Apunts Med Esport. 2017;52(196):131–138

apunts
MEDICINA DE L'ESPORT
www.apunts/org

ORIGINAL ARTICLE

Physiological and performance responses to high-intensity interval training in female inline speed skaters

Sara Fereshtian [a], Mohsen Sheykhlouvand [b,c,*], Scott Forbes [d], Hamid Agha-Alinejad [e], Mohammadali Gharaat [f]

[a] *Department of Exercise Physiology, Faculty of Physical Education & Sport Sciences, Islamic Azad University, Central Tehran Branch, Tehran, Iran*
[b] *Department of Exercise Physiology, Faculty of Physical Education & Sport Sciences, University of Guilan, Rasht, Iran*
[c] *Department of Exercise Physiology, Faculty of Humanities, Islamic Azad University, Ardabil Branch, Ardabil, Iran*
[d] *Human Kinetics, Okanagan College, Penticton, Canada*
[e] *Department of Physical Education and Sports Sciences, Faculty of Humanities, Tarbiat Modares University, Tehran, Iran*
[f] *Department of Exercise Physiology, Faculty of Physical Education & Sport Sciences, Shahid Rajaee Teacher Training University, Tehran, Iran*

Received 7 February 2017; accepted 12 June 2017
Available online 14 October 2017

KEYWORDS
Running;
Oxygen consumption;
Anaerobic threshold;
Athletic performance;
Skating

Abstract
Objective: To evaluate and compare the effects of high-intensity interval training (HIIT) varying in exercise intensities to traditional endurance training (TET) on physiological and performance adaptations in trained female inline speed skaters.
Methods: Participants were randomly assigned to one of 3 HIIT groups: 6,8,10 (repetitions/session from 1st to 3rd week respectively) × 60 seconds (s) at the running speed associated with $\dot{V}O_{2\,max}$ (100%$v\dot{V}O_{2\,max}$) (H_{100}, $N = 7$), 115%$v\dot{V}O_{2\,max}$ (H_{115}, $N = 7$), and 130%$v\dot{V}O_{2\,max}$ (H_{130}, $N = 7$), 1:3 work to recovery ratio; and/or TET group ($N = 7$): 60-minute running at 75%$v\dot{V}O_{2\,max}$ three sessions per week.
Results: Significant (except as shown) improvements ($p < 0.05$) following HIIT were found in: $\dot{V}O_{2\,max}$ (H_{100} = +7.6%, H_{115} = +6.1%, H_{130} = +0.1%; $p = 0.4$), $v\dot{V}O_{2\,max}$ (H_{100} = +10.3%, H_{115} = +6.3%, H_{130} = +9.8%), peak power output (PPO) (H_{100} = +10.3%, H_{115} = +9.1%, H_{130} = +5.5%; $p = 0.2$), mean power output (MPO) (H_{100} = +22.6%, H_{115} = +24.1%, H_{130} = +21.9%), 3000 meter (m) skating performance (H_{100} = −15.2%, H_{115} = −7.9%, H_{130} = −10.6%), and T_{max} (H_{100} = +39.4%, H_{115} = +5.0%; $p = 0.5$, H_{130} = +17.8%; $p = 0.1$). No significant differences were found among groups. Also, no changes in these variables were found in the TET group.

* Corresponding author.
E-mail address: m.sheykhlouvand@gmail.com (M. Sheykhlouvand).

http://dx.doi.org/10.1016/j.apunts.2017.06.003

Conclusions: Present findings suggest that three weeks of HIIT program with low volume (almost 6 or 10 min per session) is associated with improvements in $\dot{V}O_{2\,max}$, $v\dot{V}O_{2\,max}$, PPO, MPO, 3000 m skating performance, and T_{max} in trained female inline speed skaters.

PALABRAS CLAVE
Carrera;
Consumo de oxígeno;
Umbral anaeróbico;
Rendimiento deportivo;
Patinaje

Respuestas fisiológicas y de rendimiento sobre el entrenamiento a intervalos de alta intensidad en mujeres patinadoras de velocidad en línea

