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**Research article**

# Physiological Response Differences between Run and Cycle High Intensity Interval Training Program in Recreational Middle Age Female Runners

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## Abstract
The aim of this investigation was to compare the changes in endurance running performance and physiological variables after a four-week period of high intensity interval training (HIIT) in either running or cycling in female athletes. Fourteen recreational female runners (age = 42 ± 10 yr, height = 1.67 ± 0.06 m, body mass = 61.6 ± 10.4 kg, body mass index (BMI) = 22.2 ± 3.4 kg.m$^{-2}$) were randomly allocated to one of two HIIT training groups: running ($HIIT_{run}$) or cycling ($HIIT_{bike}$). Each group performed two HIIT sessions per week for 4 weeks, which consisted of 6 x 2 min at 95% of maximal heart rate ($HR_{max}$) and 4 x 1 min all out efforts. Maximal oxygen consumption ($VO_{2max}$) in treadmill running increased significantly after the $HIIT_{run}$ ($p < 0.01$, ES = 0.6) but remained unchanged in $HIIT_{bike}$. However, $HIIT_{bike}$ improved average velocity in a 10 km running time trial ($TT_{run}$) ($p < 0.05$, ES = -0.4), whereas, no changes were found for the $HIIT_{run}$ group. Analysing the first and last HIIT sessions, for $HIIT_{run}$ only the average rate of perceived exertion ($RPE_{av}$) increased significantly, whereas, performance variables such as average heart rate ($HR_{av}$) and average pace ($pace_{av}$) remained unchanged. $HIIT_{bike}$ enhanced significantly the average speed of HIIT sets ($speed_{av}$) and the peak power output (PPO) of the session, as well as, the $RPE_{av}$ and delayed onset muscle soreness immediately after HIIT session ($DOMS_{post}$) were increased significantly. A regime of HIIT in cycling may evoke increases in female recreational runners' power, which may be related with improvements in a 10 km $TT_{run}$ independent of changes in aerobic capacity. This may be advantageous in order to avoid overuse running related injuries.

**Key words:** gender, intermittent training, muscle damage, aerobic capacity, endurance.

## Introduction

High intensity interval training (HIIT) has been widely studied in athletic and non-athletic populations, demonstrating considerable positive benefits, such as, improved training time efficiency relative to increases in aerobic and anaerobic capacity or maintenance of endurance performance during low-volume training periods (Billat et al., 2001; García-Pinillos et al., 2017; Gunnarsson and Bangsbo, 2012; Lindsay et al., 1996). HIIT comes in many different forms and aims to improve distinct sport performances (Laursen and Jenkins, 2002). A number of authors have investigated the optimal HIIT stimulus for improvements in endurance performance such as the intensity and duration of sessions (Etxebarria et al., 2014; Gunnarsson and Bangsbo, 2012; Laursen and Jenkins, 2002; Stepto et al., 1999). Despite the fact that HIIT appears to enhance a number of physiological variables, such as, maximal oxygen consumption ($VO_2$max), peak power output (PPO), time to exhaustion at maximal velocity, first and second ventilatory threshold and vertical jumping performance (García-Pinillos et al., 2017; Helgerud et al., 2007; Laursen et al., 2002; Laursen and Jenkins, 2002; Mallol et al., 2018) the majority of research examining the effects of HIIT has been conducted with male athletes (Billat et al., 1999; Laursen et al., 2002; Lindsay et al., 1996) or with mixed male and female athletes sample (Farley et al., 2016; Koral et al., 2018; Mallol et al., 2016; Menz et al., 2015) while a group of exclusively female participants is less frequently studied. Some studies have reported less beneficial outcomes to HIIT training in females compared to males and hypothesized this may be due to a greater disposition to aerobic metabolism in females compared to males (Gibala et al., 2014; Gratas-Delamarche et al., 1994). Previous authors supported that gender might be a differentiating element in endurance performance, such as cross-country skiing, cycling and marathon running (Gibala et al., 2014; Gratas-Delamarche et al., 1994). Other studies have concluded that $VO_2$max, maximal aerobic power, power at lactate threshold (LT), power at onset blood lactate accumulation (OBLA) and peak of speed levels showed significant differences between genders. Such that the male subjects obtained greater values (Hopker et al., 2010; Reaburn et al., 2011; Sandbakk et al., 2012). Additionally, anthropometric and morphological variables such as lipid accumulation may also be an influential factor (Reaburn et al., 2011).

The limited studies on female athletes have shown greater improvements in aerobic and anaerobic capacity after a HIIT program compared with continuous training in female soccer players (Rowan et al., 2012). The authors emphasised the time saving benefits obtained from HIIT sessions, helping to focus on teamwork and sport specific skills (Rowan et al., 2012). Kinnunen et al. (2017) found that a HIIT program applied in pre-season helped to enhance the maximal and explosive strength capacity, improving neuromuscular performance in female ice-hockey

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players. Recently, Mallol et al. (2018) observed short supramaximal sets of HIIT enhanced maximal $VO_{2max}$ values and submaximal power [W] at the first and second ventilatory threshold capacity. However, no performance improvements were observed during a triathlon race simulation (Mallol et al., 2018). The context of the study was in relation to maintenance of fitness during periods of reduced training. There is minimal research examining the effects of HIIT in females. Therefore, further research is needed to achieve a greater understanding of this training method in females.

