This is a non-final version of an article published in final form in : Medicine & Science in Sports & Exercise: January 2018 - Volume 50 - Issue 1 - p 18–27
doi: 10.1249/MSS.0000000000001415

Affective adaptation to repeated SIT and MICT protocols in insulin resistant subjects

Tiina Saanijoki[1], Lauri Nummenmaa[1,2], Mikko Koivumäki[1,3], Eliisa Löyttyniemi[4], *Kari K. Kalliokoski[1], *Jarna C. Hannukainen[1]

[1]Turku PET Centre, University of Turku, Turku, Finland

[2]Department of Psychology, University of Turku, Turku, Finland

[3]Department of Nursing Science, University of Turku, Turku, Finland

[4]Department of Biostatistics, University of Turku, Turku, Finland

*Equal contribution

Corresponding author:

Tiina Saanijoki, MSc

University of Turku, Turku PET Centre

Kiinamyllynkatu 4−8

FI-20520 Turku

Finland

Tel. +358 2 3132865

Fax +358 22318191

E-mail: tiina.saanijoki@utu.fi

Running title: Affective adaptation to SIT

ABSTRACT

Introduction: The aim of this study was to investigate affective responses to repeated sessions of sprint interval training (SIT) in comparison with moderate-intensity continuous training (MICT) in insulin resistant subjects. **Methods:** Twenty-six insulin resistant adults (age: 49 (4) years, 10 women) were randomized into SIT (n=13) or MICT (n=13) groups. Subjects completed six supervised training sessions within 2 weeks (SIT session: 4-6 × 30 s all-out cycling/4-min recovery; MICT session: 40-60 min at 60% peak work load). Perceived exertion, stress and affective state were assessed with questionnaires prior to, during and after each training session. **Results:** Perceived exertion, displeasure, and arousal were higher during the SIT compared with MICT sessions (all $p < 0.01$). These, however, alleviated similarly in response to SIT and MICT over the six days of training (all $p < 0.05$). SIT versus MICT exercise increased perceived stress and decreased positive affect and feeling of satisfaction acutely after exercise especially in the beginning of the intervention (all $p < 0.05$). These negative responses declined significantly during the training period: perceived stress and positive activation were no longer different between the training groups after the third, and satisfaction after the fifth training session ($p > 0.05$). **Conclusion:** The perceptual and affective responses are more negative both during and acutely after SIT compared with MICT in untrained insulin resistant adults. These responses, however, show significant improvements already within six training sessions indicating rapid positive affective and physiological adaptations to continual exercise training, both SIT and MICT. These findings suggest that even very intense SIT is mentally tolerable alternative for untrained people with insulin resistance.

Key words: Type 2 diabetes mellitus, insulin resistance, sprint interval training, perceived exertion, affective valence, affect

INTRODUCTION

Regular physical exercise is a key component for management of type 2 diabetes mellitus (T2DM) (1). The prevailing recommendations for physical activity, i.e. minimum of 150 min of moderate-intensity physical activity per week spread over three to five sessions (2), improve glycaemic control in individuals with T2DM (3), yet most diabetic patients fail to achieve the required volume. It has been suggested that patients with T2DM would benefit from greater exercise intensities (4). The mounting evidence show that submaximal high-intensity interval training (HIIT) and supramaximal sprint interval training (SIT) elicit comparable or even superior metabolic and cardiovascular improvements as traditional moderate-intensity continuous exercise (MICT) (5–7), and are feasible options also for prevention and treatment of T2DM (8). HIIT involves alternating short (1−4 min) bouts of activity performed at near-maximal intensity (80-95 % of maximal heart rate) with recovery periods or light exercise. SIT is a form of HIIT, where the work intervals are shorter (≤ 30 s) and performed at maximal intensity in "all-out" manner (6). Thus, SIT differs with respect to volume and intensity from HIIT, and may represent even more time-efficient alternative for improving cardiovascular fitness. Already two weeks of SIT improves glycaemic control in healthy adults (9–11) and in insulin resistant individuals (12) as well as in patients with T2DM (13). The strenuous nature of SIT however, has raised concerns regarding its tolerability for sedentary people (14).

Pleasure and enjoyment motivate participation (15,16) and adherence to regular physical exercise (17–19). Moderate-intensity training is associated with positive affective changes (20) whereas higher exercise intensities are usually accompanied with increased negative affect (21). Affective responses of intense intermittent exercise have remained more disputable, most likely due to variety of studied interval training protocols, the age, sex, fitness level, and exercise background of the study participants (22–28). Our previous intervention study showed that SIT versus MICT induced higher perceived exertion, displeasure, and negative affective responses during and acutely after exercise in untrained, healthy, middle-aged men, however these negative responses started to decline already within six training sessions (22). To our knowledge, the perceptions of SIT in comparison with MICT have not been assessed in diabetic individuals.

Somatic health may affect the perceptual responses to exercise. For instance, T2DM may increase the feelings of fatigue (29), depression, and anxiety (30), and additionally, rapid fluctuations in blood glucose may cause impaired mood and cognitive functions (31). As such symptoms can interfere with daily activities as well as exercise tolerance and adherence (29), they could also exaggerate exercise effort (32), and hence exacerbate the aversion of strenuous exercise such as SIT. Furthermore, obesity and poor cardiorespiratory fitness, which typically coincide with diabetes, may also worsen the decline in affect (33). Although recent findings suggest that HIIT may be feasible exercise option in individuals with prediabetes (34), the repeated SIT-induced perceptual adaptation in this patient group lacks empirical evidence. Given the positive impact of SIT on insulin sensitivity as well as favourable perceptual responses of shorter high-intensity intervals (35), the aim of the present study was to investigate the affective responses to repeated sessions of SIT in untrained insulin resistant individuals. As a secondary analysis, the responses were compared to SIT-induced affective responses in inactive but healthy individuals by combining data from our previous study that used similar research design (22). We hypothesized that among insulin resistant subjects, SIT would cause higher perceived exertion and more negative affect compared to MICT, both during and after exercise, but that these would alleviate over the repeated sessions of exercise. In comparison with healthy individuals, we hypothesized that

SIT would result in higher perceived exertion and negative affect among insulin resistant individuals.

METHODS

The present study was a part of a larger study entitled "The effects of short-time high-intensity interval training on tissue glucose and fat metabolism in healthy subjects and in patients with type 2 diabetes" (NCT01344928). The study was conducted at the Turku PET Centre, University of Turku and Turku University Hospital (Turku, Finland) according to the Declaration of Helsinki, and the study protocol was approved by the Ethics Committee of the Hospital District of South-West Finland (decision 95/180/2010 §228).