Resumen
Objetivo: Valorar y comparar los efectos de las adaptaciones fisiológicas y de resistencia del entrenamiento por intervalos de alta intensidad (EIAI) sobre el entrenamiento de resistencia tradicional (ERT), modificando la intensidad del ejercicio, en mujeres patinadoras de velocidad en línea entrenadas.
Método: Las participantes fueron asignadas aleatoriamente a uno de los 3 grupos EIAI: 6, 8, 10 (repeticiones/sesión de 1 a 3 semanas respectivamente) $\times$ 60 segundos (s) a una velocidad de carrera asociada al $\dot{V}O_{2\,max}$ (100%$v\dot{V}O_{2\,max}$) (H_{100}, n = 7), 115%$v\dot{V}O_{2\,max}$ (H_{115}, n = 7), y 130%$v\dot{V}O_{2\,max}$ (H_{130}, n = 7), 1:3 relación esfuerzo recuperación; y/o grupo ERT (n = 7): 60 min de carrera 75% $v\dot{V}O_{2\,max}$ tres sesiones por semana.
Resultados: Se hallaron las siguientes mejoras significativas ($p < 0{,}05$) (excepto, como se indica) EIAI en: $\dot{V}O_{2\,max}$ (H_{100} = +7,6%, H_{115} = +6,1%, H_{130} = +0,1%; p = 0,4), $v\dot{V}O_{2\,max}$ (H_{100} = +10,3%, H_{115} = +6,3%, H_{130} = +9,8%), pico de potencia máxima (PPO) (H_{100} = +10,3%, H_{115} = +9,1%, H_{130} = +5,5%; p = 0,2), potencia media (MPO) (H_{100} = +22,6%, H_{115} = +24,1%, H_{130} = +21,9%), rendimiento 3.000 metros (m) de patinaje (H_{100} = −15,2%, H_{115} = −7,9%, H_{130} = −10,6%), y T_{max} (H_{100} = +39,4%, H_{115} = +5,0%; p = 0,5, H_{130} = +17,8%; p = 0,1). No se hallaron diferencias entre los grupos. Tampoco se hallaron cambios en estas variables en el grupo ERT.
Conclusiones: Estos hallazgos sugieren que tres semanas de un programa EIAI, a un entrenamiento bajo (unos 6 o 10 min por sesión), se asocia a mejoras en el rendimiento de 3.000 m de patinaje en $\dot{V}O_{2\,max}$, $v\dot{V}O_{2\,max}$, PPO, MPO, y T_{max} en mujeres patinadoras de velocidad en línea entrenadas.

Introduction

Inline speed skating at the World Championships is divided into two major disciplines; track and road racing. Official distances of track races range from 300 m to 15,000 m and road races range from 200 m to 42,195 m. Both track and road races require high intensity bouts of sprinting, interspersed with short periods of low-to-moderate intensity ''rest'' periods.[1] Success in inline speed skating has been attributed to powerful starts and high rates of ATP re-phosphorylation via non-oxidative (''anaerobic'')[2,3] and oxidative metabolism.[4,5] As such, inline speed skaters require well-developed anaerobic and aerobic energy systems.[2,5,6]

Inline speed skaters are required to obtain peak performance several times over an annual training. Training programs capable of increasing aerobic metabolism are based mainly on periods of at least 6 weeks and such programs are often based on continuous endurance training,[7] in these cases, low-volume HIIT may represent an alternative to endurance training to improve aerobic and anaerobic performance in a short time frame.[13]

High-intensity interval training (HIIT) is a potent training stimulus to improve anaerobic and aerobic energy systems[8–11] over a short time period (e.g., 6 sessions over 2 weeks[12,13]). HIIT performed with various intensities (%$v\dot{V}O_{2\,max}$) have been used to improve performance in athletes from a wide range of sports;[10,14] however, to date information regarding the effects of HIIT on performance in female inline speed skating athletes is limited. Furthermore, Because of the paucity of data that relate directly to our understanding of the physiological and performance adaptations that occur following high-intensity interval training in trained athletes,[14] it is unclear which intensity of HIIT is more effective for improving required adaptations of female speed skaters in short period. Accordingly, the aim of the present study was to examine the effects of three different HIIT protocols with different intensities (100, 115, and 130% velocity at $\dot{V}O_{2\,max}$ [$v\dot{V}O_{2\,max}$]) compared to traditional endurance training (TET) over 3 weeks on physiological, hematological and performance adaptations in trained female inline speed skaters. The hypothesis is that traditional endurance training will show less training effects on aerobic and anaerobic performances than HIIT. In addition, we hypothesize that HIIT with intensity equivalent to $\dot{V}O_{2\,max}$ would induce greater physiological and performance adaptations compared to higher intensities.

Material and methods

Participants

Twenty-eight female inline speed skaters (mean ± SD; age: 20 ± 4 years; height: 160.5 ± 13 cm; body mass: 59.5 ± 13 kg) volunteered for the study. All subjects had a minimum of 3 years of inline speed skating experience (years' experience: 7 ± 3 years), competed at the national level, and currently trained at least 3 times per week. Prior to any participation, the experimental procedures and potential risks were explained fully to the subjects and all provided written informed consent. All the procedures were in accordance with ethical principles of declaration of Helsinki, approved by ethical committee of local University.