Previous researchers concluded that an intensified period of training in running results in a higher level of cumulative fatigue, greater muscle damage and potential injury in runners (Burt et al., 2012; Del Coso et al., 2013). An intensified training program, high volume and/or intensity, presents a demanding stimulus requiring careful planning and monitoring. Running can lead to higher levels of muscle damage and cumulative fatigue owing to eccentric muscle contractions which is evidenced by higher biochemical and perceptual markers of muscle damage and soreness such as creatine kinase (CK) (Burt et al., 2012; Cipryan, 2017; Keane et al., 2015; Quinn and Manley, 2012). In particular, muscle damage is typically observed in the periods after HIIT sessions. Elevated levels of CK, myoglobin and lactate dehydrogenase were induced by 15 s, 30 s and 60 s HIIT running protocols (Cipryan, 2017). Moreover, the muscular eccentric component of down-hill running training involved higher CK values and greater exercise induced inflammatory responses in female runners (Köhne et al., 2016). In female sports teams such as soccer, rugby and netball, female athletes presented an increased level of muscle damage after high intensity sprint training (Le Meur et al., 2011). Intensified HIIT in cycling, which is a more concentric based activity than running, may not result in the same cumulative level of soreness. Therefore, the current study focused on the comparing the residual effects of HIIT in cycling and running modalities. Additionally, Burt et al. (Burt et al., 2012) have presented data showing that different levels of exercise-induce muscle damage were evident following running and cycling exercises. However, as a general form of training HIIT in cycling might nonetheless induce performance changes similar to those shown following running HIIT programs (Burt et al., 2012; Millet et al., 2002) but this has not been extensively investigated. Several studies in well trained runners have observed positive effects on running performance when a part of their run training volume was replaced by cycle training sessions (Etxebarria et al., 2014; Tanaka, 1994; White et al., 2003). Overall, relatively few investigations have been conducted with female athletes in order to examine how an intensified running training program affects CK, as a biomarker of muscle damage. There is also limited research showing how exercise induced CK varies between running and cycling HIIT modes after a period of HIIT in running or cycling.

Therefore, the current investigation focused on examining the difference in physiological responses, performance outcomes and muscle damage, as acute effects, occurring between run and cycle HIIT modes in female athletes.

## Methods

### Participants

A group of fourteen recreational middle-aged female athletes (age = 42 ± 10 yr, height = 1.67 ± 0.06 m, body mass = 61.6 ± 10.4 kg, body mass index (BMI) = 22.2 ± 3.4 $kg.m^{-2}$) were recruited from a number of community clubs and institutions. Participants were randomly distributed in two groups: a running HIIT group ($HIIT_{run}$, n = 7, age = 41 ± 7 yr, height = 1.64 ± 0.07 m, body mass = 60.7 ± 9.3 kg, BMI = 22.6 ± 2.3 $kg.m^{-2}$) who completed two run HIIT sessions per week, and a cycling HIIT group ($HIIT_{bike}$, n = 7, age = 43 ± 13 yr; height = 1.70 ± 0.03 m; body mass = 62.5 ± 12.1 kg; BMI = 21.8 ± 4.5 $kg.m^{-2}$) who performed an identical HIIT session protocol on the cycle ergometer. The inclusion criteria were: participants were habitual and active runners, $\geq$ two running sessions per week, and were able to run 10 km in < 70 min. Participants were excluded if they had no running training in the previous one month, or had an injury that prevented them from participating in training or testing.

Participants were informed of the protocols and experimental procedures and signed a formal written consent. The study followed the guidelines established by the Declaration of Helsinki (2013) and was approved by the Human Research Ethics Committee (HREC code 334.16).

### Procedures

The study examined the physiological and performance benefits, as well as, the muscle damage generated by four weeks of HIIT using running or cycling in female runners. Participants attended Flinders University Exercise Physiology Laboratory twice weekly at the same time of day, to perform the HIIT sessions. To determine differences between the HIIT programs, participants were divided into two groups: $HIIT_{run}$ who performed supervised running HIIT sessions on an outdoor grass running track and $HIIT_{bike}$ who performed supervised cycling ergometer HIIT sessions in the laboratory. All participants performed identical testing procedures before and after the four-week intervention period. Each subject undertook the initial and final tests (laboratory testing and 10 km running time trial) at approximately the same time of day and were asked to follow a similar protocol for test preparation. The environmental conditions in the laboratory were maintained between 20-22ºC and 55-65% humidity.

### Laboratory incremental running test

Each participant completed a 'fast' incremental exercise test to exhaustion using treadmill running in the week prior to and a week after the training intervention. The test procedure included (a) 10 minutes of their usual warm-up intensity on the treadmill (b) an incremental running test where the initial stage was set at 8 $km·h^{-1}$. Each stage lasted one min and the speed was increased by 1 $km·h^{-1}$ until exhaustion (Noakes et al., 1990). Expired gases were analysed by TrueOne2400 (ParvoMedics, Utah, USA), to determine maximal oxygen consumption ($VO_{2max}$) on a treadmill, the gas was analysed every 5 seconds but the 2 highest consecutive values over 30s was used. Before the warm up, blood lactate concentration was obtained from a fingertip sample and analysed using a portable lactate analyser (Lactate Pro, Arkray, KDK Corporation, Kyoto, Japan). Heart rate (HR), maximal speed achieved during the last stage completed ($speed_{max}$) and rating of perceived exertion (RPE) were recorded in the final 15 s of every stage. HR was recorded using Polar RS400 series (Kempele, Finland) HR monitor until test completion. The Borg Scale (from 0 to 10) (Borg, 1982) was employed to monitor the RPE at the end of each stage. Participants were previously familiarised to the perceived exertion method and the 10- point Borg Scale.

