Germany) to control for default training intensity and adjust for fitness changes over the weeks. After every training session, the exercise training data (i.e., second-by-second power output, cadence, and HR) were exported and stored for further processing (for details, see Mattioni Maturana et al., 2021).

Affect-related assessments

Participants underwent three assessment phases (at baseline, follow-up I, and follow-up II; see Figure 1) during which they were asked to complete a paper-pencil questionnaire on affective determinants of exercise behavior. Moreover, participants performed a 60-min standardized VICE session on a calibrated cycle ergometer (Ergoselect 200; Ergoline GmbH, Bitz, Germany), with the following exercise intensity values based on the incremental step test performed at each assessment phase: After a 10-min warm-up at a PO corresponding to 90% of LTP1, participants cycled at a constant PO corresponding to the midpoint between LTP1 and LTP2 (i.e., vigorous-intensity domain) for 50 minutes. During the VICE session, in-situ assessments were performed to delineate affect-related responses to acute exercise. Participants' responses were recorded via smartphone (Google Nexus 5; LG Group, Seoul, South Korea) with the movisensXS application (movisens GmbH, Karlsruhe, Germany). During exercise, A3 posters were used as visual reference and participants' responses were recorded by the investigator so that the participants could concentrate on the exercise itself. The post-exercise survey was conducted independently by the participants with smartphone in hand.

Statistical analyses

Descriptive statistics were generated and intraclass correlation coefficients (ICCs) were calculated for the outcome measures. Furthermore, estimates of the within-person variability across the three standardized VICE sessions as well as the between-person variability in the affect-related outcomes were calculated. For the trajectory analysis across the training program, violin plots were created for each outcome based on the derived type- and sequence-descriptive statistics (see Supplementary Table 1). Effect sizes (d) and confidence intervals (95% CI) were calculated for repeated measures within training groups (baseline vs. follow-up I; follow-up I vs. follow-up II) or sequences (baseline vs. follow-up II) (Morris and DeShon, 2002; see Supplementary Table 2). Following the conventions suggested by Cohen (1988), effect sizes were interpreted as small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$). Reported were those changes in affective determinants whose 95% CI do not contain zero.

We fitted a mixed model for repeated measures with the three levels group sequence (MICT - HIIT vs. HIIT - MICT), subject (ID), and session (follow-up I and follow-up II), including the fixed effects training type (MICT vs. HIIT), training period (period 1 vs. 2), and training sequence according to a 2x2 cross-over design and a random intercept on the subject level. Models were calculated separately for each of the four affect-related constructs (Model AA: affective attitude, Model IM: intrinsic motivation, Model AV: affective valence, and Model EE: exercise enjoyment) as dependent variables. The respective baseline value was included in the model as a covariate. Due to low numbers of units on the subject level, simple covariance structures (scaled identity) had to be chosen to reach convergence in all the models. Following the study protocol, a modified intention-to-treat (ITT) population was used: Subjects who did not contribute outcome measurements for either of the two periods were excluded. For subjects who contributed data for at least one period, multiple imputation (MI) was applied under the assumption of a missing-at-random (MAR) mechanism. As our data were approximately normal, we applied the Amelia package for longitudinal imputations under the use of the expectation-maximization (EM) algorithm generating m = 25 sets (Honaker et al., 2011).

Although all convergence criteria were fulfilled, we faced non-positive-definite hessian matrices on some of the MI datasets for one of the outcomes (affective valence). Despite choosing a simple covariance structure and increasing the number of step-halvings or the number of Fisher scoring steps, we could not resolve this problem and therefore applied a sensitivity analysis running the model on the reduced number of MI sets with valid hessians only (m = 18).

All analyses were conducted with R (R version 4.1.1 and RStudio 1.4.1717, PBC, Boston, MA, USA) and SPSS (Version 26, IBM Corp, Armonk, NY, USA). Given the four affective outcome measures, we set the significance level of $\alpha = 0.0125$ to adjust for multiple testing using the Bonferroni correction to control for the family-wise error rate.

