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Case report

Title:

Development of running performance and endurance in youth soccer players following high-intensity continuous running of short exercise duration

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High-intensity continuous running in youth soccer

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ABSTRACT

BACKGROUND: In young soccer players, the performance and endurance effects of high-intensity interval running (>85% maximal heart rate (HR_{max})) are relatively well documented. However, no studies have investigated the training effects of high-intensity continuous running (HICR, >85% HR_{max}) in young soccer players. This study aimed, therefore, to examine the development of running performance and endurance in youth soccer players by adding HICR of short exercise duration to regular soccer training.

METHODS: In this case series study, five male U15 youth soccer players *(subjects A–E)* performed 10 min of almost exhausting HICR (90–95% HR_{max}) immediately following regular soccer training, two times/week, for six weeks.

RESULTS: All five players *(subjects A–E)* increased time to exhaustion *(s)* and peak velocity *($km \cdot h^{-1}$)* by 10–38% and 3–10%, respectively, indicating substantial running performance gains following the training intervention period. Three of five players *(subjects A, B and D)* increased maximal oxygen consumption in absolute ($L \cdot min^{-1}$: 7–13%) and relative values ($ml \cdot kg^{-1} \cdot min^{-1}$: 4–12%, $ml \cdot kg^{-0.75} \cdot min^{-1}$: 5–13%). Oxygen cost decreased by 3–6% in three of five players *(subjects B, C and E)*, indicating improved running economy. In four of five players *(subjects B–E)*, submaximal respiratory gas-exchange ratio decreased by 1–5%, indicating enhanced fat oxidation. Moreover, blood lactate concentration two min after a ramp test increased by 9–32% in four of five players *(subjects A, B, C and E)*, indicating a possible improvement of anaerobic capacity.

CONCLUSION: HICR of short exercise duration, as a supplement to regular soccer training, can help improve the running performance and endurance of youth soccer players.

Key Words: Time to exhaustion, maximal oxygen consumption, running economy, fat oxidation, anaerobic capacity.

INTRODUCTION

Soccer is classified as a high-intensity, intermittent team sport,[1] which places demands on various physiological characteristics of players.[2] Despite the high-intensity, intermittent nature of soccer, which taxes the anaerobic energy system, approximately 98–99% of the total energy demand during a 90-min soccer match (covering a total distance of ~8–12 km) appears to be covered by aerobic energy release.[3(p.257),4] Aerobic training, e.g. running exercise, is thus important for the development of running performance in soccer. Unfortunately, running exercise is not a favorite activity among soccer players.[2] Therefore, time-efficient aerobic training is of great value for many soccer players. In this context, previous studies have investigated and reported physiological (improved maximal oxygen consumption ($\dot{V}O_{2max}$) and running economy) and running performance gains (increased high-intensity activity, repeated sprint ability and total distance covered during soccer match-play) following four–eight weeks of two weekly sessions of 4 x 4 min high-intensity interval running (HIIR; 90-95% HR_{max}), interspersed with 3 x 3 min of active breaks (50–70% HR_{max}), in U17–U19 junior soccer players.[5,6] Also, in U14 youth soccer players, five weeks of two–three weekly sessions of various HIIR (e.g. 4 x 4 min HIIR/3 x 3 min breaks, or combined 12 x 30-s sprint/30-s breaks and 6 x 2 min HIIR/5 x 2 min breaks, 90–95% HR_{max}) has shown physiological (increased $\dot{V}O_{2max}$) and running performance improvements (enhanced time-trial time).[7] Indeed, such examples of HIIR[5–7] is time-efficient aerobic training, lasting ~25–30 min, including intervals and breaks. However, our practical experience from U15 youth soccer is that ~25–30 min of additional aerobic training, two–three times/week, for several weeks, means that some players do not perform the exercise frequently enough, over a sufficient period of time, to achieve similar physiological and performance effects as observed in those studies of HIIR in U14 youth[7] and U17–U19 junior soccer players.[5,6] Hence, in these young soccer players there is a need for an aerobic training modality that is even more time-efficient than those HIIR regimes previously investigated.[5–7]

We know of no studies that have investigated the training effects of high-intensity continuous running (HICR) in youth soccer players. The aim of the present study, therefore, was to examine the development of running performance and endurance in youth soccer players by adding HICR of short exercise duration to regular soccer training.