## Running time trial (TT)

After a 60 min break from the incremental running test the participants completed a 10 km TT individually on a 400 m grass running track. Distance was previously measured and marked on the track by the researchers, participants were asked to complete 25 laps. Average and maximum speed ($speed_{av}$ and $speed_{max}$), and HR ($HR_{av}$ and $HR_{max}$) were recorded (Garmin Forerunner 910XT Olathe, Kansas, USA). RPE average ($RPE_{av}$) was calculated from values obtained every 2 km throughout the trial. Instantaneous pace and HR were recorded every 2 km. Immediately after the test, lactate concentration was measured from a fingertip sample (Lactate Pro, Arkray, KDK Corporation, Kyoto, Japan).

## Training intervention

Participants randomly allocated to the HIIT groups ($HIIT_{run}$ and $HIIT_{bike}$) attended supervised training sessions twice a week. The session structure was similar for all HIIT training: a 10 min warm-up where participants determined their warm-up intensity from the maximal test, followed by 6 x 2 min at 95% of maximal heart rate ($HR_{max}$) and 4 x 1 min all out (Bogdanis et al., 1996) followed by a 5 min cool-down. The recovery periods for the 1 and 2 min interval sets were 1 min 30 s and 2 min, respectively, with athletes continuing active recovery at a low intensity. $HIIT_{run}$ performed the training outdoors around the same track as used for the 10 km TT. Individual training intensity at 95% of $HR_{max}$ and maximal intensity for the $HIIT_{run}$ group were determined for each participant based on their pre-intervention testing. The $HITT_{bike}$ sessions were performed using a cycle ergometer (Wattbike, Nottingham, UK). The $HIIT_{bike}$ intensity were extrapolated from the treadmill test based on Millet et al. (Millet et al., 2009) review were researchers concluded that $HR_{max}$ obtained from a maximal cycle ergometer test is about 5% (between 6-10 bpm) lower than $HR_{max}$ recorded in a maximal treadmill test. The intensity was also corroborated with RPE values (Basset and Boulay, 2000; Norton et al., 2010) which showed a similar pattern for HR during cycling interval training (Green et al., 2006). Participants could change the cycle resistance as they needed as long as they achieved the stipulated HR. In order to recognise their usual training load, they were asked to complete a 1-week training diary before the intervention to ensure that no significant differences existed between participants. During intervention weeks participants recorded their individual training sessions outside of the HIIT program. Every session was documented in a personal training diary which included the running training duration, distance and $RPE_{av}$ allowing for the session RPE-min to be calculated (Table 1).

## Acute response to HIIT

The physiological responses to the first (1st) and last HIIT (8th) session in each mode ($HIIT_{run}$ and $HIIT_{bike}$) were measured. Blood lactate (Lactate Pro Analyser, Arkray, Japan) and CK concentrations (Reflotron Plus system, Rotkreuz, Switzerland) were measured before and immediately after the training session from fingertip blood samples. Participants came back to the laboratory 24 h after the HIIT sessions in order to measure $CK_{24h}$ (Quinn and Manley, 2012). Delayed onset muscle soreness (DOMS) was recorded using a CR-10 scale (Lau et al., 2015) before, after and 24 h after session. During each $HIIT_{run}$ session the average and peak HR, HR during recovery intervals, pace, distance covered and average/maximal RPE values were recorded (Borg, 1982). During the $HIIT_{bike}$ average and maximal HR, recovery HR intervals and average and maximal RPE values (Borg, 1982) were recorded. Speed, power and cadence average, maximal power and cadence were also recorded for the $HIIT_{bike}$ group.

## Statistical analyses

Results are presented as mean ± SD. A t-test for independent samples was used to analyze the differences between $HIIT_{run}$ and $HIIT_{bike}$ at baseline (pre-test). The between-group ($HIIT_{run}$ vs $HIIT_{bike}$) comparison from pre-test to post-test or 1st and 8th HIIT sessions for data obtained in the laboratory tests and 10 km TT was calculated using a 2-way mixed ANOVA (group x time). In addition, a t-test for paired samples was used to analyze the differences between the pre-test and post-test independently for each group ($HIIT_{run}$ or $HIIT_{bike}$). Cohen's effect size (Cohen, 1988) was calculated to assess a practical significance between the pre-test and post-test in each group. Effect sizes (ES) of above 0.8, between 0.8 and 0.5, between 0.5 and 0.2, and lower than 0.2 were considered as large, moderate, small, and trivial, respectively (Cohen, 1988). Data analysis was performed using the Statistical Package for Social

**Table 1. Quantification of training sessions, excluding HIIT sessions, for Run (HIITrun) and Bike (HIITbike) groups.**

| | $HIIT_{run}$ | $HIIT_{bike}$ | p | Dif. (%) | ES |
|---|---|---|---|---|---|
| **Duration (min)** | 49.97 ± 33.06 | 50.89 ± 23.99 | 0.84 | 1.84 | 0.0 |
| **Running distance (km)** | 6.59 ± 4.59 | 7.84 ± 4.22 | 0.12 | 18.99 | 0.3 |
| **$RPE_{av}$** | 4.31 ± 1.92 | 4.92 ± 1.90 | 0.06 | 14.28 | 0.3 |
| **Session RPE-min (AU)** | 227.53 ± 217.80 | 261.27 ± 166.36 | 0.27 | 14.83 | 0.1 |

Dif. (%) = mean differences in percentage, ES = effect size, RPEav = average rate of perceived exertion, Session RPE-min = control method based on rate of perceived exertion per minute.