Subjects

Participants were recruited via local newspaper advertisements. The inclusion criteria consisted of age 40-55 years, body mass index 18.5-35 $kg \cdot m^{-2}$, blood pressure ≤ 160/100 mmHg, sedentary lifestyle (exercise twice a week or less, peak oxygen uptake $VO_{2peak} \leq 40$ $ml \cdot kg^{-1} \cdot min^{-1}$), and impaired glucose tolerance according to the criteria of the American Diabetes Association (36) and HbA_{1c} less than 7.5 mmol/l. The exclusion criteria consisted of regular use of tobacco products, significant use of alcohol and a condition that could potentially endanger the participant's health during the study or interfere with the interpretation of the results. After careful interview and medical examination including ECG and oral glucose tolerance test, 26 subjects (age: 49 (4) years, BMI: 30.5 (2.7) $kg \cdot m^{-2}$ and VO_{2peak}: 27.2 (4.6) $ml \cdot kg^{-1} \cdot min^{-1}$) met the eligibility criteria and were admitted into the study after providing written informed consent. 17 subjects (6 women) met the criteria of T2DM (36) and the remaining 9 (4 women) subjects met the criteria of prediabetes, having impaired fasting glucose and/or impaired glucose tolerance (36). The sample size is a reflection of related research on perceptual changes in response to repeated exercise (37). Participants were randomised for SIT and MICT with 1:1 allocation ratio, resulting in n=13 in SIT and n=13 in MICT group. Two subjects from the SIT group dropped out during the trial, one because of claustrophobic feelings during pre-intervention imaging procedures and one due to migraine during the first SIT session. Three subjects from the MICT group discontinued the trial due to personal reasons. Thus, 11 subjects in SIT and 10 subjects in MICT group finalized all their assigned training sessions.

In a subsequent analysis we compared the affective responses to exercise in these insulin resistant subjects and in age-matched healthy untrained subjects (age: 47 (5) years, BMI: 26.1 (2.5) kg·m^{-2} and VO_{2peak}: 34.2 (4.1) ml·kg^{-1}·min^{-1}), who underwent similar exercise intervention and of which results have been reported previously (22).

Training intervention

The training intervention consisted of six supervised exercise sessions within two weeks. The SIT sessions comprised of warm-up and 4–6 × 30 s all out cycling efforts with 4 min recovery between bouts (Monark 894E, Vansbro, Sweden). The number of bouts was increased from four to five, and further to six after every other training session. Each bout started with a few seconds acceleration to maximal cadence without resistance, followed by a sudden increase of the load (10% of fat free mass in kg) and maximal cycling for 30 seconds. Participants were familiarised with SIT training during screening phase (2 × 30 s sprints). The MICT group performed continuous aerobic cycling for 40–60 min (Tunturi E85, Tunturi Fitness, Almere, The Netherlands) at the intensity of 60 % of peak workload. Training duration was increased from 40 to 50 min and further to 60 min after every other session. Blood lactate concentration was measured from capillary samples before and within 1 minute after each training session.

Questionnaires and other measurements

The perceptual and affective responses induced by exercise were assessed as previously described (22). Briefly, Borg's Rating of Perceived Exertion (RPE) 6–20 scale and Self-Assessment Manikin (SAM) rating scale (38) were administered repeatedly during each training session (before training session and after each sprint in the SIT group and in every ten minutes in the MICT group) to assess participants' subjective exertion and feelings of affective valence (pleasantness versus unpleasantness) and arousal (calm versus excited). With RPE scale, the participants were instructed as follows: "While doing physical activity, we want you to rate your perception of exertion. This feeling should reflect how heavy and strenuous the exercise feels to you. Borg's rating scale ranges from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion." Choose the number from the scale that best describes your level of exertion at that specific time point." SAM is a nine-point pictorial assessment technique to measure core affect and it is easy to administer during exercise. Only the valence and arousal scales of SAM were used in the present study, with following instructions: "We want you to rate how pleasant or unpleasant you feel at certain time points. These caricatures show facial expressions ranging from very happy to very unhappy. Very happy face reflects feelings such as extreme happiness, pleasantness, or, hopefulness. Very unhappy face reflects feelings such as extreme sadness, displeasure, upset, or irritation. Choose the caricature that best describes your level of pleasure at that specific time point. We also want you to rate how calm or aroused you feel at certain time points. These caricatures show physical signs ranging from sleepiness (eyes closed) to extreme activation (heart pounding). Sleepy caricature reflects very low activation state such as extreme calmness, relaxation, sleepiness or slowness. Heart ponding caricature reflects very high activation state such as extreme excitement, enthusiasm, restlessness or anger. Choose the caricature that best describes your level of arousal at that specific time point."

The Perceived Stress Questionnaire (PSQ) (39), the Positive and Negative Affect Schedule (PANAS) (40) and a visual analogue scale (VAS; separate scales for tension, irritation, pain, exhaustion, satisfaction and motivation to exercise) with extreme statements anchored at each end (i.e. not at all irritated to extremely irritated) were administered prior to and within five minutes after each training session to measure changes in experienced stress and pleasant versus unpleasant emotions. Participants were asked to respond to each scale in terms of how they felt at that moment.

VO_{2peak} test was performed as previously described in details by Kiviniemi et al. (41) on a bicycle ergometer (Ergoline 800s; VIASYS Healthcare, Germany) before the intervention and about 96 hours after the last training session at the Paavo Nurmi Centre, University of Turku, Turku, Finland. The test started at 50 W and followed by an increase of 30 W every 2 minutes until volitional exhaustion. Ventilation and gas exchange were measured (Jaeger Oxycon Pro; VIASYS Healthcare, Germany) and reported as the mean value per minute. The peak respiratory exchange ratio was ≥ 1.17, and the peak blood lactate concentration, measured from capillary samples immediately and 1 minute after exhaustion (analysed using YSI 2300 Stat Plus; YSI Incorporated Life Sciences, Yellow Springs, OH, USA), was ≥ 7.4 mmol/L for all the tests. The highest 1-minute mean value of oxygen consumption was defined as VO_{2peak}. Peak workload ($Load_{peak}$) was calculated as an average workload during the last 2 min of the test and used as a measure of maximal performance. Body composition was measured by bioimpedance monitor (InBody 720, Mega Electronics Ltd., Kuopio, Finland).

Statistical analyses

Statistical analyses were performed using SAS System for Windows 9.3 (SAS Institute Inc., Cary, NC). The training adaptations (VO_{2peak} test results) were assessed with hierarchical linear mixed model with training (pre vs. post intervention) as within- subjects factor and group (SIT vs. MICT) as between-subjects factor. Because of positively and negatively skewed distributions, PANAS negative, tension, and irritation values were log-transformed, pain was square root -transformed, and motivation x^2-transformed prior to statistical analyses. The changes in the parameters measured during exercise (RPE, valence, and arousal) were analysed with hierarchical linear mixed model where bout (pre-exercise score and 1-4 maximal sprints in the SIT group, and pre-exercise score and 10, 20, 30, and 40 min time intervals in the MICT group) and training session (1-6) were used as within- subjects factors and group as between-subjects factor. These time points were selected for analysis, since they were completed across all six sessions of training. Unstructured covariance structure was used for bout and compound symmetry covariance structure for session. The diabetes status (T2DM/prediabetes) and sex were used as additional between factors for the analyses. The changes in the parameters measured before and after every training session (PSQ, PANAS and VAS scores, and lactate) were analysed with hierarchical linear mixed model including session (1-6) and time (pre vs. post exercise) as within-factors and group (SIT vs. MICT) as between-factor. Unstructured covariance structure was used for session and compound symmetry covariance structure for time. The diabetes status (T2DM/prediabetes) and sex were used as additional main factors for the analyses. Subjects with one value, but another missing (drop outs, technical problems) are included in this model, thus model-based mean (SAS least square means) values are reported for all the parameters. Linear model was used to test the association between the affective parameters and the changes in $VO2_{peak}$ and $Load_{peak}$. Model included the mean value of the PSQ, PANAS, and VAS scores measured before every training session as covariate and group as between-subject factor and the change in VO_{2peak}

and $Load_{peak}$ as the dependent variables. An alpha level of $p \leq 0.05$ and two-sides tests was used in all statistical testing.