Results

Participants

Data were analyzed from 40 previously insufficiently active healthy adults (72% female) aged between 20 and 40 years (M = 27, SD = 6). An overview of participants' demographic, anthropometric, and physical activity characteristics at baseline can be found in Table 1. A total of 58 participants were assessed for eligibility, 49 of which were included in the randomization process and nine of which were excluded during medical screening (Consort Flow Diagram, Figure 2). During the baseline assessment, five participants dropped out for different reasons. Two other participants did not complete the first training period due to illness and thus inability to complete the minimum adherence. The nine participants of the last recruitment wave (MICT - HIIT group: n = 5; HIIT - MICT group: n = 4) had to terminate the second training period due to COVID-19 restrictions but were still included in the intention-to-treat analysis (for missing values, see Table 2). Two non-native speakers included in deviation from the study protocol were subsequently excluded from this data analysis because comprehension of the questionnaires could not be guaranteed.

Descriptive analyses

Descriptive between-person and within-person statistics of the study variables can be found in Table 2. The grand mean of each outcome was in the upper half of the respective scale. The empirical range of person means varied from 2.50 to 6.92 for affective attitude, from 1.67 to 5.67 for intrinsic motivation, from -1.58 to 3.92 for affective valence, and from 11.67 to 83.50 for exercise enjoyment, indicating substantial between-person variability. The ICCs indicated that in affective attitude and intrinsic motivation 76% of the total variance referred to between-person differences, while in affective valence and exercise enjoyment 50% or 56% could be attributed to within-person differences with a range of 0.00 to 3.54 or 1.41 to 38.21. Thus, it can be noted that the between-person stability is higher for the questionnaire data than for the in-situ measurements.

Table 1. Demographic, anthropometric, and physical activity characteristics of participants (N = 40) at baseline.

Characteristic	M ± SD	Range
Age (years)	27 ± 6	20 - 40
Gender (female / male)	40[a]	29 (72%)[b] / 11 (28%)[c]
Height (cm)	171.2 ± 9.1	155.0 - 190.0
Weight (kg)	69.4 ± 11.1	45.0 - 101.4
BMI ($kg \cdot m^{-2}$)	23.6 ± 2.6	17.6 - 30.3
HEPA index (min/week)	36.1 ± 40.5	0.0 - 140.0
$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	31.4 ± 4.2	24.2 - 41.4
HR_{max} ($b \cdot min^{-1}$)	191 ± 11	168 - 207
PO_{peak} (W)	162 ± 26	112 - 217
LTP1 (W)	68 ± 18	35 - 116
LTP2 (W)	122 ± 22	75 - 171

BMI = body mass index, HEPA = health enhancing physical activity of at least moderate intensity (derived from EHIS–PAQ; Finger et al., 2015), $\dot{V}O_2max$ = maximal oxygen uptake, HR_{max} = maximal heart rate, PO_{peak} = peak power output, LTP1 = first lactate turning point, and LTP2 = second lactate turning point. [a] Total number of participants. [b] Number (percentage) of females. [c] Number (percentage) of males.

Table 2. Descriptive statistics for the main study variables.

Variable	Between-person variability					Within-person variability			
	ICC	N	M	SD	Range	n	mV	SD	Range
Affective Attitude [1-7]	.76	40	5.26	1.03	2.50 - 6.92	117	3	0.44	0.00 - 1.28
Intrinsic Motivation [1-6]	.76	40	3.96	0.97	1.67 - 5.67	117	3	0.42	0.19 - 1.50
Affective Valence [-5-+5]	.50	40	1.95	1.47	-1.58 - 3.92	111	9	1.00	0.00 - 3.54
Exercise Enjoyment [0-100]	.44	40	52.18	18.78	11.67 - 83.50	111	9	14.06	1.41 - 38.21

ICC = intraclass correlation coefficient, N = number of participants, n = number of data points (measured at baseline, follow-up I, and follow-up II), mV = missing values due to COVID-19 restrictions.