**Table 2. Results for Run ($HIIT_{run}$) and Bike ($HIIT_{bike}$) group in pre and post-intervention testing in maximal oxygen consumption ($VO_{2max}$), maximum heart rate ($HR_{max}$) and maximum speed ($Speed_{max}$) obtained during maximal treadmill testing.**

| | $HIIT_{run}$ | | | | | $HIIT_{bike}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre test | Post test | p | Dif. (%) | ES | Pre test | Post test | p | Dif. (%) | ES |
| $VO_{2max}$ ($mL·kg^{-1}·min^{-1}$) | 42.1 ± 4.9 | 45.2 ± 5.2**# | 0.00 | 3.1 ± 1.6 | 0.6 | 41.0 ± 5.3 | 41.8 ± 6.5 | 0.26 | 0.8 ± 1.5 | 0.1 |
| $HR_{max}$ (bpm) | 187 ± 8 | 181 ±11 | 0.09 | -5.9 ± 7.7 | -0.5 | 174 ±9 | 173 ±10 | 0.16 | -1.6 ±2.6 | -0.2 |
| $Speed_{max}$ ($km·h^{-1}$) | 14.1 ± 1.4 | 14.6 ±1.6 | 0.11 | 0.4 ± 0.6 | 0.3 | 13.8 ±1.5 | 14.3 ±1.9 | 0.20 | 0.5 ±0.8 | 0.3 |

Dif. (%) = mean differences in percentage, ES = effect size. ** p < 0.01 significant differences with pre test. # p < 0.05, two way mixed ANOVA analysis (group x time) statistical differences.

Sciences (SPSS Inc, version 24.0 for Windows, Chicago, IL, USA). The statistical significance was set at $p < 0.05$. Despite the fact that in some cases, a variable showed a p value > 0.05, whereas, ES was greater than 0.5 (moderate), was considered practical difference.

## Results

No significant differences were found pre-intervention between $HIIT_{run}$ and $HIIT_{bike}$ for $VO_{2max}$, $HR_{max}$ and $Speed_{max}$ in the incremental treadmill test or any variable obtained during the 10 km TT. After 4-weeks of the HIIT intervention, $HIIT_{run}$ improved $VO_{2max}$ significantly ($p < 0.01$, ES = 0.6, moderate), and decreased $HR_{max}$ (p = 0.09, ES = -0.5, moderate) whereas the $Speed_{max}$ values were maintained (p = 0.11, ES = 0.3, small). In the $HIIT_{bike}$, no changes were observed after 4-weeks for $VO_{2max}$, $HR_{max}$ and $Speed_{max}$ (p = 0.16 to 0.26, ES = -0.2 to 0.3, trivial to small) (Table 2). According to the two-way mixed ANOVA analysis (group x time), only $VO_{2max}$ showed a statistically significant difference. The $HIIT_{run}$ group enhanced the $VO_{2max}$ result in the post-test (p = 0.01) while the $HIIT_{bike}$ group showed no change.

After 4-weeks of the intervention, neither $HIIT_{run}$ nor $HIIT_{bike}$ changed either the time to complete the 10 km TT (p = 0.06 to 0.84), ES = 0.1 to -0.2, trivial to small), or average heart rate ($HR_{av}$) (p = 0.14 to 0.58, ES = -0.2 to -0.3, small) (Table 3). $HIIT_{run}$ resulted in a highe lactate concentration at the end of the test ($Lactate_{post}$) (p = 0.18 to 0.05, ES = 3.6, very large). There was a significant increase in the average and maximum rating of perceived exertion ($RPE_{av}$) (p = 0.04, ES = 1.7, large) and $RPE_{max}$ (p = 0.04, ES = 1.6, large), whereas, $HR_{av}$ did not change significantly (p > 0.05, ES = -0.2, trivial) (Table 3). In the $HIIT_{bike}$ group the average pace decreased significantly (p = 0.02, ES = -0.3 small) and the maximal rate of perceived exertion ($RPE_{max}$) increased during the 10 km TT post-test (p = 0.04, ES = 0.9, large) (Table 3). There were no group x time differences.

Table 3 and Figure 1 show the results for the 1st and 8th HIIT sessions. $HIIT_{run}$ demonstrated a significant increase for $RPE_{av}$ (p = 0.03, ES = 0.8, moderate) and an increase in lactate concentration values immediately after the session ($Lactate_{post}$) (p = 0.14, ES = 0.6, moderate) (Table 4) and creatine-kinase (CK) concentration before session ($CK_{pre}$) (p = 0.15, ES = 1.0, large) (Figure 1). No significant differences were observed for the remaining variables. The $HIIT_{bike}$ group showed a significant improvement in $Speed_{av}$, $P_{av}$, and $P_{max}$ (p = 0.01 to 0.03, ES = 0.6 to 0.7, moderate), while increases in $RPE_{av}$ and delayed onset muscle soreness immediately after training ($DOMS_{post}$) were also observed (p = 0.02, ES = 1.4 to 2.2, large) (Table 4). The maximal heart rate obtained during HIIT sets and recovering sets ($HR_{max-work}$ and $HR_{maxrecovery}$) and $Lactate_{post}$ demonstrated practical increases although these were not significant (p = 0.16 to 0.34, ES = 0.6 to 2.0, moderate to large). The average heart rate recorded during recovery intervals ($HR_{av\ recovery}$) and the concentration of CK 24-hour after the HIIT session ($CK_{24after}$) decreased practically (p = 0.46 to 0.49, ES = -0.6 to -1.0, moderate to large) (Figure 1). According to the two-way mixed ANOVA analysis (group x time), only $DOMS_{post}$ showed statistical significance (p = 0.017).