In the subsequent analyses the affective measures were compared between insulin resistant subjects from this study to previously reported results in age-matched healthy untrained men (22). Statistical analyses for RPE, valence, and arousal values after the fourth maximal sprint in the SIT groups and after 40 min in the MICT groups (because those were measured in all six sessions) were performed using hierarchical mixed linear model with unstructured covariance structure, including one within-factor (sessions), two between-factors [diabetes status (healthy or insulin resistant) and group (SIT or MICT)], and their interaction terms. To avoid too complicated statistical model, analyses for PSQ, PANAS and VAS scores, and lactate were performed separately for the values measured before and after the exercise sessions. Also these were analysed using hierarchical mixed linear model with unstructured covariance structure, including one within-factor (sessions), two between-factors [diabetes status (healthy or insulin resistant) and group (SIT or MICT)], and their interaction terms. The measurements for healthy subjects were performed between March 2011 and February 2013 and for insulin resistant subjects between February 2013 and November 2015.

RESULTS

Insulin resistant subject characteristics and training efficacy:

The SIT and MICT groups were well matched at the baseline, based on the whole-body parameters (Table 1). Body mass, BMI, and fat free mass remained unchanged after two weeks of training whereas fat percent reduced (p=0.018, time). $Load_{peak}$ was improved in both groups (p<0.001, time), however the response of VO_{2peak} was different between SIT and MICT (p=0.050 for group×time interaction), and only SIT improved VO_{2peak} (p=0.013 for training effect in SIT). Lactate was higher after SIT than MICT ($p<0.001$ for group×time interaction, least squares means ± standard error: SITpre = 1.33 ± 0.28; SITpost = 14.22 ± 0.29; MICTpre = 1.26 ± 0.26; MICTpost = 3.89 ± 0.26) (see Table SDC1, summary of the results of the linear mixed model).

Affect and perception of exertion during exercise in insulin resistant subjects:

The results are summarized in the Figure 1 and in the Table SDC2 (summary of the linear mixed model results). Perceived exertion (Fig. 1A) and arousal (Fig. 1C) increased and valence (Fig. 1B) decreased more in the SIT than MICT group during the training sessions (all $p<0.05$ for group×bout interaction). Perceived exertion ($p<0.001$, session) and arousal ($p=0.024$ for session×bout interaction) experienced during the exercise sessions decreased and affective valence increased ($p<0.001$, session) over the training period, but the effect was similar for SIT and MICT (Fig. 1D-1F).

Affective responses before and after exercise and during the training intervention in insulin resistant subjects:

Affective responses before and after exercise and during the training intervention are summarized in Figures 2 and in Table SDC1 (summary of the linear mixed model results). MICT sessions did not affect perceived stress (PSQ), but SIT sessions increased it. PSQ remained unaltered during the training period in the MICT group, but post-SIT stress declined towards the end of the training intervention ($p=0.035$ for group×session×time interaction; Fig. 2A). PSQ scores were significantly higher after the first two SIT sessions than after the first two MICT sessions (all $p<0.05$), however from the third exercise session the difference of PSQ-ratings after exercise was no longer significant between SIT and MICT ($p>0.05$). In parallel, PANAS positive score decreased after the SIT sessions in the beginning of the intervention, but started to increase over the training period, whereas in the MICT group PANAS positive score was higher after the training yet declining towards the end of the intervention ($p=0.014$ for group×session×time interaction; Fig. 2B). PANAS positive score was significantly lower after the first two SIT sessions than after the first two MICT sessions ($p<0.05$), but from the third exercise session the difference of positive affect after exercise was no longer significant between SIT and MICT. Satisfaction was higher after versus before the training in the MICT group throughout the intervention, whereas in the SIT group both pre and post exercise satisfaction increased throughout the training period ($p=0.031$ for group×session×time interaction; Fig. 2C). Between the training modes, satisfaction was significantly lower after the first two and the fourth SIT sessions than after the corresponding MICT sessions (all $p<0.05$), but from the fifth exercise session no significant differences were observed ($p>0.05$). Pain increased in both groups after the training sessions but more in the SIT group, however also pain alleviated in the SIT group during the training period ($p=0.033$ for group×session×time interaction; Fig. 2D). After MICT, motivation to exercise increased more than after SIT ($p=0.006$ for group×time interaction). Pre-training ratings of motivation to exercise declined during the training period until the last training session, but post-training ratings increased during the intervention similarly between the groups ($p=0.047$ for session×time interaction) (Fig. 2E). Exhaustion was higher after than before the training sessions ($p=0.003$, time) and varied between the training sessions ($p=0.002$, session) without significant interactions (Fig. 2F). PANAS negative score and feeling of tension varied between the training sessions ($p=0.006$ and 0.008, session, respectively) (Fig. 2G and Fig. 2H). Exercise did not significantly affect the feeling of irritation (Fig. 2I). No significant associations were found between the acute exercise responses in affect and the changes in lactate, VO_{2peak} or $Load_{peak}$ (correlation data not shown).

Comparison of the affective responses between the insulin resistant subjects and the healthy subjects:

The results are summarized in the Figures 3 and 4 and in the Tables SDC3 and SDC4 (summaries of the linear mixed model results). Perceived exertion and arousal values after the fourth maximal SIT sprint and after 40 min of MICT were not different between the healthy and insulin resistant subjects (Fig. 3A and 3C). However, in the same time points the difference in valence between SIT and MICT was significantly larger in the insulin resistant subjects than in the healthy subjects ($p=0.018$ for group×diabetes status interaction) so that pleasantness after four bouts of SIT was lower in the insulin resistant subjects compared to healthy subjects (2.5 vs. 3.9), but higher after 40 min of MICT (5.9 vs. 5.1, respectively) over the training sessions (Fig. 3B).

The pre-training ratings of PSQ, PANAS, and VAS parameters were analysed separately from post-training ratings. Exhaustion before the training sessions varied differently between the healthy and insulin resistant subjects and SIT and MICT ($p=0.047$ for session×group×diabetes status interaction) during the intervention, but showed a decreasing trend towards the end of the training period so that all the groups were less exhausted before the last than before the first training session (Fig. 4A). Also the feelings of irritation before the training sessions varied differently between the healthy and insulin resistant subjects and SIT and MICT ($p=0.047$ for session×group×diabetes status interaction) during the intervention, but it did not differ significantly between the first and last training sessions. Pain ratings prior to training sessions varied differently between the healthy and insulin resistant subjects during the training intervention independently of training mode ($p=0.017$ for session×diabetes status interaction). The initial pain ratings in the first training session were higher in insulin resistant than in healthy subjects, however pre-exercise pain ratings alleviated only in insulin resistant subjects over the course of intervention (Fig. 4B). No other differences in pre-training affect ratings between healthy and insulin resistant subjects were observed.

The post training ratings of PSQ, PANAS, and VAS were considered to reflect the affective state stimulated by experienced exercise session. After SIT, PANAS positive scores significantly increased over the course of the intervention in the insulin resistant subjects, while remained unaltered among healthy subjects, whereas after MICT, PANAS positive score decreased in both healthy and insulin resistant subjects during the intervention ($p=0.002$ for session×group×diabetes status interaction) (Fig. 4C). Post-SIT pain ratings remained unchanged within healthy subjects but decreased significantly in the insulin resistant subjects during the intervention, whereas after MICT, the pain ratings did not change over the training period neither in healthy nor insulin resistant subjects ($p=0.005$ for session×group×diabetes status interaction) (Fig. 4D). No other differences in post-training affect ratings between healthy and insulin resistant subjects were observed.