Experimental protocol and procedures

The experimental procedures consisted of a familiarization phase (including 3 sessions to familiarize the participants to the equipment and protocols and to reduce any learning effect), followed by pre-testing, then 3 weeks of treadmill training, and then post-testing (Fig. 1). The training was conducted on a treadmill because during the winter month's weather conditions make sport specific training difficult,[5] as such inline speed skaters often cross train on treadmills, which are highly accessible. Pretesting of aerobic and anaerobic performances, along with hematological parameters, was conducted before the beginning of the preseason phase of the athletes' yearly training program. Before and after the training programs, participants reported to the laboratory on three occasions, each session was separated by 48 hours. The first day of testing included an incremental test to exhaustion to determine maximum oxygen uptake ($\dot{V}O_{2\,max}$), anaerobic threshold (AT (%$\dot{V}O_{2\,max}$)), and time to exhaustion at $v\dot{V}O_{2\,max}$ (T_{max}). The second day included a 30-second lower-body Wingate test to determine peak power output (PPO) and mean power output (MPO) on an electrically braked ergometer. The third day consisted of a sport specific 300 m and 3000 m time trial on a 200 m skating track.

Following pre-testing participants were randomly assigned to one of four groups. Participants completed either a progressive HIIT program or TET program three sessions per week. These protocols were modified from previous research using similar training intensities and durations.[7,15] Two days after the completion of the last training session participants repeated the same battery of tests in the same order and under similar conditions as pre-testing. Dietary food records were collected two days before pre testing and this diet was replicated prior to post testing, to reduce any dietary influence on performance.

Procedures

Graded exercise test. In order to determination of $\dot{V}O_{2\,max}$, $v\dot{V}O_{2\,max}$, O_2 pulse and AT, participants performed an incremental treadmill test consisting of a 3 min walking warm-up at 6 km h^{-1} with 0% incline, followed by 1 km h^{-1} increments each minute until volitional exhaustion.[7,16,17] Metabolic variables were measured using a gas analyser (Cosmed K4B2, Italia) that was calibrated before, and verified after each test according to the manufacturer's instructions. $\dot{V}O_{2\,max}$ was confirmed when 3 or more of the following criteria were met: (1) a plateau in $\dot{V}O_2$ despite an increase in running speed; (2) a respiratory exchange ratio (RER) higher than 1.1; (3) a heart rate within 10 bpm of its predicted maximum; and/or (4) volitional exhaustion. $v\dot{V}O_{2\,max}$ was recorded as the minimal velocity at which the athlete was running when $\dot{V}O_{2\,max}$ occurred.[7,17,18] O_2 pulse was determined by dividing the absolute $\dot{V}O_2$ by the corresponding heart rate. Anaerobic threshold (%$\dot{V}O_{2\,max}$) was determined using the V-Slope method.[7,19]

Determination of T_{max}. For determination of T_{max}, after a 10 min warm up on a treadmill (Techngym, DAK9EC, Italia), speed was increased to $v\dot{V}O_{2\,max}$ and participants were verbally encouraged to run as long as possible. Time to exhaustion at $v\dot{V}O_{2\,max}$ (T_{max}) was recorded.[16] The post-HIIT T_{max} test was completed at the same speed as the pre-HIIT T_{max} test under the same conditions.[9]

Anaerobic power. Peak power output (PPO) and mean power output (MPO) were assessed by a 30-second all-out effort (Wingate test) on a cycle ergometer (894E, Monark, Sweden) against a resistance equivalent to 0.075 kg kg^{-1} body mass.[20] The subjects' feet were firmly strapped to the pedals, and the seat height was adjusted for optimal comfort and pedaling efficiency. Participants reached maximum pedaling velocity against the ergometer's inertial resistance over 2 seconds before the full load was applied and the electronic revolution counter was activated. Participants were verbally encouraged to continue pedaling as fast as possible throughout the 30-second test. The 5 second PPO, and 30 second MPO were subsequently determined using a data-acquisition system.[7,16,17]

Blood sampling. For hematological measurements, blood was drawn by venepuncture and dispensed into EDTA tubes. Red blood cell (BBC), hemoglobin (Hb), hematocrit (Hct), and mean corpuscular hemoglobin (MCH) counts were measured using an automated cell counter (Diatron, Abacus C, Hungary).

