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FIVE-WEEK OF HIGH-INTENSITY CONTINUOUS RUNNING OF SHORT EXERCISE DURATION ON RUNNING AND AEROBIC ENDURANCE PERFORMANCES OF MODERATELY TRAINED LEISURE RUNNER: A CASE STUDY

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ABSTRACT: The purpose of this study was to examine the running performance and aerobic endurance following high-intensity continuous running (HICR) of short exercise duration in a moderately trained leisure runner. In this case study, a 42-yr-old moderately trained male leisure runner, with a pre-training relative maximal oxygen consumption (VO_{2max}) of 55.8 $mL\cdot kg^{-1}\cdot min^{-1}$, performed 10 min of HICR (90% to 95% of maximal heart rate (HR_{max}) 3 $times\cdot wk^{-1}$, for 5 weeks. Following the training intervention period, time to exhaustion during a ~4 min to ~6 min treadmill ramp test procedure increased by 57 sec (23%), which indicates a substantial improvement in running performance. Velocity at VO_{2max} and velocity at lactate threshold increased by 1.8 $km\cdot hr^{-1}$ (13%) and 1.4 $km\cdot hr^{-1}$ (14%), correspondingly. Furthermore, the participant increased absolute and relative VO_{2max} by 0.33 $L\cdot min^{-1}$ (9.5%) and 7.5 $mL\cdot kg^{-1}\cdot min^{-1}$ (13%), respectively. Oxygen pulse at VO_{2max} increased by 2.1 $mL\cdot beat^{-1}$ (13%), and submaximal heart rate decreased by 12 $beats\cdot min^{-1}$ (7.9%), while no notable change in running economy was observed, indicating an upsurge in maximal cardiac stroke volume. Moreover, the results indicated an upsurge in relative fat oxidation from ~36% to ~43% of the total energy turnover, which appeared to be due to the substantial improvement in relative VO_{2max}. It can be concluded that HICR of short exercise duration can be effective in improving running performance and aerobic capacity when the initial aerobic fitness level is moderate.

Keywords: Leisure runner, Maximal oxygen consumption, Time to exhaustion, Velocity at lactate threshold, Velocity at VO_{2max},

INTRODUCTION

Some studies (Esfarjani & Laursen, 2007; Franch, Madsen, Djurhuus, & Pedersen, 1998; Helgerud, Høydal, Wang, Karlsen, Berg, Bjerkaas, Simonsen, Helgesen, Hjorth, & Bach, 2007; Jarstad & Mamen, 2019; Thomas, Adeniran, & Etheridge, 1984) have assessed the training outcomes of high-intensity aerobic running exercise of ~80% to ~100% of maximal oxygen consumption (VO_{2max})/>85% of maximal heart rate (HR_{max}) in physically active and moderately trained leisure athletes and reported relative VO_{2max} at pre-training corresponding to ~50 $mL\cdot kg^{-1}\cdot min^{-1}$ to ~60 $mL\cdot kg^{-1}\cdot min^{-1}$. In their studies, considerable progresses were obvious in running performances (23% to 94% increase in time to exhaustion (Esfarjani & Laursen, 2007; Franch et al., 1998; Jarstad & Mamen, 2019), or 7.3% improvement in 3000 m time-trial time (Esfarjani & Laursen, 2007) and aerobic endurance (3.4% to ~9.1% increase in absolute VO_{2max} (Esfarjani & Laursen, 2007; Franch *et al.*, 1998; Helgerud *et al.*, 2007; Jarstad & Mamen, 2019; Thomas *et al.*, 1984), and 3% to 10% improvement in running economy (Franch *et al.*, 1998; Helgerud *et al.*, 2007; Jarstad & Mamen, 2019) have been reported following high-intensity continuous running (HICR, 20 min to 30 min, ~83% VO_{2max}/~91% to ~93% of peak heart rate (i.e., ~88% to ~90% HR_{max} (Franch et al., 1998; Jarstad & Mamen, 2019), short high-intensity interval running (HIIR, 30 times to 47 times 15 sec at 90% to 95% HR_{max}, interspersed with 15 sec of active pauses at ~60% to ~70% HR_{max}) (Franch *et al.*, 1998; Helgerud *et al.*, 2007) and long HIIR (4 to 8 times in 1 to 4 min at ~100% of velocity at VO_{2max} (vVO_{2max})/90% to 95% HR_{max}, interspersed with 2 min to 3.5 min of active pauses at ~50% vVO_{2max}/~60% to ~70% HR_{max}/jogging/walking) (Esfarjani & Laursen, 2007; Franch *et al.*, 1998; Helgerud *et al.*, 2007; Thomas *et al.*, 1984).