CASE SERIES REPORT

Experimental approach

In this study, we evaluated youth soccer players who played matches in a local second division. To avoid, in the best possible manner, influence of regular soccer training on physiological adaptations during the training intervention period, we conducted the project midway (February–March) into the pre-season (December–April), when the players most likely had adapted physiologically to their regular soccer training the last ~8 weeks before the study commenced. Pre- and post-tests were executed by the same test engineer, at approximately the same time of the day, in a similar temperature and relative humidity in a laboratory. Prior to the study, all players were familiar with treadmill running.

Subjects

Five male U15 youth soccer players, who performed soccer training two–three times/week, volunteered to participate in this study. The study was conducted in the spirit of the ethical guidelines of the Helsinki declaration. In Norway, studies that intend to investigate training effects in healthy young athletes related to performance are considered outside the Health Research Act. The present study, therefore, did not need approval from the Regional Committee for Medical and Health Research Ethics. After an information meeting with talks about the purpose of, and potential discomforts connected to, the project, all the participants and their parents signed a medical history and test/training consent form prior to the study.

Test procedures

Following measurement of body mass, calculation of body mass index (BMI) and ~25 min of warm-up, oxygen consumption ($\dot{V}O_2$), heart rate (HR) and respiratory gas-exchange ratio (RER) were recorded in steady-state phase (between the third and fifth min) during a 5-min submaximal run at 9.0 km·h^{-1} and 1º/1.7% inclination (54–68% of pre-training $\dot{V}O_{2max}$ (Tables 1 and 2)) to evaluate running economy and substrate oxidation, respectively. After 5 min of active recovery (walking at 5 km·h^{-1} and 0% inclination), an exhausting ramp test protocol was used to measure $\dot{V}O_{2max}$ and running performance (time to exhaustion and peak velocity). During the ramp test (3º/5.3% inclination), which was started at the same individual velocity (75–98% of the individual pre-training $\dot{V}O_{2max}$) at both pre- and post-test, running speed was increased each min by 1.0 km·h^{-1} to a supramaximal velocity (104–121% of pre- and post-training $\dot{V}O_{2max}$) and volitional exhaustion within 4–6 min.[8] The highest 30-sec $\dot{V}O_2$ measurement was defined as $\dot{V}O_{2max}$. Two of the following criteria had to be achieved to confirm a sufficiently exhausting test: a RER ≥1.05,[9] a blood lactate concentration (BLC) ≥9 mmol·L^{-1} two min after exhaustion,[10] a rate of perceived exertion (RPE) ≥17 on the $BORG_{6-20}$ RPE-scale,[10] and visible exhaustion of the subject.[11] BLC measured following the ramp test at pre- and post-training was also used to indicate changes in anaerobic capacity (i.e. changes in the organism's buffering capacity of hydrogen ions (H^+) from lactic anaerobic metabolism/lactic acid (HLa ↔ H^+ La^-)), similarly to the study by Enoksen et al.[12] Peak HR + 5 beats·min^{-1} was calculated as HR_{max}.[8]

Instruments

The running tests were performed on a Woodway PPS MED55 treadmill (Woodway GmbH, Weil am Rhein, Germany). $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$), RER and ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) were assessed using a Sensor Medics VMax29 ergo-spirometry system with a mixing chamber (Vyaire Medical, Höchberg, Germany). During the treadmill tests, the participants wore a nose clip and breathed through a mouthpiece connected to a two-way non-rebreathing valve (2700 series, Hans Rudolph Inc., Kansas, USA), where the expired air was led via a tube into the mixing chamber for analyses of $\dot{V}O_2$, $\dot{V}CO_2$, RER and $\dot{V}_E/\dot{V}O_2$. Gas and volume calibration were executed in accordance with the user manual of the test equipment. BLC was analyzed with a Lactate Scout$^+$ analyzer (EKF Diagnostics, UK). HR was recorded using a HR monitor (Polar Electro Oy, Kempele, Finland), while running time was measured with a digital stopwatch (Hanhart Prisma 200, Hanhart GmbH, Germany). During the HICR sessions on the soccer field, real-time HR was monitored using a Polar Team wearable player tracking system (Polar Electro Oy, Kempele, Finland).