HIIT and TET protocols. The study consisted of four training interventions (Fig. 1). The training sessions of each HIIT group (H_{100}, H_{115}, H_{130}) consisted of 60 seconds of running performed at 100%$v\dot{V}O_{2\,max}$ (i.e., H_{100}), 115%$v\dot{V}O_{2\,max}$ (i.e., H_{115}), and 130%$v\dot{V}O_{2\,max}$ (i.e., H_{130}). Training volume (bouts/session) increased each week (6 [1st week], 8 [2nd week], 10 [3rd week] bouts/session) in all three HIIT groups. In all HIIT groups, recovery between intervals was set at 3 min. The participants in the TET group performed 3 sessions per week consisting of 60 min at an intensity equivalent to 75%$v\dot{V}O_{2\,max}$.[9] All subjects were instructed to not engage in strength training or change their diet for the duration of the study.[21] All training sessions for all groups were directly supervised by a study investigator.

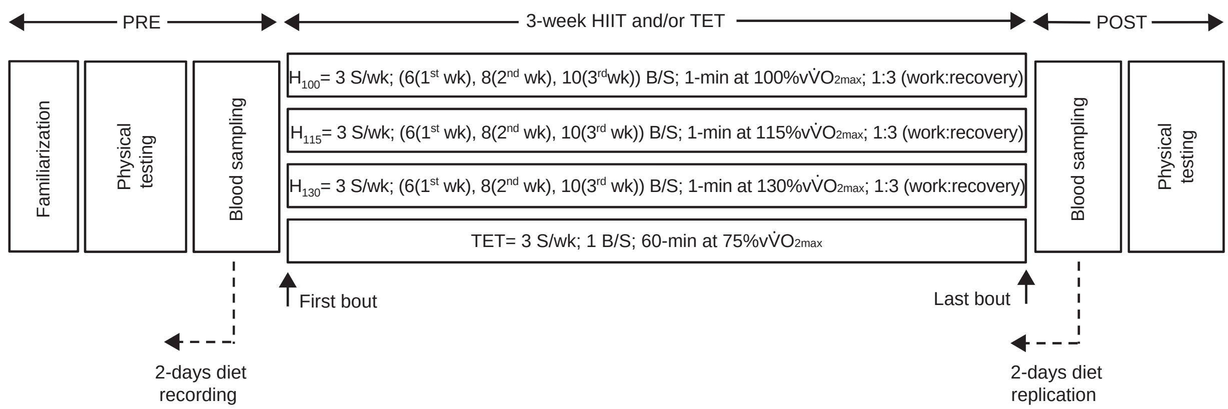

Figure 1 Overview of experimental protocol. **PRE**, pre-exercise; **POST**, post-exercise; **HIIT**, high-intensity interval Training; **TET**, traditional endurance training; **wk**, week; **d**, day; **S/wk**, sessions/week; **B/S**, bouts/session.

Statistical analysis

Results were expressed as means ± SD. The Shapiro–Wilk's test was used to test the normality of the distribution. A 2 (pre, post) by 4 (groups) repeated-measures ANOVA compared changes in the dependent measures over time and between groups. A Tukey's post hoc test compared differences between groups when a significant *F*-ratio was observed. Statistical analyses were completed using Statistica, version 8.0 (StatsSoft Inc., Tulsa, OK), with α set at ≤ 0.05.

Results

Changes in physiological variables are presented in Table 1. Following training $\dot{V}O_{2\,max}$ significantly increased in the H_{100} ($p = 0.01$) and H_{115} ($p = 0.04$), but not in the H_{130} and TET groups with no difference among groups. HIIT increased $v\dot{V}O_{2\,max}$ in H_{100} ($p = 0.04$), H_{115} ($p = 0.05$) and H_{130} ($p = 0.03$); however, there was no significant change over time following TET ($p > 0.05$). No differences were found among groups in $v\dot{V}O_{2\,max}$. Also, no significant changes took place in O_2 pulse and AT (%$\dot{V}O_{2\,max}$) to all training protocols.

PPO was not significantly different among groups, but significantly improved in H_{100} ($p = 0.03$) and H_{115} ($p = 0.05$); despite no changes following H_{115}, H_{130}, and TET. MPO was significantly improved in H_{100} ($p = 0.01$), H_{115} ($p = 0.01$) and H_{130} ($p = 0.01$) and remained unchanged following TET ($p > 0.05$). No significant differences were observed among groups in PPO and MPO.

The 3000-m time trial performance was significantly improved following H_{100} ($p = 0.05$), H_{115} ($p = 0.04$), and H_{130} ($p = 0.004$); while there was no significant change following TET ($p > 0.05$) (Table 2) with no difference among groups. There was no significant interaction, time or group effect for the 300 m time trial (Table 2). T_{max} significantly increased following H_{100} ($p = 0.01$), while did not improve following H_{115}, H_{130}, and TET.

There was no significant interaction, time, or group effects for any of the hematological responses (RBC, Hb, Hct, and MCH) (Table 3).