Therefore, such exemplars of high-intensity training (Esfarjani & Laursen, 2007; Franch *et al.*, 1998; Helgerud *et al.*, 2007; Jarstad & Mamen, 2019; Thomas *et al.*, 1984) are relatively time-efficient aerobic exercise; each training session lasts on average ~17 min to ~42 min, including intermissions during HIIR (excluding warm-up and recovery, usually lasting 10 min and 3 min to 10 min, respectively) (Esfarjani & Laursen, 2007; Helgerud *et al.*, 2007; Jarstad & Mamen, 2019). Nonetheless, for some leisure athletes, even exercise durations such as ~17 min to ~42 min, in addition to 13 min to 20 min of warm-up and recovery, can sometimes be too time-consuming in a busy life. It is thus of numerous interests to the researchers to establish if an aerobic running exercise modality of considerably shorter training duration can generate comparable running performance and aerobic endurance outcomes as those seen in training intervention studies.

To the best of researchers' information, no single study has assessed the training effects of HICR of short exercise duration in moderately trained leisure athletes. Hence, the purpose of this study was to examine the development of running performance and aerobic endurance following HICR of short exercise duration in a moderately trained leisure runner.

There was also a relatively short warm-up and recovery in connection with the HICR session.

METHODOLOGY

Participant

A 42-yr-old healthy male (a former Nigerian national badminton player), who performed aerobic running exercise ~2 times·wk^{-1}, and was moderately aerobically fit (pre-training relative VO_{2max} (mL·kg^{-1}·min^{-1}), volunteered to partake in this study. The case study was guided in accordance with the ethical guidelines of the Helsinki Declaration. Prior to the study, the participant gave informed consent. The study design, conduct and report was purely based on Schoch (2016) concepts of case study research.

Test Procedures

The present case study used the submaximal and maximal test procedures and calculations as described in Jarstad and Mamen (2019), except for the following modifications:

i. Lactate threshold (LT) was estimated as individual blood lactate concentration (BLC) during warm-up + 2.0 mmol·L^{-1}, which is a useful approach to the "gold standard", maximal lactate steady state (Mamen, Laparidist, & Van Den Tillaar, 2011),

ii. Running economy (oxygen cost) and substrate oxidation (respiratory gas-exchange ratio (RER), and supplementary variables for these, were taken as the mean steady-state values (measurements between the 3rd min and the 5th min) from five submaximal velocities between 5.5 km·hr^{-1} to 11.5 km·hr^{-1} (increments of 1.5 km·hr^{-1} each 5th min, from 49% to 84% pre-training VO_{2max}). Furthermore, it is worth noting that the HICR participant was familiar with the test procedures prior to the study (had performed the test procedures several times before the study commenced).

Similarly, all tests were conducted at the Human Performance Laboratory of the Department of Human Kinetics and Health Education, Ahmadu Bello University, Zaria – Nigeria. Most ventilatory equipment were sourced from Ahmadu Bello University Teaching Hospital, Zaria – Nigeria.