DISCUSSION

Our main finding was that the levels of perceived exertion and arousal increased and pleasantness decreased during both exercise modes, but as hypothesized, significantly more steeply during SIT compared with MICT sessions in insulin resistant untrained adults. Perceived exertion alleviated and pleasantness increased towards the end of the training period and not differently between the training modes, suggesting that repeated sessions of exercise resulted in affective adaptation, the process of weakening of emotional responses over time. Furthermore, SIT acutely increased perceived stress and pain, and decreased positive affect more than MICT especially in the beginning of the training period. As the intervention progressed, perceived stress and pain experienced after SIT alleviated and positive affect and satisfaction increased to the level comparable to MICT. Our findings suggest, that in the beginning of training SIT feels worse than MICT during and acutely after the exercise session. However, mental and physiological adaptations occur already within a few exercise sessions leading to similar affective responses after both SIT and MICT. Consequently, even very strenuous SIT appears to be tolerable training method for insulin resistant adults.

SIT-induced affective responses in people with insulin resistance have not been previously investigated. Previous research shows that interval training (SIT/HIIT) is physiologically a feasible alternative to MICT in the prevention and treatment of T2DM (8). Given that affective responses influence future physical activity behavior, at least during MICT (18), understanding SIT-induced perceptual and affective changes is important when evaluating the feasibility of SIT for T2DM patients. Higher exercise intensity parallels with higher exertion and displeasure during exercise (20,22,23,26). In line with our previous findings in healthy individuals (22), already the second bout of SIT increased ratings of perceived exertion and displeasure to higher level than what was observed during 40 minutes of MICT in insulin resistant subjects. Similarly, affective valence, i.e. pleasure, has consistently been reported lower also during HIIT versus MICT in inactive lean (26) and obese individuals (23) and in recreationally active individuals (25). Perceptual and affective responses to exercise may, at least partly, be determined by metabolic and cardiovascular strain, as perceived exertion has been associated with higher lactate and ventilation as well as with heart rate (42), which also has been linked to more negative feelings (43). Significantly higher blood lactate concentration after SIT than MICT indicates considerably larger contribution from anaerobic metabolism for energy production in SIT, as of course can be expected. Somewhat elevated lactate levels also after MICT suggests that, despite being performed at the intensity of only 60 % of peak workload, MICT intensity was close to vigorous for these subjects. However, in the present study we did not observe associations between blood lactate concentration and perceived exertion or affective measures. Interestingly, although SIT and HIIT induce similar negative perceptual and affective responses in comparison with MICT, it has been suggested that shorter-duration interval bouts may be more tolerable for novice exercisers (35). Perceptual responses and enjoyment have been found more positive during shorter than longer intervals in inactive obese individuals (35,44), thus speculatively, sprint bouts even shorter than 30 seconds might be favoured over few minutes intervals.

As the affective and perceptual responses regarding the first bout exposure might promote MICT over SIT, the development of these responses over time and repeated sessions of SIT have remained less documented. Considering the adoption of a new exercise routine, it is intriguing that perceived exertion, arousal, and displeasure experienced during exercise attenuate regardless of the training mode already within six training sessions as shown here and previously in healthy sedentary middle-aged men (22). These finding accord also with previous work demonstrating attenuated perceived exertion and leg pain in response to six days of SIT in young active individuals (45). Such alleviations are likely due to rapid adaptations in physiological systems such as metabolic, neuromuscular, cardiovascular, and respiratory systems, as well as improvements in pain tolerance and in psychological and cognitive elements. Furthermore, we found that stress and pain were significantly higher and positive affect and satisfaction were significantly lower after the first sessions of SIT than MICT, but the disparities in these measures abolished in fact after three exercise sessions. The notable drop in post-SIT ratings of pain, as well as the clear increase in positive affect over six exercise sessions in addition to growing exercise motivation after SIT may indicate that exercise enjoyment increases in response to repeated SIT. Importantly, SIT does not seem to worsen the feelings of fatigue and pain in insulin resistant subjects, which might compromise regular exercise. These positive affective adaptations to repeated training likely facilitates exercise adherence, as found previously in people with prediabetes, who were able to maintain regular HIIT program independently for one month following a brief supervised laboratory intervention (34). Yet further research investigating the complex and dynamic elements of long-term adherence to SIT is required, since the decision-making and psychological factors that underlie the initiation of a new exercise pattern are not necessarily the same that help to sustain the routine (46,47).

Our secondary finding was that untrained insulin resistant and healthy individuals show relatively similar affective responses during SIT and MICT, yet adaptation to repeated SIT appears somewhat more positive in insulin resistant than healthy subjects. Diabetes is typically accompanied with obesity and low cardiorespiratory fitness, which may in part exacerbate the aversion for physical activity and exercise. Higher exercise intensities may elicit more negative perceptual changes (21) and the changes are even more negative among sedentary and overweight individuals compared to healthy lean subjects (33). Reckon with this and that T2DM is often associated with increased pain (48) as well as additional feelings of fatigue (29), we expected SIT to induce higher perceived exertion and displeasure in the group of insulin resistant subjects compared with our previous cohort of healthy sedentary subjects. In line with our hypothesis, we found that subjective pleasantness during SIT sessions was markedly lower among insulin resistant than in healthy subjects, and opposite was found in pleasantness during MICT. In contrast, no differences in perceived exertion, arousal or lactate between healthy and insulin resistant subjects were observed despite significantly lower cardiorespiratory fitness and higher BMI in the insulin resistant group. Somewhat surprisingly we observed signs of more positive adaptation to SIT among insulin resistant than healthy subjects over the training period. The decrease of pre-exercise pain ratings in the insulin resistant group point to well-established beneficial effects of exercise on pain management (49). Interestingly, post-SIT ratings of pain decreased and positive affect increased more in insulin resistant than healthy subjects over six exercise sessions, whereas post-MICT ratings of positive affect decreased in both groups. Individual variability in metabolic strain induced by exercise may explain some of the differences between healthy and insulin resistant subjects, although no correlations were found between affective responses and physiological measures VO_{2max}, lactate or BMI. Nevertheless, these findings suggest that SIT may be at least equally well, if not even better, adopted by untrained insulin resistant than healthy individuals.

Several issues limited the present study. We examined the affective responses only during and immediately after exercise, which limits our interpretation of the result only to these time points. The sample size in the present study was relatively small, and men and women as well as T2DM and prediabetic subjects were not equally divided between the SIT and MICT groups. These both were used as factors in the analyses, but because of small sub-groups of men/women and T2DM/prediabetes, we did not test the interactions between other factors and cannot therefore say whether the training responses were different between men and women, for example. As there may be differences in exercise affect between men and women (50), this should be investigated in the future in larger groups of subjects. Additionally, the sample size calculations of the whole project were based on physiological variables, while they were the primary outcome measures of the larger project. Thus no power analysis was performed specifically for affective parameters. Given the fluctuating nature of affect, all changes observed in perceptual and affective measures may not be induced purely by exercise. However, for example for the Borg's scale, reliability (alpha) of the first workbout RPE measurements (first bout of SIT/10min of MICT) across sessions was 0.90, suggesting high level of consistency across subjects. It must also be noted that our study did not include a non-exercise control group. However, the main purpose of this study was to compare the effects of SIT and MICT directly. The exercise intervention of six training sessions was short, warranting more research on the long-term development of SIT-induced affective responses over time. Finally, the training sessions were performed individually in laboratory conditions under supervision and encouragement. Since social support from family and personal trainer is a dominant factor in exercise adoption and maintenance within diabetics (47), and positive feedback during SIT has been linked to higher exercise enjoyment and satisfaction (51), whether SIT can be initiated, adopted, and sustained independently in real life by inactive, overweight to obese people with T2DM or prediabetes remain elusive and require further investigation.