Discussion

This is the first study to examine HIIT in trained female inline speed skaters. The main findings of the present study support our hypothesis that HIIT would provide higher improvements in aerobic and anaerobic performance changes compared to endurance training. Interestingly, HIIT performed at 100 and 115% $v\dot{V}O_{2\,max}$ provided superior cardio-respiratory responses following 3 weeks of training.

In the present study, HIIT at 100 and 115% of $v\dot{V}O_{2\,max}$ (i.e. H_{100} and H_{115}) were able to statistically increase $\dot{V}O_{2\,max}$, which support previous findings.[7,10,22] Interestingly there was no change in $\dot{V}O_{2\,max}$ in the group training at 130% of $v\dot{V}O_{2\,max}$ and the TET group, suggesting that there may be an optimal training intensity. Improvement in $\dot{V}O_{2\,max}$ may be attributed to an increase in the delivery of oxygen (i.e., increases in stroke volume) to exercising skeletal muscles and or an increase in oxygen utilization.[9,10,16] O_2 pulse is an indirect measure of stroke volume[16] which was not altered in any of the groups in the present study. On the other hand, no significant change in blood volume was observed in the HIIT groups. RBC and Hb did not increase for any of the groups, indicating no change in oxygen-carrying capacity with training. Hence, blood volume and oxygen-carrying capacity of the blood do not seem to explain the changes in $\dot{V}O_{2\,max}$ in this experiment. This supports the studies of Farzad et al.[16] and Laursen et al.[21] who reported no change in hematological variables and plasma volume in response to a short-term HIIT. These results suggest that HIIT may have increased oxygen extraction due to an increase in peripheral rather than central adaptations.[10,22] To support of this, Gibala and McGee[23] found an increase in muscle oxidative capacity (assessed using the maximal activity or protein content of mitochondrial enzymes such as citrate synthase and cytochrome oxidase) ranging from approximately 15% to 35% following six sessions of HIIT over 2 weeks indicating peripheral adaptations are likely responsible for enhanced consumed oxygen following HIIT performed in short period of time. In this regard, MacPherson et al.[22] demonstrated that post-training enhancements in stroke volume and maximal cardiac output (Q_{max}) were only observed following endurance training, and they concluded that $\dot{V}O_{2\,max}$ improvement following HIIT

Table 1 Pre-training vs. post-training values for physiological variables in the different training groups.

	Group ($N = 7$ for each)			
	H_{100}	H_{115}	H_{130}	TET
$\dot{V}O_{2\,max}$ (mL kg^{-1} min^{-1})				
Pre	42.4 (5.29)	41.8 (7.57)	42.0 (4.50)	42.4 (4.66)
Post	45.7 (8.94)[a]	44.4 (9.70)[a]	42.4 (5.65)	42.7 (4.84)
%Δ	+7.6	+6.1	+0.1	+0.07
$v\dot{V}O_{2\,max}$ (km h^{-1})				
Pre	11.6 (0.5)	12.2 (1.6)	12.2 (2.5)	13.2 (1.3)
Post	12.8 (0.8)[a]	13.0 (1.5)[a]	13.4 (2.6)[a]	13.4 (1.1)
%Δ	+10.3	+6.5	+9.8	+1.5
$\dot{V}O_2$/HR (mL b min^{-1})				
Pre	15.8 (3.9)	14.8 (2.1)	13.0 (1.1)	13.1 (2.9)
Post	15.0 (1.3)	15.4 (3.1)	12.9 (1.3)	12.3 (2.1)
%Δ	−5.3	+4.0	−0.07	−6.5
AT (%$\dot{V}O_{2\,max}$)				
Pre	90.4 (14.4)	82.0 (13.0)	81.0 (17.7)	83.6 (4.3)
Post	86.8 (19.9)	84.4 (9.2)	84.2 (9.1)	81.8 (7.6)
%Δ	−4.1	+2.9	+3.9	−2.2
PPO (W)				
Pre	477.8 (39.3)	494.2 (51.1)	494.1 (37.6)	495.1 (51.8)
Post	527.2 (45.3)[a]	539.3 (99.3)[a]	521.3 (79.1)	519.4 (36.8)
%Δ	+10.3	+9.1	+5.5	+4.9
MPO (W)				
Pre	380.9 (47.6)	377.8 (46.8)	372.7 (39.0)	403.9 (56.1)
Post	467.1 (37.8)[a]	469.0 (67.4)[a]	454.5 (65.6)[a]	447.4 (56.0)
%Δ	+22.6	+24.1	+21.9	+10.7

Note. All values are means (±SD). $\dot{V}O_{2\,max}$ = maximum oxygen uptake; $v\dot{V}O_{2\,max}$ = velocity at $\dot{V}O_{2\,max}$; $\dot{V}O_2$/HR = O_2 pulse; AT (%$\dot{V}O_{2\,max}$) = anaerobic threshold (percentage of $\dot{V}O_{2\,max}$); PPO = peak power output; MPO = mean power output.
[a] Significantly greater than pre-training value ($p < 0.05$).