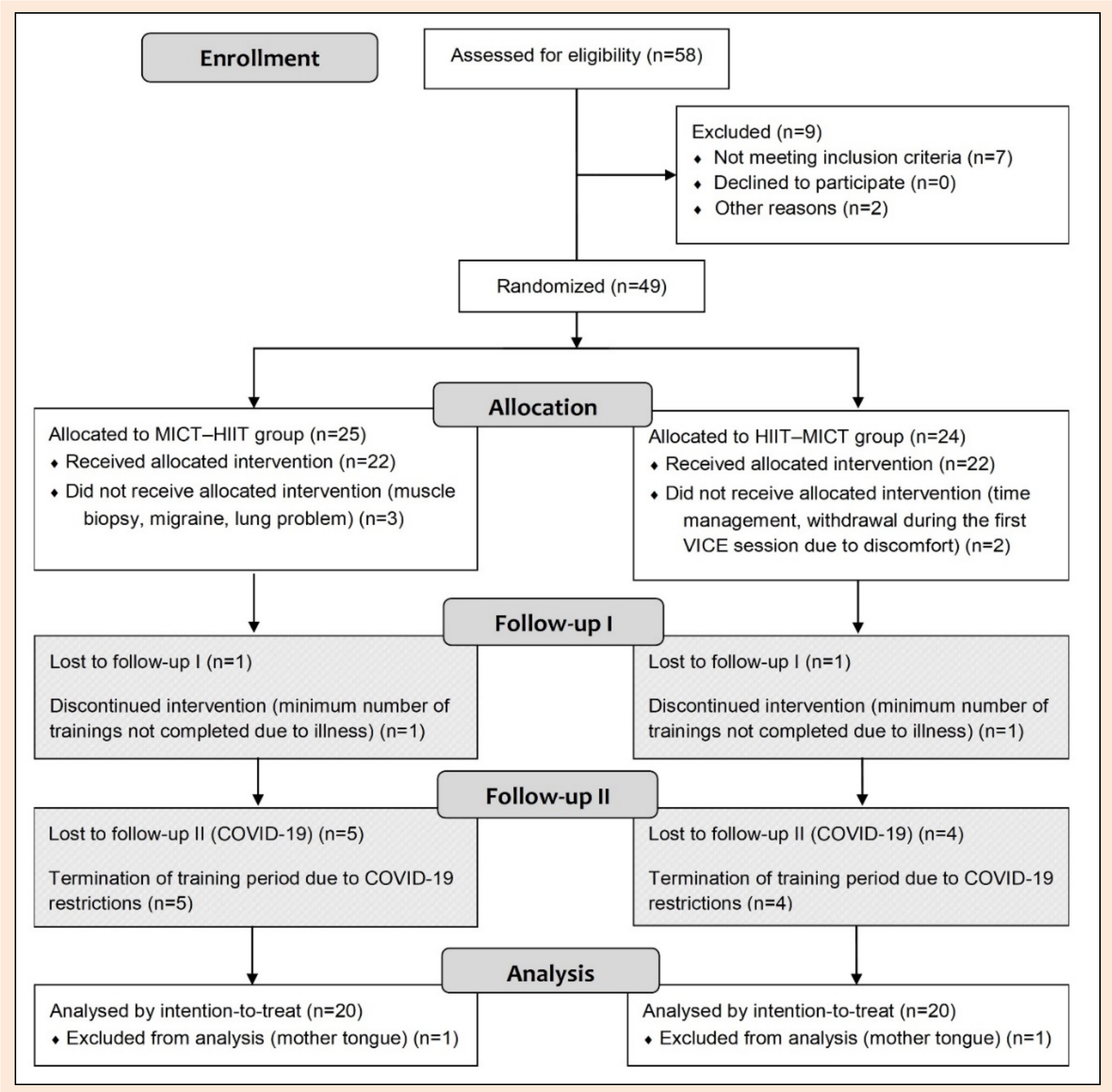

Figure 2. **CONSORT Flow diagram of the iReAct study.**

Table 3. **Associations of training type, period, and sequence with affective exercise determinants.**

	MODEL AA: AFFECTIVE ATTITUDE			MODEL IM: INTRINSIC MOTIVATION			MODEL AV: AFFECTIVE VALENCE			MODEL EE: EXERCISE ENJOYMENT		
FIXED EFFECT	B	SE	p	B	SE	p	B	SE	p	B	SE	p
Training Type (MICT VS. HIIT)	-0.001	0.157	.994	-0.072	0.165	.663	-0.664	0.331	.045	-4.684	4.263	.272
Training Period (FOLLOW-UP I VS. II)	-0.093	0.162	.566	-0.108	0.163	.506	0.109	0.337	.746	0.938	4.468	.834
Training Sequence (MICT–HIIT VS. HIIT–MICT)	0.464	0.225	.837	0.123	0.228	.590	0.923	0.360	.011*	6.254	5.341	.242

Estimates based on fixed effects. * indicates a significant influence of training sequence on affective valence ($p < .0125$, Bonferroni-adjusted). In each of the four mixed models, we controlled for the baseline value of the respective dependent variable.