CONCLUSION

When comparing first bout exposure of SIT and MICT, SIT undeniably increases perceived exertion, displeasure and arousal more during exercise, and increases perceived stress, pain and decreases positive affect more acutely after exercise in untrained, overweight to obese insulin resistant adults. However, the negative affective responses after exercise improve significantly within a few training sessions to the level comparable with MICT, and perceived exertion and displeasure during exercise decline in both exercise modes in response to repeated training. These findings are encouraging in regards of tolerability of SIT, and support the potential feasibility of even very intense SIT as an alternative exercise strategy to untrained people with insulin resistance.

ACKNOWLEDGEMENTS

The authors thank the study participants and the staff of Turku PET Centre and Paavo Nurmi Centre, University of Turku, for their excellent assistance in the study. This study was conducted within the Centre of Excellence in Cardiovascular and Metabolic Research, supported by the Academy of Finland, the University of Turku, Turku University Hospital, and Åbo Akademi University. The study was financially supported by the Academy of Finland (Grants 251399, 251572, 256470, 281440, and 283319); the Ministry of Education of the State of Finland; the Paavo Nurmi Foundation; the Finnish Cultural Foundation; the Novo Nordisk Foundation; the European Foundation for the Study of Diabetes; the Hospital District of Southwest Finland; the Orion Research Foundation; the Finnish Cardiovascular Foundation; the Finnish Diabetes Foundation, the Emil Aaltonen Foundation, the Juho Vainio Foundation, the Veritas Foundation, the Instrumentarium Science Foundation, and University of Turku Doctoral Programme of Clinical Investigation.

CONFLICT OF INTEREST

The authors declare no conflict of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

REFERENCES

1. Way KL, Hackett DA, Baker MK, Johnson NA. The Effect of Regular Exercise on Insulin Sensitivity in Type 2 Diabetes Mellitus: A Systematic Review and Meta-Analysis. Diabetes Metab J. 2016;40(4):253–71.
2. Colberg SR, Albright AL, Blissmer BJ, et al. Exercise and type 2 diabetes: American College of Sports Medicine and the American Diabetes Association: joint position statement. Exercise and type 2 diabetes. Med Sci Sports Exerc. 2010;42(12):2282–303.

3. Umpierre D, Ribeiro PAB, Kramer CK, et al. Physical Activity Advice Only or Structured Exercise Training and Association With HbA $_{1c}$ Levels in Type 2 Diabetes. JAMA. 2011;305(17):1790.

4. Boulé NG, Kenny GP, Haddad E, Wells GA, Sigal RJ. Meta-analysis of the effect of structured exercise training on cardiorespiratory fitness in Type 2 diabetes mellitus. Diabetologia. 2003;46(8):1071–81.

5. Milanović Z, Sporiš G, Weston M. Effectiveness of High-Intensity Interval Training (HIT) and Continuous Endurance Training for VO2max Improvements: A Systematic Review and Meta-Analysis of Controlled Trials. Sports Med. 2015;45(10):1469–81.

6. Weston KS, Wisløff U, Coombes JS. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: a systematic review and meta-analysis. Br J Sports Med. 2014;48(16):1227–34.

7. Ramos JS, Dalleck LC, Tjonna AE, Beetham KS, Coombes JS. The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: a systematic review and meta-analysis. Sports Med. 2015;45(5):679–92.

8. Jelleyman C, Yates T, O'Donovan G, et al. The effects of high-intensity interval training on glucose regulation and insulin resistance: a meta-analysis. Obes Rev. 2015;16(11):942–61.

9. Babraj JA, Vollaard NBJ, Keast C, Guppy FM, Cottrell G, Timmons JA. Extremely short duration high intensity interval training substantially improves insulin action in young healthy males. BMC Endocr Disord. 2009;9:3.

10. Eskelinen JJ, Heinonen I, Löyttyniemi E, et al. Muscle-specific glucose and free fatty acid uptake after sprint interval and moderate-intensity training in healthy middle-aged men. J Appl Physiol. 2015;118(9):1172–80.

11. Richards JC, Johnson TK, Kuzma JN, et al. Short-term sprint interval training

increases insulin sensitivity in healthy adults but does not affect the thermogenic response to beta-adrenergic stimulation. J Physiol. 2010;588(Pt 15):2961–72.

12. Sjöros TJ, Heiskanen MA, Motiani KK, et al. Increased insulin-stimulated glucose uptake in both leg and arm muscles after sprint interval and moderate-intensity training in subjects with type 2 diabetes or prediabetes. Scand J Med Sci Sports. 2017;

13. Shaban N, Kenno KA, Milne KJ. The effects of a 2 week modified high intensity interval training program on the homeostatic model of insulin resistance (HOMA-IR) in adults with type 2 diabetes. J Sports Med Phys Fitness. 2014;54(2):203–9.

14. Hardcastle SJ, Ray H, Beale L, Hagger MS. Why sprint interval training is inappropriate for a largely sedentary population. Front Psychol. 2014;5:1505.

15. Aaltonen S, Leskinen T, Morris T, et al. Motives for and barriers to physical activity in twin pairs discordant for leisure time physical activity for 30 years. Int J Sports Med. 2012;33(2):157–63.

16. Korkiakangas EE, Alahuhta MA, Husman PM, Keinänen-Kiukaanniemi S, Taanila AM, Laitinen JH. Motivators and barriers to exercise among adults with a high risk of type 2 diabetes - a qualitative study. Scand J Caring Sci. 2011;25(1):62–9.

17. Williams DM, Dunsiger S, Ciccolo JT, Lewis BA, Albrecht AE, Marcus BH. Acute Affective Response to a Moderate-intensity Exercise Stimulus Predicts Physical Activity Participation 6 and 12 Months Later. Psychol Sport Exerc. 2008;9(3):231–45.

18. Rhodes RE, Kates A. Can the Affective Response to Exercise Predict Future Motives and Physical Activity Behavior? A Systematic Review of Published Evidence. Ann Behav Med. 2015;49(5):715–31.

19. Kiviniemi MT, Voss-Humke AM, Seifert AL. How do I feel about the behavior? The interplay of affective associations with behaviors and cognitive beliefs as influences on physical activity behavior. Health Psychol. 2007;26(2):152–8.

20. Ekkekakis P, Parfitt G, Petruzzello SJ. The Pleasure and Displeasure People Feel When they Exercise at Different Intensities. Sport Med. 2011;41(8):641–71.

21. Ekkekakis P, Petruzzello SJ. Acute aerobic exercise and affect: current status, problems and prospects regarding dose-response. Sport Med. 1999;28(5):337–74.

22. Saanijoki T, Nummenmaa L, Eskelinen JJ, et al. Affective Responses to Repeated Sessions of High-Intensity Interval Training. Med Sci Sports Exerc. 2015;47(12):2604–11.

23. Decker ES, Ekkekakis P. More efficient, perhaps, but at what price? Pleasure and enjoyment responses to high-intensity interval exercise in low-active women with obesity. Psychol Sport Exerc. 2017;28:1–10.