Test Instruments

The tests were performed on a HERA-7000 treadmill (Xuzhoushi Ruibu Fitness Equipment Co. Ltd, Jiangsu, China), using a 5.3% incline. Oxygen consumption (VO_2), carbon-dioxide production (VCO_2), RER and ventilatory equivalent for oxygen (V_E/VO_2) were assessed using a S-3A/II metabolic analyzer with a mixing chamber and AEI Flow Measurement System (AEI Technologies, USA). Gas and volume calibration were performed in accordance with the user manual of the test equipment. BLC was analyzed with a Lactate Scout$^+$ analyzer (EKF Diagnostics, UK). Heart rate (HR) was recorded using a Polar HR monitor (Polar Electro Oy, Kempele, Finland), while running time was measured with a digital stopwatch (Traceable® Water/Shock-Resistant Stopwatch, Thomas Scientific, Swedesboro, NJ 08085, USA).

Training Intervention

The training intervention session was performed on a treadmill (5.3% inclination) and consisted of 7 min of warm-up (jogging at ~60% to ~80% HR_{max}), 10 min of HICR (90% to 97% VO_{2max}/90% to 95% HR_{max}), and 3 min of active recovery (walking), 3 times·wk^{-1}, for 5 weeks. Heart rate was monitored during all the training intervention sessions. The HICR participant did not perform any regular aerobic training during the study.

RESULTS

Running Performance

Time to exhaustion during a ~4 to ~6 min treadmill ramp test technique amplified by 57 sec (23%), from 247 sec to 304 sec (Figure 1).

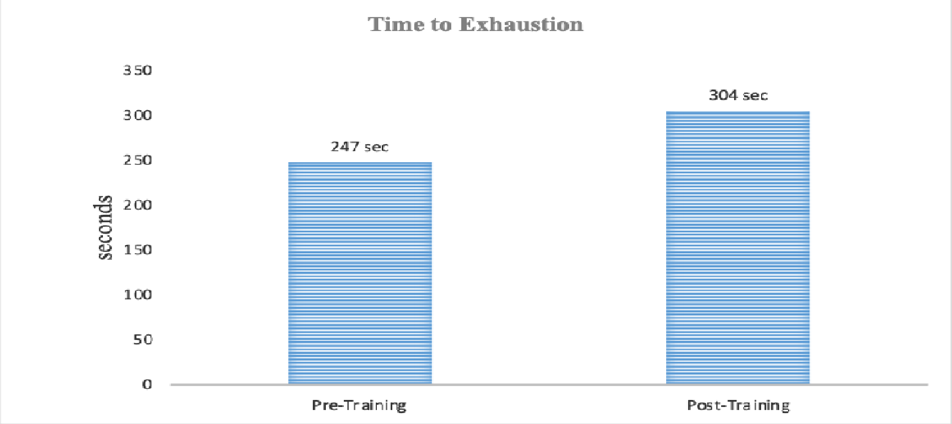

Figure 1. Running Performance (Time to Exhaustion) at Pre-Training (Pre) and Post-Training (Post) for the HICR Participant.

Velocities Associated with VO_{2max} and LT

vVO_{2max} increased by 1.8 km·hr^{-1} (13%), from 14.1 km·hr^{-1} to 15.9 km·hr^{-1}; whereas, the velocity at LT (vLT) increased by 1.4 km·hr^{-1} (14%), from 10.3 km·hr^{-1} to 11.7 km·hr^{-1} (Figure 2).