## Discussion

Previous studies have analysed the effects of HIIT in individual exercise modes on a single mode of activity (Cook et al., 2010; Laursen et al., 2002; Sijie et al., 2012). However, the effects of this training method in running or cycling on performance in a single mode such as running in female athletes has not been studied. In the current investigation, only the $HIIT_{run}$ group evoked significant improvement in $VO_{2max}$ during a maximal treadmill test. Neither $HIIT_{run}$ nor $HIIT_{bike}$ significantly enhanced the time to complete 10 km TT, despite a significant decrease in average pace for the $HIIT_{bike}$ participants. Running HIIT generated a significantly greater level of muscular fatigue in non-

**Table 3. Results for Run ($HIIT_{run}$) and Bike ($HIIT_{bike}$) group in pre and post- intervention tests for, lactate values, average pace ($Pace_{av}$), Time, heart rate average ($HR_{av}$), maximum heart rate ($HR_{max}$), average rating of perceived exertion ($RPE_{av}$) and maximum rate of perceived exertion ($RPE_{max}$) obtained in the 10 km time trial.**

| | $HIIT_{run}$ | | | | | $HIIT_{bike}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre test | Post test | p | Dif. (%) | ES | Pre test | Post test | p | Dif. (%) | ES |
| Lactate (mmol/l) | 3.3 ± 0.8 | 6.6 ± 0.9 | 0.18 | 3.3 ± 0.6 | 3.6 | 5.9 ± 2.5 | 7.8 ± 4.4 | 0.23 | 1.8 ± 3.6 | 0.4 |
| $Pace_{av}$ (min/km) | 5.36 ± 0.8 | 5.36 ± 0.7 | 0.91 | 0.0 ± .5 | 0.0 | 5.48 ± 1.3 | 5.30± 1.0* | 0.02 | -0.4 ± 0.3 | -0.4 |
| Time (min) | 57.4 ± 7.3 | 57.8 ± 6.0 | 0.84 | -0.4 ± 4.5 | 0.1 | 59.7 ± 11.9 | 57.5 ± 10.8 | 0.06 | -2.1 ± 2.5 | -0.02 |
| $HR_{av}$ (bpm) | 172 ± 9 | 170 ± 8 | 0.58 | -1.4 ± 6.5 | -0.2 | 169 ± 10 | 166 ± 12 | 0.14 | -3.6 ± 5.5 | -0.3 |
| $RPE_{av}$ (AU) | 5 ± 2 | 7 ± 1* | 0.05 | 1.5 ± 1.6 | 1.7 | 6 ± 2 | 6 ± 2 | 0.41 | 0.4 ± 1.3 | 0.3 |
| $RPE_{max}$ (AU) | 7 ± 2 | 8 ± 1* | 0.04 | 1.3 ± 1.3 | 1.6 | 6 ± 1 | 8 ± 2* | 0.05 | 1.6 ± 1.7 | 0.9 |

Dif. (%) = mean differences in percentage, ES = effect size. *p < 0.05 significant differences with pre test

**Table 4. Results in 1st and 8th HIIT session for Run HIIT ($HIIT_{run}$) and for Bike HIIT ($HIIT_{bike}$) group.**

| | | 1st HIIT | 8th HIIT 8 | p | Dif. (%) | ES |
|---|---|---|---|---|---|---|
| $HIIT_{run}$ | $HR_{av\text{-}work}$ (bpm) | 167 ± 5 | 166 ± 10 | 0.91 | -0.3 ± 6.4 | -0.0 |
| | $HR_{max\text{-}work}$ (bpm) | 182 ± 6 | 183 ± 10 | 0.69 | 1.0 ± 5.7 | 0.1 |
| | $HR_{av\ recovery}$ (bpm) | 148 ± 9 | 147 ± 17 | 0.91 | -0.4 ± 9.6 | -0.0 |
| | $HR_{max\ recovery}$ (bpm) | 181 ± 7 | 181 ± 10 | 1.00 | 0.0 ± 4.2 | 0.0 |
| | $Pace_{av}$ ($min \cdot km^{-1}$) | 4.11 ± 0.5 | 3.59 ± 0.4 | 0.27 | -0.1 ± 0.3 | -0.4 |
| | $Distance_{av}$ (m) | 386.2 ± 22.5 | 389.8 ± 30.6 | 0.54 | 3.6 ± 11.9 | 0.1 |
| | $RPE_{av}$ (AU) | 7 ± 1 | 8 ± 2* | 0.03 | 1.1 ± 1.1 | 0.8 |
| | $RPE_{max}$ (AU) | 10 ± 1 | 10 ± 1 | 1.00 | 0.0 ± 1.0 | 0.0 |
| | $Lactate_{pre}$ ($U \cdot L^{-1}$) | 1.7 ± 0.4 | 1.6 ± 0.7 | 0.74 | -0.1 ± 0.6 | -0.1 |
| | $Lactate_{post}$ ($U \cdot L^{-1}$) | 6.3 ± 2.2 | 8.0 ± 3.2 | 0.14 | 1.8 ± 2.8 | 0.6 |
| | $DOMS_{pre}$ (AU) | 0.6 ± 1.5 | 1.0 ± 2.2 | 0.20 | 0.4 ± 0.8 | 0.2 |
| | $DOMS_{post}$ (AU) | 2.0 ± 1.6 | 2.4 ± 1.9 | 0.43 | 0.4 ± 1.1 | 0.2 |
| | $DOMS_{24After}$ (AU) | 1.0 ± 2.4 | 1.2 ± 2.4 | 0.36 | 0.2 ± 0.4 | 0.1 |
| $HIIT_{bike}$ | $HR_{av\text{-}work}$ (bpm) | 153 ± 6 | 152 ± 12 | 0.77 | -1.3 ± 11.0 | -0.1 |
| | $HR_{max\text{-}work}$ (bpm) | 155 ± 23 | 164 ± 13 | 0.16 | 9.2 ± 12.0 | 0.7 |
| | $HR_{av\ recovery}$ (bpm) | 145 ± 15 | 139 ± 11 | 0.49 | -6.2 ± 20.3 | -0.6 |
| | $HR_{max\ recovery}$ (bpm) | 156 ± 18 | 168 ± 6 | 0.29 | 12.2 ± 22.3 | 2.0 |
| | $Speed_{av}$ ($km \cdot h^{-1}$) | 33.9 ± 4,5 | 36.2 ± 3.0* | 0.02 | 2.3 ± 1.8 | 0.7 |
| | $P_{av}$ (W) | 166 ± 49 | 198 ± 44** | 0.01 | 32.4 ± 20.0 | 0.7 |
| | $P_{max}$ (W) | 240 ± 77 | 280 ± 63* | 0.03 | 40.0 ± 36.8 | 0.6 |
| | $Cadence_{av}$ (rpm) | 93 ± 12 | 93 ± 6 | 0.84 | 0.7 ± 9.0 | 0.1 |
| | $Cadence_{max}$ (rpm) | 103 ± 13 | 104 ± 8 | 0.86 | 0.7 ± 9.9 | 0.1 |
| | $RPE_{av}$ (AU) | 7 ± 1 | 8 ± 1* | 0.02 | 1.7 ± 1.5 | 2.2 |
| | $RPE_{max}$ (AU) | 9 ± 1 | 10 ± 1 | 0.09 | 0.7 ± 1.0 | 1.5 |
| | $Lactate_{pre}$ ($mmol \cdot l^{-1}$) | 1.8 ± 0.6 | 1.5 ± 0.6 | 0.39 | -0.3 ± 0.8 | -0.5 |
| | $Lactate_{post}$ ($mmol \cdot l^{-1}$) | 10.3 ± 3.8 | 11.6 ± 2.3 | 0.34 | 1.3 ± 3.4 | 0.6 |
| | $DOMS_{pre}$ (AU) | 0.3 ± 0.8 | 2.0 ± 2.2 | 0.12 | 1.7 ± 2.5 | 0.8 |
| | $DOMS_{post}$ (AU) | 1.9 ± 1.1 | 6.1 ± 3.0*# | 0.02 | 4.3 ± 3.4 | 1.4 |
| | $DOMS_{24After}$ (AU) | 2.3 ± 2.2 | 1.6 ±1.4 | 0.14 | -0.7 ± 1.1 | -0.5 |