Main Analyses

For the two questionnaire measures, there were somewhat different trajectories over time with respect to training types and sequences. A moderate increase in mean affective attitude from baseline to follow-up II was observed for both training sequences ($d_{MICT - HIIT} = 0.52$, 95% CI: 0.08 – 1.34; $d_{HIIT - MICT} = 0.70$, 95% CI: 0.69 - 1.97) with somewhat higher values in the MICT - HIIT group (Figure 3A). In the HIIT - MICT group, a moderate increase was already observed after the first period of HIIT (d = 0.50, 95% CI: 0.55 - 1.84), followed by a small increase after the second period of MICT (d = 0.34, 95% CI: 0.07 - 1.35). However, Model AA revealed no significant fixed effect for training type (T = -0.01, p = 0.994), training period (T = -0.58, p = 0.566), or training sequence (T = 0.21, p = 0.837) on affective attitude measures (see Table 3). With regard to mean intrinsic motivation, no substantial changes could be observed for both training sequences (Figure 3B). Accordingly, Model IM revealed no significant fixed effect for training type (T = -0.44, p = 0.663), training period (T =

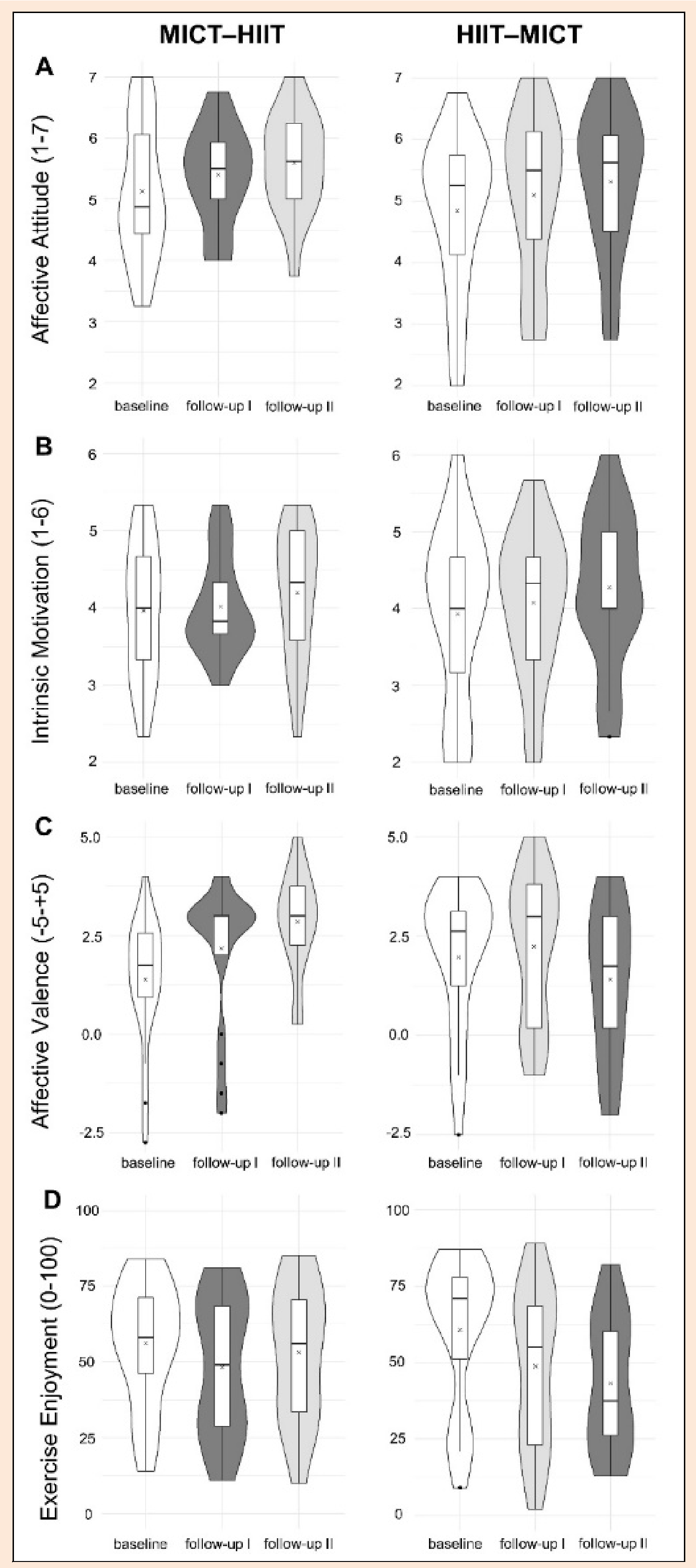

Figure 3. Violin plots (mirrored estimated kernel density plot on each side of the boxplot, tails are trimmed to the range of the data) to visualize the distribution of affective exercise determinants depending on the type of intervention and treatment sequence. Assessments took place at baseline (white plot: without previous training), at follow-up I and follow-up II (light grey plot: after HIIT; dark grey plot: after MICT). The corresponding descriptive statistics are provided in *Supplementary Table 1*.

-0.67, p = 0.506), or training sequence (T = 0.54, p = 0.590) on individuals' intrinsic motivation (see Table 3).

For the in-situ measurements, there were different changes in affect measures between the training sequence groups. In the MICT - HIIT group, mean affective valence - assessed during VICE - showed a moderate to large increase from baseline to follow-up I (d = 0.61, 95% CI: 0.09 - 1.36) and follow-up II (d = 0.91, 95% CI: 0.26 - 1.76). In contrast, no substantial changes could be observed in the HIIT - MICT group (Figure 3C). Conformingly, Model AV revealed a significant fixed effect for training sequence (T = 2.56, p = 0.011) on affective valence (see Table 3). However, the fixed effect for training type (T = -2.00, p = 0.045) missed the significance level (α = .0125). Mean exercise enjoyment assessed right after termination of VICE - showed no