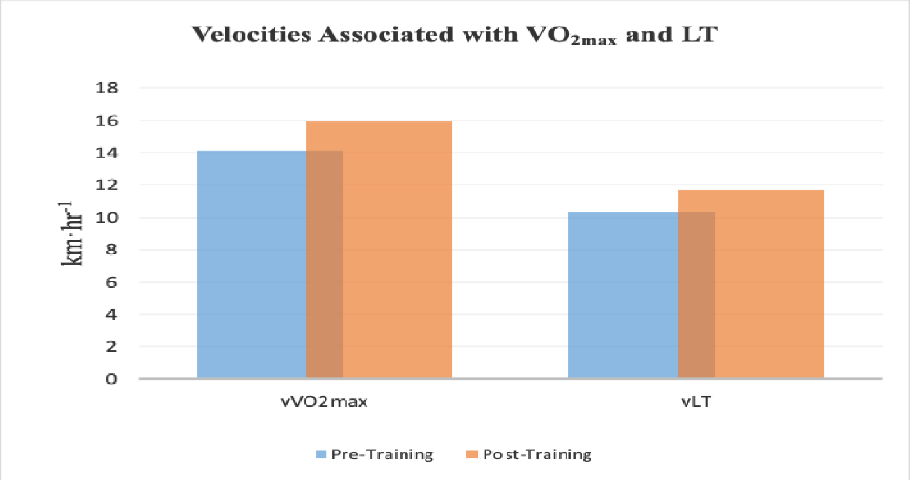

Figure 2. vVO_{2max} and vLT at Pre-Training (Pre) and Post-Training (Post) for the HICR Participant.

Anthropometry

Body mass and body mass index (BMI) reduced by 2.0 kg (3.2%) and 0.8 kg·m^{-2} (3.4%), respectively (Table 1).

Table 1. Anthropometric Variables for the HICR Participant at Pre- and Post-Training.

Variables	Pre-Training	Post-Training
BM (kg)	62.3	60.3
BMI (kg·m^{-2})	23.5	22.7

BM = Body Mass, BMI = Body Mass Index

Aerobic Endurance

Absolute VO_{2max} increased by 0.33 L·min^{-1} (9.5%); whereas, relative conventional and allometrically scaled VO_{2max} improved by 7.5 mL·kg^{-1}·min^{-1} (13%) and 20.1 mL·kg$^{-0.75}$·min^{-1} (13%), respectively (Table 2). Oxygen pulse at VO_{2max} increased by 2.1 mL·beat^{-1} (13%) (Table 2). The LT percentage of VO_{2max} (LT %VO_{2max}) did not change (Table 2). Oxygen cost and submaximal HR decreased by 0.01 mL·kg$^{-0.75}$·m^{-1} (1.4%) and 12 beats·min^{-1} (7.9%), respectively (Table 2).

Table 2. Aerobic Endurance for the HICR Participant at Pre- and Post-Training.

Variables	Pre-Training	Post-Training
VO_{2max}		
$L \cdot min^{-1}$	3.48	3.81
$mL \cdot kg^{-1} \cdot min^{-1}$	55.8	63.3
$mL \cdot kg^{-0.75} \cdot min^{-1}$	156.5	176.6
Oxygen Pulse ($mL \cdot beat^{-1}$)	16.7	18.8
HR_{max} ($beats \cdot min^{-1}$)	209	203
BLC ($mmol \cdot L^{-1}$)	12.5	12.0
RER peak (VCO_2/VO_2)	1.14	1.06
V_E/VO_2	31	30
RPE ($Borg_{6\text{-}20}$)	18	19
LT		
$\%VO_{2max}$	78	78
$\%HR_{max}$	80	84
BLC ($mmol \cdot L^{-1}$)	3.0	2.9
Running Economy		
VO_2 ($mL \cdot kg^{-0.75} \cdot m^{-1}$)	0.74	0.73
HR ($beats \cdot min^{-1}$)	151	139

%HRmax = Percentage of Maximal Heart Rate; %VO2max = Percentage of VO2max; BLC = Blood Lactate Concentration; HR = Heart Rate; HRmax = Maximal Heart Rate; LT = Lactate Threshold; RER Peak = Peak Respiratory Gas-Exchange Ratio; RPE = Rate of Perceived Exertion; VE/VO2 = Ventilatory Equivalent for Oxygen; vLT = Velocity at Lactate Threshold; VO2 = Oxygen Consumption; VO2max = Maximal Oxygen Consumption.

Substrate Oxidation

RER and V_E/VO_2 decreased by 0.02 units (2.2%) and 1 unit (4.2%), respectively (Table 3). Percentage VO_{2max} ($\%VO_{2max}$) decreased by 8 percentage points (12%) (Table 3). BLC decreased by 0.9 $mmol \cdot L^{-1}$ (41%) (Table 3).