*Variables:* Work interval average Heart rate ($HR_{av\text{-}work}$ Work interval maximum Heart rate ($HR_{max\text{-}work}$) , recovery interval average Heart rate ($HR_{av\text{-}recovery}$), recovery interval maximum Heart rate ($HR_{max\text{-}recovery}$ ), average pace ($Pace_{av}$), work average distance ($Distance_{av}$) average speed ( $Speed_{av}$ ), Power average ($P_{av}$), Maximum Power obtained($P_{max}$), Averge cadence ($Cadence_{av}$ ), maximum cadence($Cadence_{max}$), average work interval rate of perceived exertion ($RPE_{av}$) and work interval maximum rate of perceived exertion ($RPE_{max}$), Lactate concentration pre test ($Lactate_{pre}$), lactate concentration post test ($Lactate_{post}$), Delayed Onset Muscle soreness pre test ($DOMS_{pre}$) , Delayed Onset Muscle soreness post test ($DOMS_{post}$), Delayed Onset Muscle soreness 24 hour after test ($DOMS_{24After}$). Dif. (%) = mean differences in percentage, ES = effect size. *$p < 0.05$, ** $p < 0.01$ significant differences with pre test. # $p < 0.05$, two way mixed ANOVA analysis (group x HIIT session) statistical differences.

competitive female runners compared to cycling HIIT.

As noted above, $VO_{2max}$ improved significantly in the $HIIT_{run}$ group while the remaining maximal test variables in each training group were not significantly modified. This situation may be due in part to an excessive training amount accumulated by runners who may not have been accustomed to structured HIIT. Previous investigations observed improvements in $VO_{2max}$ and maximal test variables such as HR and speed or power, however the performance level changed from the current investigation. Rowan et al. (2012) observed an enhancement of 4.73% in $VO_{2max}$ after 5-week of 5 x 30 s with 4.5 min recovery in female soccer players, however, similar results were obtained from the control group who performed 40 min continuous running at 80% of $VO_{2max}$. In another study, Gunnarsson and Bangsbo (2012) showed that 7-weeks of short interval HIIT improved $VO_{2max}$ in moderately trained male and female runners. Mallol et al. (2018) concluded that after 4-weeks of a cycling HIIT program in moderately trained triathletes, participants improved 6.7% in $VO_{2max}$ and 15% in peak power. Finally, Lesmes et al. (1978) after 8-weeks of two types of supra maximal interval training (short duration at 170% of velocity at $VO_{2max}$ ($vVO_{2max}$) and long duration at 130% at $vVO_{2max}$) concluded that the frequency of training, interval distances and intensities were independent of changes in aerobic power and submaximal HR in females, whereas, interval training intensity was essential to improve these variables in males rather than frequency and interval distance. In our study, $HIIT_{run}$ achieved greater changes than $HIIT_{bike}$ and this may be due to the specificity of the activity. For future investigations, it would be relevant to consider the effects of cycling HIIT during a maximal test using a cycle ergometer. Additionally, comparing different HIIT interventions of different intensity and work to rest characteristics.