Table 2 Pre-training vs. post-training values for 300-m performance, 3000-m performance, and T_{max} in the different training groups.

	Group ($N = 7$ for each)			
	H_{100}	H_{115}	H_{130}	TET
300-m performance (s)				
Pre	36.1 (5.9)	35.8 (5.1)	34.5 (4.6)	34.5 (3.8)
Post	35.9 (5.8)	35.5 (5.3)	33.4 (3.5)	35.2 (2.9)
%Δ	−0.05	−0.08	−3.2	+2.0
3000-m performance (min)				
Pre	7.63 (0.68)	6.94 (1.08)	6.64 (1.04)	6.50 (0.98)
Post	6.62 (1.35)[a]	6.43 (1.23)[a]	6.00 (0.81)[a]	6.24 (0.94)
%Δ	−15.2	−7.9	−10.6	−4.1
T_{max} (min)				
Pre	4.31 (1.83)	4.72 (2.55)	4.21 (2.07)	5.16 (1.84)
Post	6.01 (2.70)[a]	4.96 (0.85)	4.96 (1.33)	5.95 (2.85)
%Δ	+39.4	+5.0	+17.8	+15.3

Note. All values are means (± SD). 300-m performance = 300 m skating time trial; 3000-m performance = 3000 m skating time trial; T_{max} = time to exhaustion at $v\dot{V}O_{2\,max}$.
[a] Significantly greater than pre-training value ($p < 0.05$).

Table 3 Pre-training vs. post-training values for hematological variables in the different training groups.

	Group ($N = 7$ for each)			
	H_{100}	H_{115}	H_{130}	TET
RBC (Mill/mm³)				
Pre	4.8 (0.28)	4.7 (0.25)	4.8 (0.24)	4.8 (0.55)
Post	4.8 (0.25)	4.7 (0.28)	4.9 (0.28)	4.9 (0.45)
%Δ	0.0	0.0	+2.0	+2.0
Hb (g/dL)				
Pre	14.2 (0.9)	13.4 (0.5)	13.6 (0.8)	13.4 (1.4)
Post	13.8 (1.0)	13.3 (0.4)	13.8 (1.2)	13.9 (1.3)
%Δ	−2.8	−0.07	+1.4	+3.7
Hc (%)				
Pre	41.0 (1.97)	39.8 (2.3)	40.8 (1.6)	40.1 (4.0)
Post	41.3 (2.54)	40.9 (0.85)	42.0 (3.6)	41.2 (2.3)
%Δ	+0.07	+2.7	+2.9	+2.7
MCH (pg)				
Pre	29.1 (2.0)	28.5 (1.11)	28.2 (2.0)	28.5 (4.9)
Post	28.7 (1.7)	28.1 (1.2)	27.9 (1.6)	28.8 (4.7)
%Δ	−1.4	−1.4	−1.0	+1.0

Note. All values are means (± SD). RBC = red blood cell; Hb = hemoglobin; Hc = hematocrit; MCH = mean corpuscular hemoglobin.

are due to peripheral adaptations. Mechanistically, HIIT activates AMP-activated protein kinase (AMPK) and p38 mitogen-activated protein kinase (MAPK) which are both known to activate peroxisome proliferator-activated receptor co-activator (PGC-1α) and have been implicated in exercise-induced mitochondrial biogenesis.[13] PGC-1α coactivates transcription factors to activate signaling pathways leading to mitochondrial and metabolic adaptations.[13] A limitation of the present study was no muscle biopsies were taken to directly determine muscle oxidative capacity. Future research examining oxidative capacity in trained female athletes is warranted.

Velocity at $\dot{V}O_{2\,max}$ significantly increased following 3 weeks of training in the present study. These findings are in accordance with previous research reporting an improvement in $v\dot{V}O_{2\,max}$ (3 to 10%) after HIIT in subjects of varying aerobic capacities.[9–11] Beside enhanced $\dot{V}O_{2\,max}$, improvements in anaerobic capability,[24] running economy[9] muscle power,[25] and neuromuscular skill,[25] may be responsible for the improvement in $v\dot{V}O_{2\,max}$.