substantial changes from baseline to follow-up I for both training sequences. In contrast, enjoyment values in the HIIT - MICT group decreased to a large extent from baseline to follow-up II (d = -0.90, 95% CI: -1.93 - -0.47) (Figure 3D). However, Model EE revealed no significant fixed effect for training type (T = -1.10, p = 0.272), training period (T = 0.21, p = 0.834), or training sequence (T = 1.17, p = 0.242) on exercise enjoyment (see Table 3).

Discussion

The aim of this within-subject study was to investigate type- and sequence-dependent changes in four different affective exercise determinants in insufficiently active adults over a structured multi-week training period. By comparing two different types and sequences of training (MICT - HIIT vs. HIIT - MICT), we examined whether the general evaluation of exercise or attitudes toward it changed as a result of the training intervention. Essentially, it can be stated that for *in-task affective valence* (first category of the AHBF), a significant effect of training sequence, in favor of the MICT - HIIT sequence, but not of training type was observed. Moreover, no significant training type or sequence effects were found for the constructs of reflective processing examined here: *exercise enjoyment*, *affective attitude*, and *intrinsic motivation* (second and third categories of the AHBF; Williams and Evans, 2014).

Confirming our hypothesis and previous evidence using pre-post questionnaires (Thøgersen - Ntoumani et al., 2016; Gerber et al., 2018; Santos et al., 2021), *affective attitude* toward exercise showed a comparable moderate positive change after both training sequences. Although after the first 6-week period this positive trend was only observed in the HIIT - MICT group, with a small increase in attitude values after the HIIT period, no effect of training type or sequence on affective attitude improvement was detected. In contrast, *intrinsic motivation* for exercise did not change substantially after the first and second training period in either group. Thus, despite the higher between-person stability in the questionnaire constructs, the endurance-oriented training with three exercise sessions per week resulted in positive change in *affective attitude* towards exercise, which may be beneficial for future exercise behavior, whereas intrinsic motivation showed no sensitivity for change after completing the study's bicycle ergometer training. However, this conclusion should be verified based on further research with, if possible, larger samples.