During the 10 km TT the $HIIT_{run}$ performance remained unchanged but $RPE_{av}$ increased significantly indicating a greater perception of effort. At the same time, $HR_{max}$ decreased after 4-week of $HIIT_{run}$ program. Perceived exertion may have increased during post -intervention running 10 km TT because of individual fatigue accumulated after the HIIT program possibility due to insufficient recovery after the period of intensified training. Controversially, other researchers have observed improvements in running performances after a HIIT program. Gunnarsson and Bangsbo (2012) obtained an improvement of 6% and 4% in 1500 m and 5 km running tests, respectively. The protocol employed included 7-weeks of interval running working at intensities of 90% of $HR_{max}$ with a 54% training volume reduction in moderately trained females.

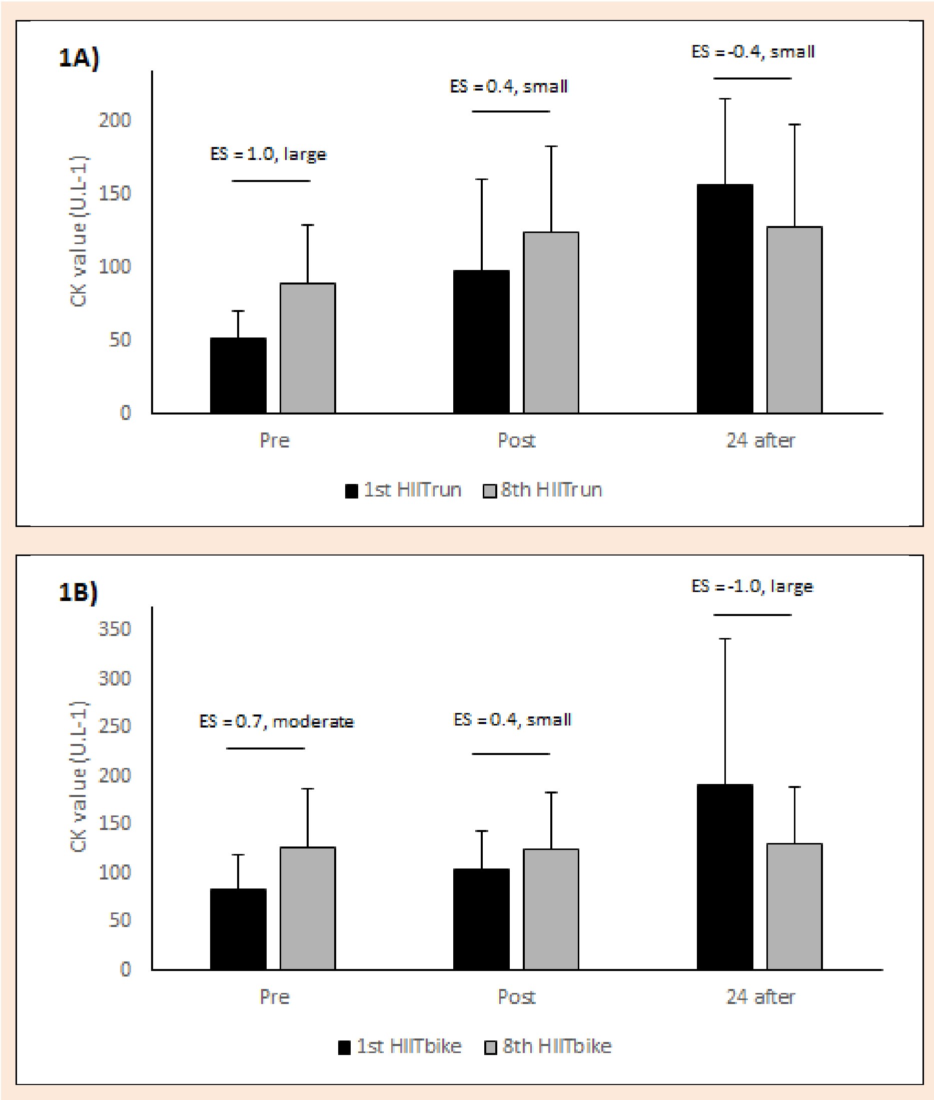


**Figure 1. Comparison between A) $HIIT_{run}$ and B) $HIIT_{bike}$ for CK pre, immediately post and 24-hour after HIIT session.** *Variables:* Creatine Kinase values pre session (pre); Creatine Kinase values immediately post session (post); CK values 24 hour after the session (24 after); First HIIT session of the program (1st HIIT); last session of the program (8th HIIT).

In addition Paavolainen et al. (1999) showed an improvement in 5 km run time in well-conditioned athletes with no changes in $VO_{2max}$, similar to that observed in the current study results for $HIIT_{bike}$ participants. Furthermore, Bangsbo et al. (2009) observed a decrease of 1 min in 10 km performance (from 37 min to 36 min) after a 6-9-week training period with intervals near maximal speed with a 30% reduced total training volume. However, Iaia et al. (2009) determined that after 4-week of 8-12 x 30 s maximal speed intervals and a 64% reduction in total training volume, but there were no improvements in 10 km TT run in these endurance trained participants. The studies mentioned above enhanced running performance after HIIT interventions, however, a number of these studies replaced a part of the participants' usual training volume with HIIT sessions. In the current research, the intensities employed during HIIT intervals were maximal or close to maximal which may have generated an excessive training stress, and therefore, excess residual fatigue to the amateur female runners.