Table 3. Substrate Oxidation (RER), and Supplementary Variables, for the HICR Participant at Pre- and Post-Training.

Variables	Pre-Training	Post-Training
RER (VCO_2/VO_2)	0.89	0.87
V_E/VO_2	24	23
$\%VO_{2max}$	66	58
BLC ($mmol \cdot L^{-1}$)	2.2	1.3

%VO2max = Percentage of VO2max; BLC = Blood Lactate Concentration; RER = Respiratory Gas-Exchange Ratio; VE/VO2 = Ventilatory Equivalent for Oxygen;

DISCUSSION

The main finding of this case study was that running performance, evaluated as time to exhaustion, improved substantially following HICR. Other notable outcomes were significant increases in vVO_{2max}, vLT, VO_{2max} and fat oxidation (decreased RER). The improvements in time to exhaustion, vVO_{2max}, vLT and fat oxidation appear to be mainly due to the substantial increase in absolute VO_{2max}, and, to a lesser extent, as results of the modest loss in body mass.

Running Performance

The improvement in time to exhaustion following the HICR in the present case study is in synchrony with the findings following HICR in the studies by Franch et al. (1998) and Jarstad and Mamen (2019). In fact, the percentage improvement in time to exhaustion observed in the HICR participant of this study was identical to that reported following HICR in the study by Jarstad and Mamen (2019), who used a similar performance test. Moreover, the running performance improvement (increased time to exhaustion) in the HICR participant of this study is similar to observations following short and long HIIR (Esfarjani & Laursen, 2007; Franch et al., 1998).

Velocities Associated with VO_{2max} and LT

The increase in vVO_{2max} in the HICR participant of this study was significantly greater, or slightly larger, than those previously found (1.0 $km \cdot hr^{-1}$ to 1.7 $km \cdot hr^{-1}$, 6.4% to 13%)) following HICR (Franch et al., 1998; Jarstad & Mamen, 2019) and long HIIR (Esfarjani & Laursen, 2007; Franch et al., 1998). Furthermore, the increase in vLT observed in the present case study was significantly superior than that reported (0.7 $km \cdot hr^{-1}$, 6.8%) following HICR in the study by Jarstad and Mamen (2019), as well as significantly larger, or slightly greater, than those observed (0.9 $km \cdot hr^{-1}$ to 1.2 $km \cdot hr^{-1}$, 8.7% to 11.8%) following short and/or long HIIR in the studies by Esfarjani and Laursen (2007) and Helgerud *et al.* (2007). These different results in vVO_{2max} and vLT may be explained by a slightly larger increase in relative VO_{2max} in the HICR participant of this case study versus the total improvement in relative VO_{2max} and running economy in those other studies (Esfarjani & Laursen, 2007; Franch *et al.*, 1998; Helgerud *et al.*, 2007; Jarstad & Mamen, 2019), and/or measurement variations/differences between this study and the others (Esfarjani & Laursen, 2007; Franch *et al.*, 1998; Helgerud *et al.*, 2007; Jarstad & Mamen, 2019). The substantial improvements in vVO_{2max} and vLT in the present case study support the significant enhancement in running performance (time to exhaustion) in this individual.

Anthropometry

The modest decreases in BM and BMI in the HICR participant of this study were slightly larger than those reported (body mass: 0.5 to 1.5 kg, 0.6% to 1.8%, BMI: 0.1 $kg \cdot m^{-2}$, 0.4%) following HICR and short and long HIIR of lower to similar intensities and longer total exercise durations (Franch *et al.*, 1998; Helgerud *et al.*, 2007; Jarstad & Mamen, 2019). This difference may be explained by a more restricted energy intake in the HICR participant of the present study, as this person, in total, converted considerably less energy (~700 kJ) than the amounts (~1300 to ~2500 kJ) reported in those other studies (Franch *et al.*, 1998; Helgerud *et al.*, 2007; Jarstad & Mamen, 2019).