In the present study 3000 m skating performance was significantly improved after only 3 weeks of HIIT. This finding was in line with those of previous researches found improvements in 3000 m running time trial,[9,11] and 2000 m rowing time trial[8] following HIIT. It has been shown that over 92% of the variance in performance is related to the $\%\dot{V}O_{2\,max}$ at AT and muscle capillary density.[27] However, the present study found no significant change in AT in any training group when expressed as $\%\dot{V}O_{2\,max}$. These results suggest that the precise mechanisms that enhanced 3000 m skating performance after different types of HIIT used in our experiment were multifactorial. Data from other studies suggest HIIT can stimulate a range of adaptations that might improve performance aside from changes in AT. For example, enhanced muscle buffering capacity[19] as well as increases in Na^+/K^+ pump capacity,[9] and/or motor unit activation[26] could be other potential adaptations that may contribute to an improvement in endurance performance following HIIT as recorded in our study. However, these markers were not directly assessed in the present study.

T_{max} significantly improved pre- to post-training in H_{100} group. In line with our findings, Esfarjani and Laursen[9] demonstrated that in moderately trained runners, a running-based HIIT program increased time to exhaustion at $v\dot{V}O_{2\,max}$ by 32%. Smith et al.[11] reported a significant increase (33%) in T_{max} after 4 weeks of HIIT. A decrease in the rate of glycogen depletion and thus improved exercise tolerance,[16] as well as greater muscle buffering capacity[12,28] are potential contributing factors for the improved T_{max}.

The training in the present study resulted in a significant increase in PPO and MPO. These findings support other investigations[7,16,20] which have reported increases in peak and mean anaerobic power after a short period of HIIT. Sheykhlouvand et al.[7] demonstrated that PPO and MPO increased after 3 weeks of paddling HIIT (6,7,8,9,9,9,8,7,6 repetitions/session from 1st to 9th session respectively) × 60-second at 100% $v\dot{V}O_{2\,max}$, 1:3 work to recovery ratio). In another study, Farzad et al.[16] demonstrated that peak and mean anaerobic power increased after 4 weeks of running HIIT (6 × 35-meter all-out running with 10-second recovery between each sprint). Enhanced muscle phosphocreatine concentration,[16] anaerobic enzyme activities[20] and a significant increase in fast oxidative glycolytic fibers, along with a decrease in percentage of slow twitch fibres[16] may contribute to the present findings.

A limitation of the present study was the non-specific training. Stangier and colleagues,[5] examined the influence an 8 week running or cycling program on inline speed skating performance. Both running and cycling were sufficient to improve sport specific performance over time despite possible decrements in skating technique. Furthermore, it is important to note that inline speed skaters often perform non-specific training during the winter months, since weather conditions make regular sport specific training difficult[5] more accessible modalities (e.g., treadmills) are often used.

Conclusions

The present study found that HIIT induced significant changes in aerobic, anaerobic, and performance adaptations in female inline speed skaters. Given the markedly lower training volume in HIIT groups, our result suggest that running-based HIIT is indeed a time-efficient strategy to induce rapid physiological and performance adaptations comparable to TET. Interestingly, HIIT training at 100 and 115% $v\dot{V}O_{2\,max}$ resulted in superior cardio-respiratory improvements compared to training at 130% $v\dot{V}O_{2\,max}$. Despite differences in cardio-respiratory improvements all HIIT groups were able to significantly improve 3000 m time trial performance. Future research is required to determine the ideal training intensity and volume as well as how to incorporate HIIT into a periodized annual training plan to optimally improve female inline speed skating performance. In addition, future research examining sport specific training is warranted.

Considering that such training protocols have a very low volume, inline speed skaters and their coaches can use this type of training prescriptions when speed skaters have to reach several peaks over an annual cycle, particularly when the aim is to increase performance in limited period.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgements

The authors thank Professor Philip Bishop for his precious scientific assistance and our participants for their time and effort.