By contrast, the $HIIT_{bike}$ participants significantly increased performance ($Pace_{av}$, min/km) during the 10 km TT run with an increased $RPE_{max}$. Similarly, Mikesell and Dudley (1984) noted a decrease of 81 s on 10 km distance in well-trained runners after an intensive aerobic program, combining 40 min run "all out" 3 days a week with 5 x 5 min at $VO_{2max}$ intervals with 5 min jogging on the treadmill as recovery. A number of investigations conducted with cyclists concluded that cycling HIIT significantly enhances cycling performance in a range of testing protocols and competitive simulations (Laursen et al., 2002; Lindsay et al., 1996; Stepto et al., 1999). The use of HIIT using identical activity modes to that of competition helped to improve the sports performance. Despite the fact that the $HIIT_{bike}$ group did not show significant differences for time to complete 10 km TT, the $Pace_{av}$ manifested a significant decrease, hence, performance during the 10 km TT post-test was enhanced. Whilst the mechanisms accounting for this performance improvement are unknown, it is possible that a gain in lower limb muscular power because of the cycle HIIT sessions led to this improvement. It is also possible that the exercise mode of running presented a higher physiological demand due to a greater muscle recruitment, contraction type and accumulative fatigue which was associated with the different performance adaptations between modes (Le Meur et al., 2011). Nevertheless, the present study results suggest that the $HIIT_{run}$ program did not result in an improvement in 10 km performance considering that a greater $lactate_{post}$ concentration and $RPE_{max}$ were observed post-test despite a similar $HR_{av}$ and similar time to complete the time trial.

This study is novel in that biochemical and perceptive markers associated with muscle soreness were measured in the acute stages following the first ($1^{st}$) and last ($8^{th}$) HIIT sessions. Following the $HIIT_{run}$ intervention $RPE_{av}$, $lactacte_{post}$, and specifically, $CK_{pre}$ were elevated, whereas, distance completed and $Pace_{av}$ remained the same from the $1^{st}$ HIIT compared with the $8^{th}$ HIIT session. This potentially indicates a greater level of muscle damage and lack of assimilation to the HIIT running program.By contrast, $HIIT_{bike}$ participants improved $Speed_{av}$ and $Power_{av}$ from the $1^{st}$ to $8^{th}$ HIIT session. This enhancement was associated with more positive responses for $RPE_{av}$, $RPE_{max}$, $DOMS_{post}$, $lactate_{post}$ and $HR_{max}$, although $HR_{av}$ decreased during recovery, suggesting that $HIIT_{bike}$ athletes were able to perform more effectively in the session. At the same time both groups showed greater $CK_{pre}$ during the $8^{th}$ HIIT. However, the difference between sessions were smaller, once again this may have occurred due to fatigue accumulation and lack of assimilation of the high intensity training. Furthermore, $CK_{24h}$ values after the $8^{th}$ HIIT session decreased compared with the $1^{st}$ HIIT in the $HIIT_{bike}$ group, which may show a physiological adaptation such that $HIIT_{bike}$ runners were able to achieve a superior level of recovery from muscular fatigue.

Previous studies have focused on markers of muscle damage such as, CK concentration and DOMS after a high intensity training program in runners and cyclist while performing running and cycling testing in isolation (Nieman et al., 2014). In these studies, it was shown that muscle damage was related to activity mode. Nieman et al. (2014) analysed differences between running and cycling performances on runners and cyclists after 3 consecutive days of an 'overreaching' training program, concluding that the eccentric contractions intrinsic to running, resulted in 133% greater CK concentration and 87% greater DOMS in runners immediately after 3 days of running training compared with cyclists performing similar training on a cycle ergometer. Additionally, CK concentrations remained more elevated in runners than in cyclists 1, 14 and 38 h after the training program. Similarly, DOMS presented a comparable pattern to CK at 1 and 14 h and by 38 h post intervention; the values were similar in both groups. Likewise, Bruunsgaard et al. (1997) and Proske and Allen (2005) concluded that eccentric activities generated higher levels of muscle damage (CK, DOMS and myoglobin) compared with isometric and concentric contractions. In our study, $CK_{pre}$ before the first and last HIIT were greater in the cycling group than the running group. However, the difference between sessions for $CK_{post}$ were similar in both groups. For its part, CK24h results showed that $HIIT_{bike}$ might be able to recover faster than $HIIT_{run}$ after a HIIT program.

One of the current research limitations relates to sample size. Longitudinal studies, which require the completion of exhaustive and multiple assessments during an intervention, are onerous on participants, particularly taking into account work and family commitments. This can make it difficult to recruit large numbers of participants and contributed to some of the drop out in the current study. Another limitation relates to the timing of the 10 km TT on the same day of, and following, the maximal incremental test, the completion of multiple, exhaustive tests may have detrimentally affected the performance outcomes for subsequent tests on the same day. This is somewhat ameliorated in that all participants undertook the same testing process both before and after the intervention.

## Conclusion

After 4-weeks of a HIIT program, only $HIIT_{run}$ participants improved $VO_{2max}$ whereas no improvements were observed for 10 km TT run performance potentially due to fatigue accumulation generated by the HIIT training itself. Although no significant group by time differences were observed, the $HIIT_{bike}$ participants demonstrated improved 10 km TT run performance ($Pace_{av}$) indicative of positive cross training transfer. This occurred without changes in $VO_{2max}$ during maximal incremental running tests. Both HIIT modes evoked some muscle damage although $HIIT_{bike}$ seems to have achieved faster muscular recovery 24 h after HIIT session completion. Therefore, it appears that a $HIIT_{run}$ program in recreational female athletes produces excessive stress, fatigue and muscle damage which may have resulted in inadequate stimulus for enhancement of running performance, whereas, $HIIT_{bike}$ may be a beneficial training modality that can be used to improve running performance.

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## Key points

- This article observes the effects of a HIIT program in two different modes, i.e. cycling and running, in a hardly investigated population, recreational middle-age female runners.
- The analysis of physiological variables in a HIIT session, maximal test and 10 km time trial run performance.

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