24. Kilpatrick MW, Greeley SJ, Collins LH. The Impact of Continuous and Interval Cycle Exercise on Affect and Enjoyment. Res Q Exerc Sport. 2015;86(3):244–51.

25. Thum JS, Parsons G, Whittle T, et al. High-Intensity Interval Training Elicits Higher Enjoyment than Moderate Intensity Continuous Exercise. PLoS One. 2017;12(1):e0166299.

26. Jung ME, Bourne JE, Little JP. Where Does HIT Fit? An Examination of the Affective Response to High-Intensity Intervals in Comparison to Continuous Moderate- and Continuous Vigorous-Intensity Exercise in the Exercise Intensity-Affect Continuum. PLoS One. 2014;9(12):e114541.

27. Wood KM, Olive B, LaValle K, Thompson H, Greer K, Astorino TA. Dissimilar Physiological and Perceptual Responses Between Sprint Interval Training and High-Intensity Interval Training. J Strength Cond Res. 2016;30(1):244–50.

28. Townsend LK, Islam H, Dunn E, Eys M, Robertson-Wilson J, Hazell TJ. Modified sprint interval training protocols. Part II. Psychological responses. Appl Physiol Nutr Metab. 2017;42(4):347–53.

29. Fritschi C, Quinn L. Fatigue in patients with diabetes: a review. J Psychosom Res. 2010;69(1):33–41.

30. Collins MM, Corcoran P, Perry IJ. Anxiety and depression symptoms in patients with diabetes. Diabet Med. 2009;26(2):153–61.

31. Sommerfield AJ, Deary IJ, Frier BM. Acute hyperglycemia alters mood state and impairs cognitive performance in people with type 2 diabetes. Diabetes Care. 2004;27(10):2335–40.

32. Huebschmann AG, Kohrt WM, Herlache L, et al. Type 2 diabetes exaggerates exercise effort and impairs exercise performance in older women. BMJ Open Diabetes Res Care. 2015;3(1):e000124.

33. Ekkekakis P, Lind E. Exercise does not feel the same when you are overweight: the impact of self-selected and imposed intensity on affect and exertion. Int J Obes. 2006;30(4):652–60.

34. Jung ME, Bourne JE, Beauchamp MR, Robinson E, Little JP. High-intensity interval training as an efficacious alternative to moderate-intensity continuous training for adults with prediabetes. J Diabetes Res. 2015;2015:191595.

35. Kilpatrick MW, Martinez N, Little JP, et al. Impact of High-Intensity Interval Duration on Perceived Exertion. Med Sci Sport Exerc. 2015;47(5):1038–45.

36. American Diabetes Association. (2) Classification and diagnosis of diabetes. Diabetes Care. 2015;38 Suppl:S8–16.

37. Astorino TA, Schubert MM, Palumbo E, et al. Perceptual Changes in Response to Two Regimens of Interval Training in Sedentary Women. J strength Cond Res. 2016;30(4):1067–76.

38. Bradley MM, Lang PJ. Measuring emotion: the Self-Assessment Manikin and the Semantic Differential. J Behav Ther Exp Psychiatry. 1994;25(1):49–59.

39. Levenstein S, Prantera C, Varvo V, et al. Development of the Perceived Stress Questionnaire: a new tool for psychosomatic research. J Psychosom Res. 1993;37(1):19–32.
40. Watson D, Clark LA, Tellegen A. Development and validation of brief measures of positive and negative affect: the PANAS scales. J Pers Soc Psychol. 1988;54(6):1063–70.
41. Kiviniemi AM, Tulppo MP, Eskelinen JJ, et al. Cardiac Autonomic Function and High-Intensity Interval Training in Middle-Age Men. Med Sci Sports Exerc. 2014;46(10):1960–7
42. Robertson RJ, Noble BJ. Perception of physical exertion: methods, mediators, and applications. Exerc Sport Sci Rev.1997;25:407–52.
43. Oliveira BRR, Slama FA, Deslandes AC, Furtado ES, Santos TM. Continuous and high-intensity interval training: which promotes higher pleasure? PLoS One. 2013;8(11):e79965.
44. Martinez N, Kilpatrick MW, Salomon K, Jung ME, Little JP. Affective and Enjoyment Responses to High-Intensity Interval Training in Overweight-to-Obese and Insufficiently Active Adults. J Sport Exerc Psychol. 2015;37(2):138–49.
45. Astorino TA, Allen RP, Roberson DW, Jurancich M, Lewis R, McCarthy K. Attenuated RPE and leg pain in response to short-term high-intensity interval training. Physiol Behav. 2012;105(2):402–7.
46. Rothman AJ. Toward a theory-based analysis of behavioral maintenance. Health Psychol. 2000;19(1S):64–9.
47. Tulloch H, Sweet SN, Fortier M, Capstick G, Kenny GP, Sigal RJ. Exercise Facilitators and Barriers from Adoption to Maintenance in the Diabetes Aerobic and Resistance Exercise Trial. Can J Diabetes. 2013;37(6):367–74.

48. Bair MJ, Brizendine EJ, Ackermann RT, Shen C, Kroenke K, Marrero DG. Prevalence of pain and association with quality of life, depression and glycaemic control in patients with diabetes. Diabet Med. 2010;27(5):578–84.

49. Naugle KM, Fillingim RB, Riley JL. A meta-analytic review of the hypoalgesic effects of exercise. J Pain. 2012;13(12):1139–50.

50. McDowell CP, Campbell MJ, Herring MP. Sex-Related Differences in Mood Responses to Acute Aerobic Exercise. Med Sci Sport Exerc. 2016;48(9):1798–802.

51. Tritter A, Fitzgeorge L, Cramp A, Valiulis P, Prapavessis H. Self-efficacy and affect responses to Sprint Interval Training. Psychol Sport Exerc. 2013;14:886–90.

TABLES

Table 1. Subject characteristics and training adaptations in the SIT and MICT groups.

	SIT		MICT		*p*		
	Pre	**Post**	**Pre**	**Post**	**Group**	**Time**	**Group x Time**
n	13	11	13	10			
men/women, *n*	9/4	7/4	7/6	6/4	0.69*		
T2DM/prediabetes, *n*	11/2	10/1	6/7	4/6	0.097*		
Age, year	49 (47, 51)		49 (46, 51)		0.85†		
Height, cm	173 (168, 179)		172 (167, 176)		0.61†		
Weight, kg	88.9 (80.6, 97.2)	88.4 (80.1, 96.7)	91.5 (84.5, 98.6)	91.1 (84.0, 98.1)	0.62	0.083	0.95
BMI	30.5 (28.5, 32.5)	30.3 (28.4, 32.3)	31.0 (29.4, 32.7)	30.8 (29.2, 32.5)	0.69	0.07	0.83
Fat, %	34.8 (31.4, 38.5)	33.8 (30.5, 37.5)	33.8 (30.8, 36.9)	32.9 (30.0, 36.0)	0.67	**0.018**	0.87
FFM, kg	57.0 (51.8, 62.2)	57.6 (52.4, 62.8)	59.6 (55.0, 64.2)	59.8 (55.2, 64.5)	0.49	0.11	0.54
VO_{2peak}, $l \cdot min^{-1}$	2.26 (1.99, 2.53)	2.36 (2.1, 2.63)	2.47 (2.24, 2.71)	2.43 (2.19, 2.67)	0.43	0.43	**0.039**
VO_{2peak}, $ml \cdot kg^{-1} \cdot min^{-1}$	25.7 (23.2, 28.2)	27.0 (24.6, 29.5)‡	27.0 (24.9, 29.2)	26.9 (24.6, 29.1)§	0.72	0.12	**0.05**
$Load_{peak}$, W	173 (153, 193)	187 (167, 207)	190 (173, 208)	201 (183, 219)	0.24	**<0.001**	0.48

The results are presented as means (95% CI) for age and height. For all other parameters the results are presented as model-based means (95% CI). Group p-value indicates whether there is a level difference between the groups, time p-value displays the mean change between pre- and post-measurements and group x time p-value indicates whether the mean changes are different between the groups. HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; n, number of subjects; T2DM, type 2 diabetes mellitus; FFM, fat free mass; * Fisher's exact test at baseline; † T-test; ‡ HIIT time effect, p = 0.013; § MICT time effect, p = 0.75. Significant differences are printed in boldface.