Aerobic Endurance

The substantial increase in absolute VO_{2max} in the HICR participant of this study was slightly greater than those observed (0.20 to 0.23 $L \cdot min^{-1}$, 5.0% to 5.9%) following HICR in the studies by Franch et al. (1998) and Jarstad and Mamen (2019), as well as larger than, and similar to, those reported (0.14 to ~0.34 $L \cdot min^{-1}$, 3.4% to ~9.1%) following short and long HIIR (Esfarjani & Laursen, 2007; Franch *et al.*, 1998; Helgerud *et al.*, 2007; Thomas *et al.*, 1984). There is reason to believe that the improvement in absolute VO_{2max} found in the present case study may have been due to increased maximal cardiac stroke volume (SV max), as indirectly indicated by the substantial increase in oxygen pulse at VO_{2max}. The latter is similar to that found (calculated to be ~1.9 $mL \cdot beat^{-1}$) following long HIIR in the study by Helgerud *et al.* (2007), who reported an increase in SV max of 10%. Therefore, as training intensity seems to play an important role in influencing SV max (Helgerud *et al.*, 2007), a higher exercise intensity may be a plausible explanation of the slightly larger increase in absolute VO_{2max} in the HICR participant of the present study versus those other studies of HICR (Franch et al., 1998; Jarstad & Mamen, 2019). Furthermore, a longer, or similar, total exposure time at high exercise intensity may explain the greater, or similar, increase in absolute VO_{2max}, respectively, following HICR in the present case study versus those observed following short and long HIIR (Esfarjani & Laursen, 2007; Franch *et al.*, 1998; Helgerud *et al.*, 2007).

No change in LT %VO_{2max} was experiential in the present study. This is in line with findings following HICR of longer duration and lower exercise intensity (Jarstad & Mamen, 2019), and after short and long HIIR of the same training intensity (Helgerud, 1994), in moderately trained leisure athletes, as well as those observed following high-intensity (82% to 92% HR_{max}) low-volume (50 km·wk^{-1}) training in well-trained middle-distance runners (relative VO_{2max} at pre-training corresponding to ~70 mL·kg^{-1}·min^{-1}) (Enoksen, Shalfawi, & Tønnessen, 2011). It appears, therefore, that the traditional LT %VO_{2max} (usually estimated at ~75% to 85% VO_{2max}) (Enoksen *et al.*, 2011; Helgerud, 1994; Jarstad & Mamen, 2019), in most cases, does not respond to high-intensity aerobic running exercise (~80% to 100% VO_{2max}/>85% HR_{max}) when the initial aerobic fitness level is moderate and higher.

The slight decline in oxygen cost following HICR in the present study was probably a consequence of the modest decrease in body mass, rather than physiological adaptations in the muscles or biomechanical changes. The fact that there seems to have been no training-induced improvement in running economy in the HICR participant of this study differs from previous observations following HICR (Franch et al., 1998; Jarstad & Mamen, 2019), as well as findings following short and long HIIR (Franch *et al.*, 1998; Helgerud *et al.*, 2007). This may be due to the considerably shorter exercise duration during HICR in the present study than in the other studies (Franch *et al.*, 1998; Helgerud *et al.*, 2007; Jarstad & Mamen, 2019). It may also be because the HICR participant of the present study did not increase total running distance significantly during the training intervention period compared to the regular running distance prior to the study, unlike the other studies (Franch *et al.*, 1998; Helgerud *et al.*, 2007; Jarstad & Mamen, 2019). Furthermore, the substantial decrease in submaximal HR, without any notable decline in oxygen cost, supports the notion that SV max may have increased in the HICR participant of the present study.