References

1. De Koning JJ, de Groot G, van Ingen Schenau GJ. A power equation for the sprint in speed skating. J Biomech. 1992;25:573–80.
2. Rundell KW. Compromised oxygen uptake in speed skaters during treadmill in-line skating. Med Sci Sports Exerc. 1996;28:120–7.
3. van Ingen Schenau GJ. The influence of air friction in speed skating. J Biomech. 1982;15:449–58.
4. Kuipers H, Moran J, Dubravcic-Simunjak S, Mitchell DW, Shobe J, Sakai H, et al. Hemoglobin level in elite speed skaters from 2000 up to 2005, and its relationship with competitive results. Int J Sports Med. 2007;28:16–20.
5. Stangier C, Abel T, Hesse C, Claen S, Mierau J, Hollmann W, et al. Effects of cycling vs. running training on endurance performance in preparation for inline speed skating. J Strength Cond Res. 2016;30:1597–606.
6. Krieg A, Meyer T, Clas S, Kindermann W. Characteristics of inline speed skating incremental tests and effect of drafting. Int J Sports Med. 2006;27:818–23.
7. Sheykhlouvand M, Khalili H, Agha-Alinejad H, Gharaat M. Hormonal and physiological adaptations to high-intensity interval training in professional male Canoe polo athletes. J Strength and Cond Res. 2016;30:859–66.
8. Driller MW, Fell JW, Gregory JR, Shing CM, Williams AD. The effects of high-intensity interval training in well-trained rowers. Int J Sports Physiol Perform. 2009;4:110–21.
9. Esfarjani F, Laursen PB. Manipulating high-intensity interval training: effects on $\dot{V}O_{2max}$, the lactate threshold and 3000 m running performance in moderately trained males. J Sci Med Sport. 2007;10:27–35.
10. Laursen PB, Jenkins DG. The scientific basis for high-intensity interval training. J Sport Med. 2002;32:53–73.
11. Smith TP, McNaughton LR, Marshall KJ. Effects of 4-wk training using Vmax/T_{max} on $\dot{V}O_{2max}$ and performance in athletes. Med Sci Sports Exerc. 1999;31:892–6.
12. Gibala MJ, Little JP, van Essen M, Wilkin GP, Burgomaster KA, Safdar A, et al. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. J Physiol. 2006;575 Pt 3:901–11.
13. Little JP, Safdar A, Wilkin GP, Tarnopolsky MA, Gibala MJ. A practical model of low-volume high-intensity interval training induces mitochondrial biogenesis in human skeletal muscle: potential mechanisms. J Physiol. 2010;588:1011–22.
14. Laursen PB. Training for intense exercise performance: high-intensity or high-volume training? Scand J Med Sci Sports. 2010;2:1–10.
15. Little JP, Jung ME, Wright AE, Wright W, Manders RJ. Effects of high-intensity interval exercise versus continuous moderate-intensity exercise on postprandial glycemic control assessed by continuous glucose monitoring in obese adults. Appl Physiol Nutr Metab. 2014;39:835–41.
16. Farzad B, Gharakhanlou R, Agha-Alinejad H, Curby DG, Bayati M, Bahraminejad M, et al. Physiological and performance changes from the addition of a sprint interval program to wrestling training. J Strength Cond Res. 2011;25:2392–9.
17. Sheykhlouvand M, Gharaat M, Bishop P, Khalili E, Karami E, Fereshtian S. Anthropometric, physiological, and performance characteristics of elite Canoe polo players. Psychol Neurosci. 2015;8:257–66.
18. Billat LV, Koralsztein JP. Significance of the velocity at $\dot{V}O_{2max}$ and time to exhaustion at this velocity. Sports Med. 1996;22:90–108.
19. Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol. 1986;60:2020–7.
20. MacDougall JD, Hicks AL, MacDonald JR, McKelvie RS, Green HJ, Smith KM. Muscle performance and enzymatic adaptations to sprint interval training. J Appl Physiol. 1998;84: 2138–42.
21. Laursen PB, Shing CM, Peake JH, Coombes JS, Jenkins DG. Influence of high intensity interval training on adaptations in well-trained cyclists. J Strength Cond Res. 2005;19: 527–33.
22. Macpherson RE, Hazell TJ, Olver TD, Paterson DH, Lemon PW. Run sprint interval training improves aerobic performance but not maximal cardiac output. Med Sci Sports Exerc. 2011;43:115–22.
23. Gibala MJ, McGee SL. Metabolic adaptations to short-term high intensity interval training: a little pain for a lot of gain? Exerc Sport Sci Rev. 2008;36:58–63.
24. Sheykhlouvand M, Gharaat M, Khalili E, Agha-Alinejad H. The effect of high-intensity interval training on ventilatory threshold and aerobic power in well-trained Canoe polo athletes. Science Sports. 2016;31:283–9.
25. Jones AM, Carter H. The effect of endurance training on parameters of aerobic fitness. Sports Med. 2000;29:373–86.
26. Creer AR, Ricard MD, Conlee RK, Hoyt GL, Parcell AC. Neural, metabolic, and performance adaptations to four weeks of high

intensity sprint – interval training in trained cyclists. Int J Sports Med. 2004;25:92–8.
27. Billat LV. Use of blood lactate measurements for prediction of exercise performance and for control of training, Recommendations for long-distance running. Sports Med. 1996;22: 157–75.
28. Messonnier L, Freund H, Denis C, Dormois D, Dufour AB, Lacour JR. Time to exhaustion at $\dot{V}O_{2max}$ is related to the lactate exchange and removal abilities. Int J Sports Med. 2002;23:433–8.