FIGURE LEGENDS

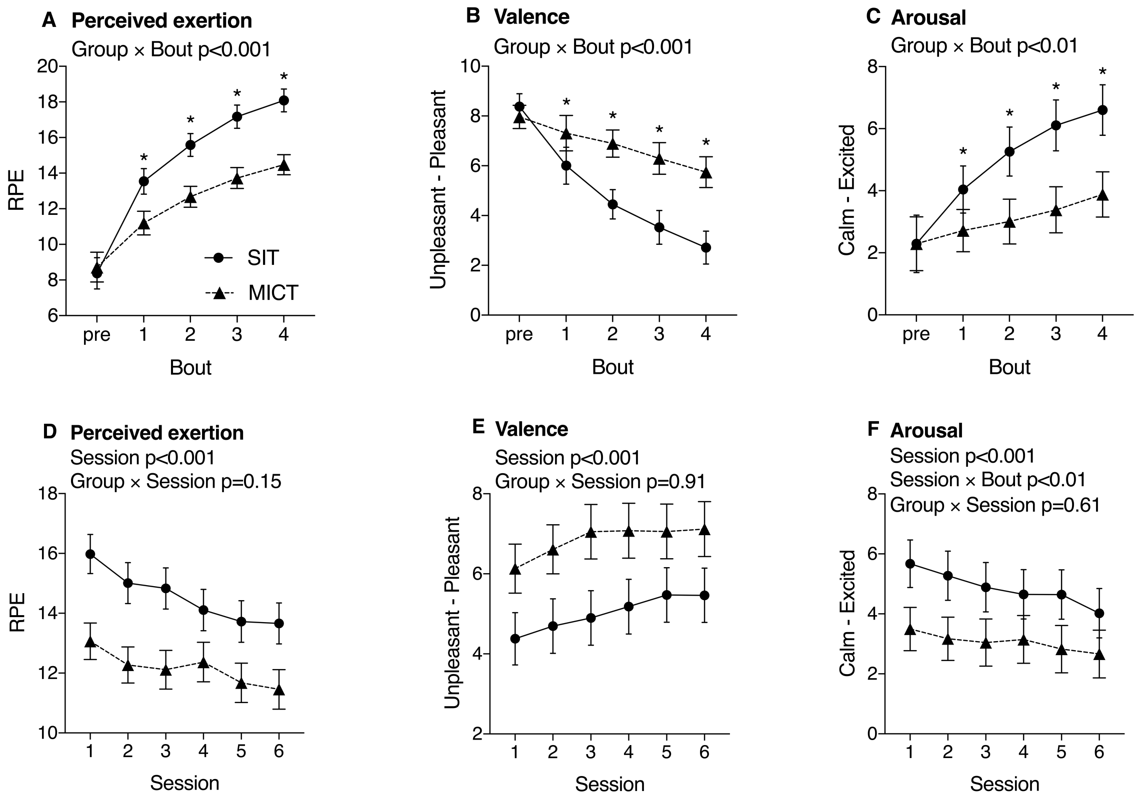

Figure 1. Ratings of perceived exertion (RPE) (A), affective valence (B) and arousal (C) during exercise in insulin resistant subjects. In the sprint interval training (SIT) group assessments were made before exercise and after every 30 s bout, in the moderate-intensity continuous training (MICT) group assessments were made before exercise and in every 10 minutes. Only the first four bouts have been included for the analysis, since these were completed across all six sessions of training. *SIT significantly differs from MICT ($p<0.05$). Changes of RPE (D), valence (E) and arousal (F) during the training intervention (six training sessions). No significant interaction of session and group was observed, however the groups are plotted separately for visual purpose. The values are least squares means and the error bars represent 95% confidence intervals.