With respect to the change in affect-related responses to a standardized VICE session using in-situ measurements, the MICT - HIIT sequence was found to be superior to the HIIT - MICT sequence in terms of changes in *in-task affective valence*. While participants in the MICT - HIIT group showed a significant positive increase across both training periods - with a moderate effect after the MICT period and a large effect after the HIIT period - the HIIT - MICT group did not show substantial changes. As regards *post-exercise enjoyment*, no significant training type or sequence effects were observed. However, a large decrease in enjoyment values could be identified when the MICT period in the second half of the sequence followed a HIIT period in the first half of the sequence. Based on this finding and previous evidence, which suggests greater *exercise enjoyment* after HIIT itself than after MICT itself (Heisz et al., 2016; Kong et al., 2016), an unfavorable effect of the HIIT - MICT sequence on enjoyment of subsequent exercise can be hypothesized. As strenuous intensities can occur in training situations despite predominant recommendations for moderate exercise intensities especially in less structured exercise programs or self-directed physical exercises a HIIT period within a training sequence may have the advantage that such activities in the vigorous domain subsequently elicit less aversion or may be experienced with a more positive affective response, potentially favoring future exercise behaviors. However, the results of this study do not provide strong corroboration of this pattern of findings: even though there was a significant decrease in enjoyment after the MICT period in the HIIT - MICT sequence, the fluctuations should not be overinterpreted given the lack of statistical significance with respect to the mixed model examined here.

Considering the results of this exploratory research, it can be concluded that the in-task effect investigated here is not a general effect, but is dependent on the training sequence. While affective experience during VICE was positively influenced when MICT was completed in the first training period (MICT - HIIT sequence), this was not the case when MICT was completed in the second period (HIIT - MICT sequence). As such sequence-dependent patterns were not evident in the other affective determinants under examination, the differentiation of AHBF into the various categories is demonstrably valuable in gaining a better understanding of the training-dependent changes in affective exercise determinants. It should be noted that there was no washout period, since methodologically we mainly investigated the training sequence. With regard to further research projects as well as with a view to practical implications, it would be of importance to investigate whether or at what temporal interval the observed sequence effect might fade.

Another important aspect to consider is the influence of the continuous nature of VICE and MICE versus the intermittent nature of HIIE, which allows periods of recovery between bouts of severe exercise. Existing evidence suggests similar (Martinez et al., 2015; Niven et al., 2018; Alicea et al., 2020; Tavares et al., 2021) or even more positive affective responses (Jung et al., 2014; Kilpatrick et al., 2015; Martinez et al., 2015) in HIIE when compared with

VICE, possibly due to reduced monotony, the prospect of getting a break, and a sense of pride at the completion of each interval. However, in addition to these arguments derived from theory, the methodological issues mentioned earlier must also be taken into account. The large heterogeneity in HIIE protocol configurations (e.g., work/rest ratio, total session duration, and energy expenditure) as well as in affect assessment (e.g., during load or recovery intervals) between studies limit the generalizability of these findings. Nevertheless, in addition to the exercise intensity aspect, the continuous nature of the exercise may have contributed to the fact that the affective experience of VICE after the second training period was less positive in the HIIT - MICT sequence (i.e., after an also continuous but less intense MICT) in comparison with the MICT - HIIT sequence (i.e., after an intermittent HIIT). Interestingly, the experience of variety has been found to be a unique predictor of exercise behavior and exercise-related well-being among physically inactive adults (Sylvester et al., 2016). In view of the former and the tenets of ART (Brand and Ekkekakis, 2018), it can be concluded that in the within-subject design with different training sequences investigated here, subjective experiences and reflective evaluations may have played an important role in contrasting the two different exercise regimens (Gropper et al., 2021).

As postulated by DMT, there was high intra-individual variability in affective responses during VICE, providing for the potential that cognitive factors (e.g., perceived monotony) influenced exercise valuations (e.g., Ekkekakis and Acevedo, 2006; Ekkekakis et al., 2011; Dierkes et al., 2021). As a result, there was greater scope for a less positive affective response during VICE, which in turn may have led to the sequence effect on affective valence found in this study. It is this affective response *during* an exercise session (i.e., first category of the AHBF) that, in particular, has been shown to predict future exercise behavior (Rhodes and Kates, 2015). Therefore, future studies should reflect these findings even more in their practical significance and investigate to what extent the experience with and the contrasting of different exercise modalities influence the affective experience in everyday training with potential breaks and changes, and which constellations prove to be favorable in this regard on the micro (days), meso (weeks), and macro (months or years) levels of exercise behavior.