Substrate Oxidation

The decline in RER indicates that relative fat oxidation increased by ~19%, from ~36% to ~43% of the total energy turnover. This change seems to be due to the substantial improvement in relative VO_{2max}, which lowered the work intensity (%VO_{2max}) and thus BLC, which in turn may have improved the physiological conditions for a higher fat oxidation rate. This finding differs from those reported by Franch et al. (1998) and Jarstad and Mamen (2019), who found no changes in RER following HICR or short and long HIIR. Although it is difficult to explain these different results, one possible explanation may be that the increase in relative VO_{2max} in the present case study was larger than the total improvement in relative VO_{2max} and running economy found in those studies (Franch et al., 1998; Jarstad & Mamen, 2019).

Increased fat oxidation can have a glycogen saving effect (Holloszy & Coyle, 1984). An improvement in maximal aerobic power, such as that as found in the present study, may therefore affect fractional utilization of VO_{2max}, and thus performance, during prolonged (>90 min) continuous endurance events, where the glycogen stores limit performance ability (Yeo, Carey, Burke, Spriet, & Hawley, 2011).

The findings of the present case study indicate that 10 min of HICR at 90% to 97% VO_{2max}/90% to 95% HR_{max} can be used as a supplementary or time-efficient alternative training modality to HICR and short and long HIIR of longer exercise duration (~17 min to 42 min) and lower to similar training intensities (~83% to 100% VO_{2max}/~88% to ~95% HR_{max}) in the development of running performance and aerobic endurance in moderately trained leisure athletes. Warm-up and recovery can also be performed as in the present study, giving a total exercise duration of only 20 min (7 min + 10 min + 3 min) for the entire session.

The reader should be aware of the practical significance of an increase in relative VO_{2max} of 7.5 $mL \cdot kg^{-1} \cdot min^{-1}$, as found in the present study, for example during a marathon. Two previous studies reported that male leisure runners with a relative VO_{2max} corresponding to ~62 $mL \cdot kg^{-1} \cdot min^{-1}$ (n = 6) and ~71 $mL \cdot kg^{-1} \cdot min^{-1}$ (n = 6) completed a marathon in 3 hours and ~20 min (Helgerud, Ingjer, & Strømme, 1990), and 2 hours and ~40 min (Helgerud, 1994), respectively. The difference in relative VO_{2max} (~9 $mL \cdot kg^{-}$

$^{1}\cdot$min^{-1}) and marathon time (~40 min) between the leisure runners in those two studies (Helgerud, 1994; Helgerud *et al.*, 1990) indicates that the increase in relative VO_{2max} (7.5 mL·kg$^{-1}\cdot$min^{-1}) in the HICR participant of the present study, in isolation, may have improved the physiological conditions in this individual's body to enable him to complete a marathon ~30 to ~35 min faster. This is quite exceptional because the HICR participant exercised for only one hour/week (including warm-up, main session, and recovery) during this five-week study.

Finally, it is worth mentioning that the HICR participant of this study, whom is a former national badminton player, increased relative VO_{2max} from a moderate level at pre-training, to a relatively high level at post-training which is similar to VO_{2max} levels observed (~61 to ~66 mL·kg$^{-1}\cdot$min^{-1}) in senior elite badminton players (Helgerud, Rodas, Kemi, & Hoff, 2011). It would therefore seem that senior badminton players could use the HICR modality examined in this study during, e.g., recovery from long-term injury or illness (when aerobic fitness is often impaired) to raise aerobic fitness back to the required level in badminton in a time-efficient manner.

Study Limitations

Time-to-exhaustion protocols lasting ~6 to ~7 min (i.e., slightly longer duration than the ramp test procedure of the present case study) have shown a coefficient of variation of ~15% (Currell & Jeukendrup, 2008). Moreover, RER is indirect evaluation of substrate oxidation. The case study was conducted using a purely purposive sampling. Therefore, the outcomes of this study must be interpreted and generalised with caution. Also, the references used were relatively timeworn.

CONCLUSION

High-Intensity Continuous Running of short exercise duration can be effective in improving running performance and aerobic capacity when the initial aerobic fitness level is moderate.

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