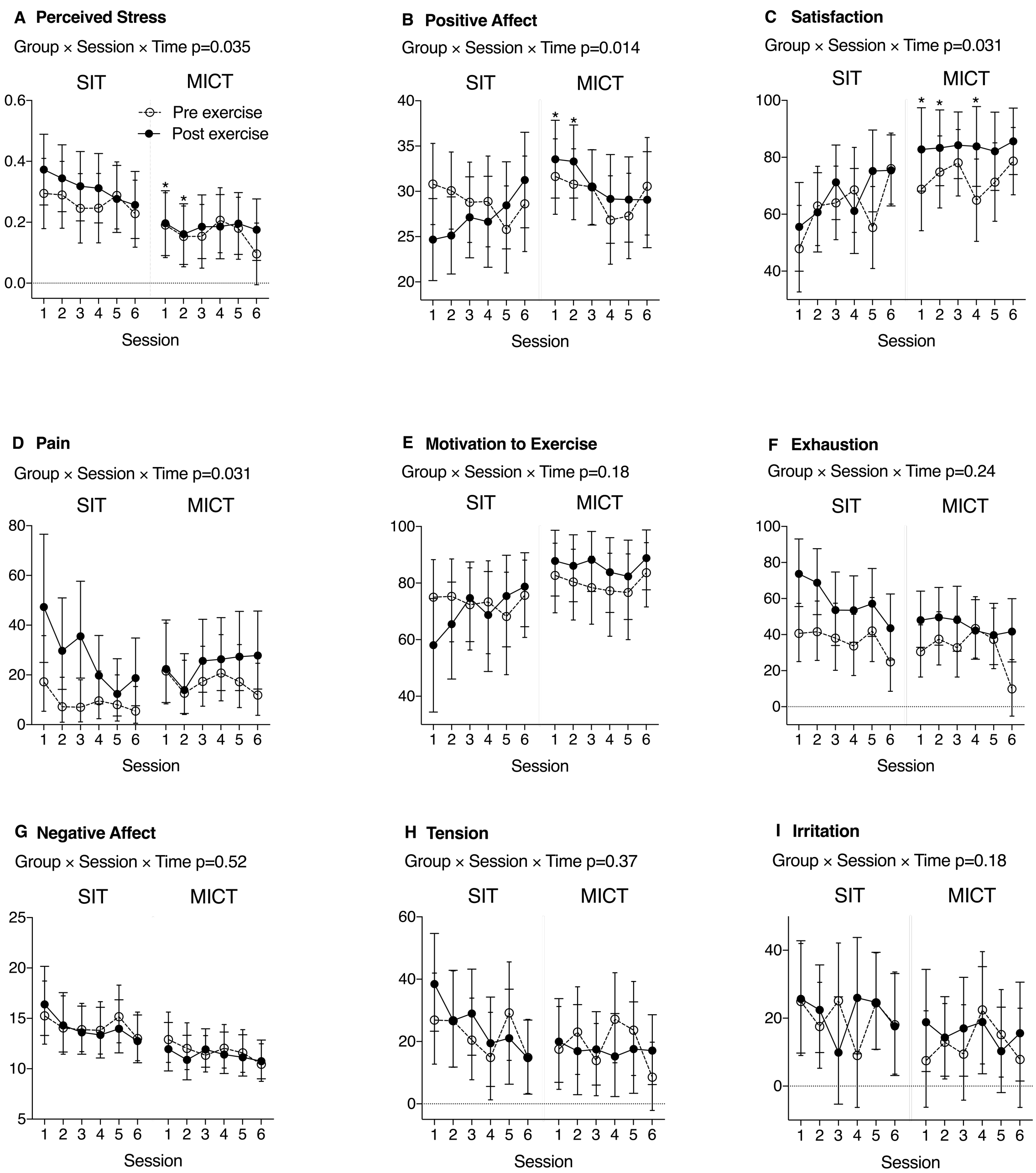

Figure 2. Affective responses before and after sprint interval training (SIT) and moderate-intensity continuous training (MICT) sessions in insulin resistant subjects. *Post-value of MICT is significantly different ($p<0.05$) from corresponding post-value of SIT. The values are least squares means and the error bars represent 95% confidence intervals.

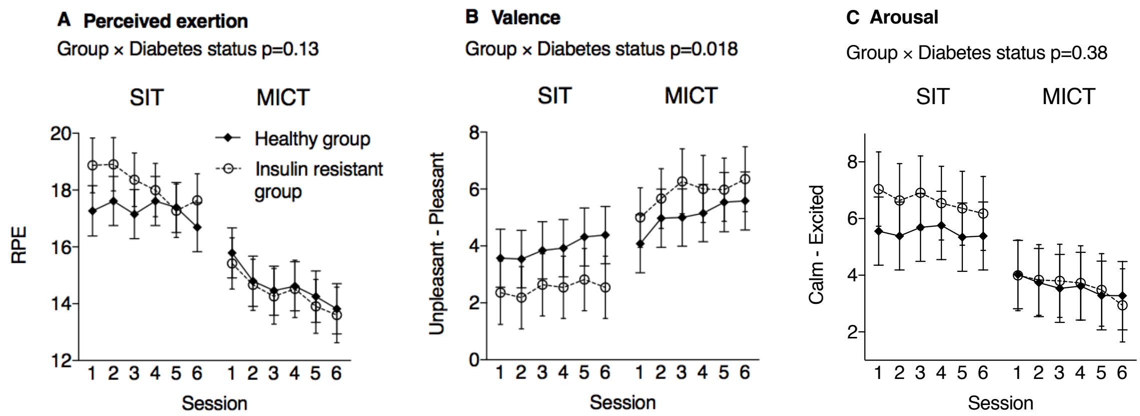

Figure 3. Ratings of perceived exertion (RPE) (A), affective valence (B) and arousal (C) after the fourth bout of sprint interval training (SIT) and after 40 min of moderate-intensity continuous training (MICT) in healthy and insulin resistant groups. The exercise sessions are illustrated separately for visual purpose. The values are least squares means and the error bars represent 95% confidence intervals.

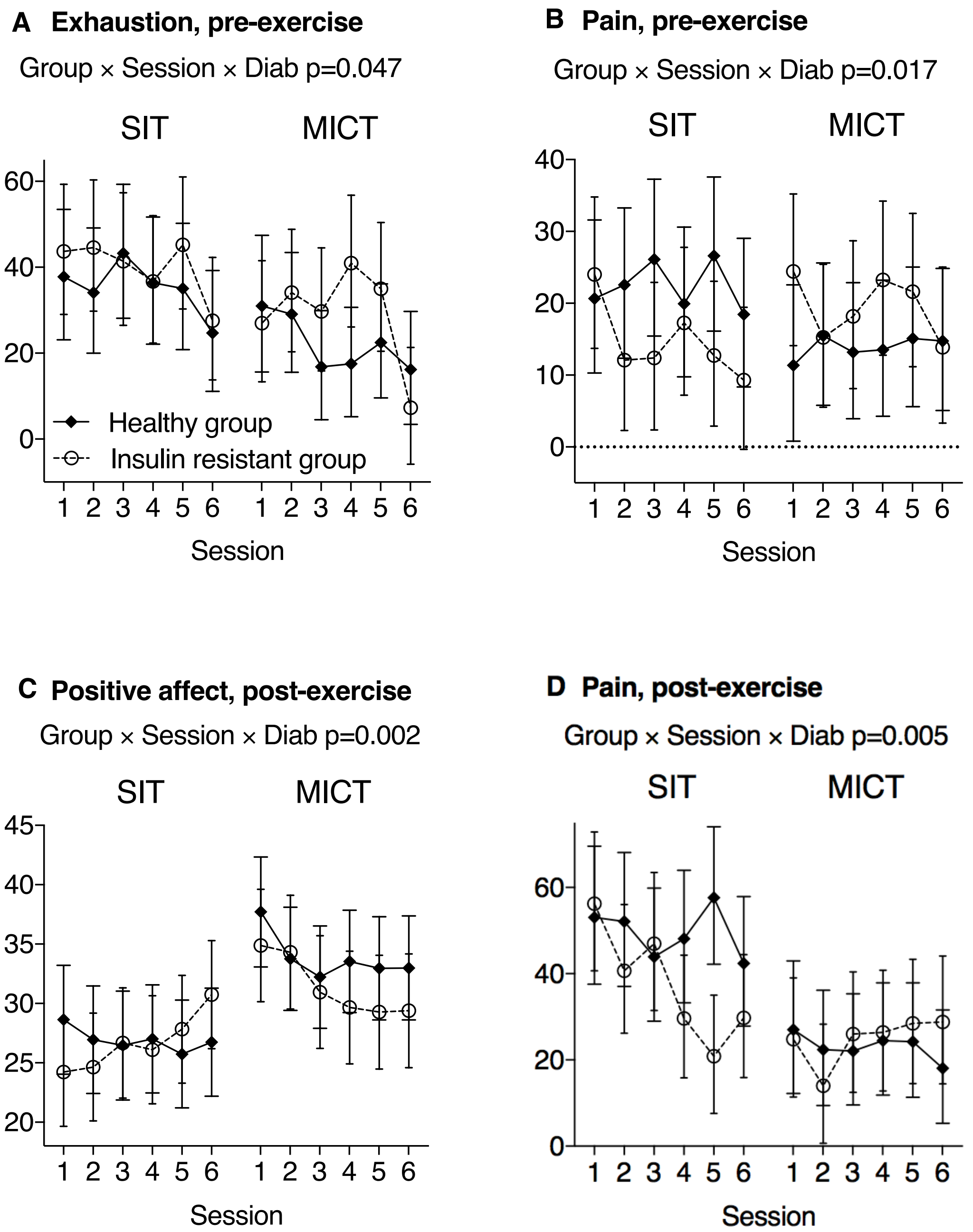

Figure 4. Affective responses before (A-B) and after (C-D) sprint interval training (SIT) and moderate-intensity continuous training (MICT) in healthy and insulin resistant subjects. The values are least squares means and the error bars represent 95% confidence intervals.

SUPPLEMENTAL DIGITAL CONTENT (SDC)

Supplemental_Digital_Content1.pdf

Supplemental_Digital_Content2.pdf

Supplemental_Digital_Content3.pdf

Supplemental_Digital_Content4.pdf