Strengths and limitations

The strength of the current study is the within-subject design that allows comparison of two different training types and sequences (MICT vs. HIIT; MICT - HIIT vs. HIIT - MICT) with data from both pre-post questionnaires and in-situ measurements during a VICE session before, between, and after two 6-week training periods. We standardized exercise intensities relative to metabolic landmarks both during training periods and prior to VICE sessions with reference to a physiological framework (Binder et al., 2008) and captured different affective exercise determinants in accordance with the AHBF (Williams and Evans, 2014). Further, we applied a multilevel modeling approach to account for the nested data structure. Finally, by recruiting adults who did not achieve the recommendations for health promoting physical activity, the current findings are of direct relevance to a segment of the population that is particularly in need of interventions for promoting exercise.

Limitations of the current study are also important to consider. As a consequence of the elaborate study design with 15-weeks of training and three extensive diagnostic blocks that did not allow for extended absences, only 40 participants could be recruited. Moreover, there are missing values because of an early termination of the last survey wave due to the COVID-19 pandemic. Consequently, MI was applied, resulting in non-positive-definite hessian matrices for affective valence in some of the MI datasets. However, sensitivity analyses showed stable results for testing the hessian matrices, and alpha adjustment was used to reduce the risk of alpha error for the present substudy. Other limiting factors include limited external validity due to the highly standardized ergometer training, possible retention effects within a multi-week training program associated with improvements in affect-related exercise determinants in both training sequences, and limited generalizability of the results due to the relatively young and healthy sample studied here. Taking all this into account, observed effects have to be interpreted with caution and should be replicated in future studies with less structured exercise modalities, a control group without exercise intervention, and larger as well as more diverse samples (e.g., in terms of transferability to people with chronic diseases).

Furthermore, we examined only the reflective constructs in the second and third categories of the AHBF. Since dual-process models such as the DMT (Ekkekakis, 2003) – and more recently the ART (Brand and Ekkekakis, 2018) – postulate that a combination of both the automatic affective valuation (type-1 process) and the reflective evaluation (type-2 process) of exercise determine whether an individual either remains in a state of physical inactivity or starts and maintains exercise, future studies should additionally examine the effects of MICT and HIIT on automatic constructs (e.g., implicit attitude, hedonic motivation). In a next step, the relevance, specific contribution, and interplay of various affective determinants in influencing future exercise behavior should be determined (Stevens et al., 2020).

Conclusion

The results suggest, in the defined sample, and with the specific exercise modalities tested in this study, a sequencedependent change in the affective determinant that was recorded during vigorous exercise itself (i.e., *in-task affective valence*) in favor of the MICT–HIIT sequence, while no sequence-dependent effects of regular exercise could be determined for those affective determinants that were more reflective and distant from the activity. Furthermore, the present results underline the positive changeability of *affective attitude* towards exercise by regular training independently of the training type or sequence of MICT and HIIT.

This study contributes to the evidence base for the effects of different exercise modalities on changes in affective determinants and thus on the maintenance of exercise behavior, in previously inactive individuals. It is recommended to keep sequence effects as well as the potential of variety (Sylvester et al., 2016) in mind when it comes to affective experience - in particular during exercise - and changes in affective exercise determinants, and to consider previous experiences with certain exercise modalities for individual training recommendations.

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Key points

- In-task affective valence was significantly influenced by the training sequence in favor of the MICT–HIIT sequence.
- No significant training type or sequence effects were found for the constructs of reflective processing examined here: exercise enjoyment, affective attitude, and intrinsic motivation.
- Individual-based training recommendations should consider effects of variety and training sequence to develop tailored interventions that lead to more positive affective experiences and thus maintenance of exercise behavior in previously inactive individuals.

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Supplementary Table 1. **Descriptive statistics for the distribution of affective exercise determinants depending on the training type and sequence.**

		MICT–HIIT										HIIT–MICT									
Variables	**Timepoint**	**N**	**mV**	**Mean**	**Median**	**SD**	**Min**	**Max**	**Percentiles**			**N**	**mV**	**Mean**	**Median**	**SD**	**Min**	**Max**	**Percentiles**		
									25%	**50%**	**75%**								**25%**	**50%**	**75%**
Affective Attitude (1-7)	Baseline	20	0	5.14	4.88	1.11	3.25	7.00	4.31	4.88	6.19	20	0	4.84	5.25	1.26	2.00	6.75	3.88	5.25	5.75
	Follow-up I	18	2	5.40	5.50	0.80	4.00	6.75	4.94	5.50	6.00	19	1	5.09	5.50	1.33	2.75	7.00	4.00	5.50	6.25
	Follow-up II	20	0	5.60	5.63	0.80	3.75	7.00	5.00	5.63	6.25	20	0	5.31	5.63	1.18	2.75	7.00	4.50	5.63	6.19
Intrinsic Motivation (1-6)	Baseline	20	0	3.97	4.00	0.89	2.33	5.33	3.33	4.00	4.67	20	0	3.80	4.00	1.26	1.33	6.00	2.42	4.00	4.67
	Follow-up I	18	2	4.02	3.83	0.64	3.00	5.33	3.67	3.83	4.42	19	1	3.81	4.33	1.23	1.33	5.67	3.33	4.33	4.67
	Follow-up II	20	0	4.20	4.33	0.86	2.33	5.33	3.42	4.33	5.00	20	0	3.88	4.00	1.33	1.67	6.00	2.75	4.00	4.92
Affective Valence (-5-+5)	Baseline	20	0	1.39	1.75	1.63	-2.75	4.00	0.81	1.75	2.69	20	0	1.98	2.63	1.81	-2.50	4.00	0.75	2.63	3.38
	Follow-up I	20	0	2.18	3.00	1.76	-2.00	4.00	2.00	3.00	3.00	20	0	2.24	3.00	1.83	-1.00	5.00	0.06	3.00	3.94
	Follow-up II	15	5	2.85	3.00	1.28	0.25	5.00	2.00	3.00	4.00	16	4	1.41	1.75	1.90	-2.00	4.00	0.06	1.75	3.00
Exercise Enjoyment (0-100)	Baseline	20	0	56.15	58.00	20.16	14.00	84.00	42.75	58.00	71.75	20	0	60.70	71.00	24.66	9.00	87.00	35.75	71.00	78.00
	Follow-up I	20	0	48.30	49.00	22.78	11.00	81.00	28.25	49.00	69.50	20	0	48.85	55.00	25.64	2.00	89.00	23.00	55.00	69.50
	Follow-up II	15	5	53.20	56.00	22.68	10.00	85.00	33.00	56.00	72.00	16	4	43.25	37.50	21.98	13.0	82.00	24.75	37.50	62.75

Note. N = number of participants, mV = missing values.

Supplementary Table 2. **Correlations (r), effect sizes (d) and confidence intervals (95% CI) for repeated measures within training groups and sequences.**

Variable	**Training Sequence**	**Baseline vs. Follow-up I**			**Baseline vs. Follow-up II**			**Follow-up I vs. Follow-up II**		
		r	**d**	**CI**	**r**	**d**	**CI**	**r**	**d**	**CI**
Affective Attitude (1-7)	MICT–HIIT	.55	0.25	-0.37 – 0.95	.68	0.52	0.08 – 1.34	.67	0.31	-0.28 – 1.03
	HIIT–MICT	.92	0.50	0.55 – 1.84	.86	0.70	0.69 – 1.97	.88	0.34	0.07 – 1.35
Intrinsic Motivation (1-6)	MICT–HIIT	.81	0.09	-0.50 – 0.81	.48	0.25	-0.37 – 0.88	.67	0.35	-0.31 – 1.00
	HIIT–MICT	.81	0.01	-0.62 – 0.66	.79	0.10	-0.48 – 0.76	.89	0.12	-0.40 – 0.87
Affective Valence (-5-+5)	MICT–HIIT	.68	0.61	0.09 – 1.36	.52	0.91	0.26 – 1.76	.61	0.43	-0.19 – 1.26
	HIIT–MICT	.41	0.13	-0.50 – 0.74	.71	-0.41	-1.23 – 0.17	.27	-0.38	-1.00 – 0.40
Exercise Enjoyment(0-100)	MICT–HIIT	.57	-0.42	-1.05 – 0.21	.65	-0.17	-0.91 – 0.52	.63	0.25	-0.43 – 1.01
	HIIT–MICT	.23	-0.39	-0.93 – 0.32	.691	-0.90	-1.93 – -0.47	.29	-0.18	-0.86 – 0.53