Training intervention

Two times/week, for six weeks, the five soccer players performed 10 min of almost exhausting HICR (90–95% HR_{max}) immediately following regular soccer training. The HICR sessions were carried out running around the soccer field and were completed with 3 min of jogging at a low speed corresponding to ~60 HR_{max}. HR was monitored during all HICR sessions in all the players via a transmitter placed on the players' chest, which transferred the players' real-time HR to the exercise physiologist's laptop computer located at the side of the soccer field.

Statistical analysis

The results are presented individually in tables. In the «Results» section, the percentage changes in the dependent variables are presented as a range. The changes in the dependent variables were calculated by using Excel spreadsheets.

Results

Anthropometry

Body mass and BMI changed by -2% to +4% in the five players *(subjects A–E)* (Table I).

Running performance

Time to exhaustion and peak velocity increased by 10–38% and 3–10%, respectively, in the five players *(subjects A–E)* (Table II).

Aerobic endurance

Three of five players *(subjects A, B and D)* increased $\dot{V}O_{2max}$ in absolute ($L \cdot min^{-1}$: 7–13%) and relative values ($ml \cdot kg^{-1} \cdot min^{-1}$: 4–12%, $ml \cdot kg^{-0.75} \cdot min^{-1}$: 5–13%) (Table III). Oxygen cost decreased by 3–6% in three of five players *(subjects B, C and E)* (Table III). RER decreased by 1–5% in four of five players *(subjects B–E)* (Table III).

Anaerobic endurance

Four of five players *(subjects A, B, C and E)* increased BLC by 9–32% (Table III).

DISCUSSION

The main finding of this study was that HICR seems to have contributed to a substantial improvement of running performance (increased time to exhaustion and peak velocity). This appeared to be mainly due to increased $\dot{V}O_{2max}$ and/or enhanced running economy (decreased oxygen cost). Furthermore, it cannot be excluded that a possible enhancement of anaerobic capacity (indicated by increased BLC) had an impact on the improvement of running performance of most of the players. Another interesting result was that most players also apparently improved fat oxidation (decreased submaximal RER).

Anthropometry

The changes in body mass of the five players *(subjects A–E)* following HICR in this study, were modest, which is similar to findings in previous studies of HIIR in U14 youth[7] and U17–U19 junior soccer players.[5,6] Furthermore, when using allometric scaling of $\dot{V}O_{2max}$ (ml·kg$^{-0.75}$·min^{-1}) and submaximal $\dot{V}O_2$ (ml·kg$^{-0.75}$·m^{-1}), which appears to be better correlated with running performance than conventional $\dot{V}O_{2max}$ expressed as ml·kg^{-1}·min^{-1} and submaximal $\dot{V}O_2$ expressed as ml·kg^{-1}·m^{-1},[13] the small changes in body mass observed in the present study probably had little or no effect on running performance.

Running performance

It is worth notice that the two players *(subjects C and E)* who did not improve $\dot{V}O_{2max}$ following HICR in the present study, achieved similar running performance gains (increased time to exhaustion and peak velocity) as those three players *(subjects A, B and D)* who did increase $\dot{V}O_{2max}$. Improved running economy and a possible increase of anaerobic capacity appear to explain the running performance improvements in those two players *(subjects C and E)* who did not enhance $\dot{V}O_{2max}$.

The substantial improvements of running performance in all five players *(subjects A–E)* show similarities with findings reported following interval exercise (4 x 4 min HIIR/3 x 3 min breaks, or e.g. combined 12 x 30-s sprint/30-s breaks and 6 x 2 min HIIR/5 x 2 min breaks, 90–95% HR_{max}) in U17–U19 junior[5] and U14 youth soccer players.[7] In those studies, Impellizzeri et al.[5] found a 12% enhancement of time-trial time during the "Ekblom test" (i.e. a ~10–12 min soccer-specific running test), whereas Sperlich et al.[7] reported a 4% improvement of time-trial time during a 1000-m running test (running in a 250-m rectangle on a soccer field). Although the running performance tests in the studies by Impellizzeri et al.[5] and Sperlich et al.[7] were more soccer specific, the findings in the present study indicate that 10 min of HICR can be an alternative, or supplementary, modality to ~25–30 min of HIIR (e.g. 4 x 4 min HIIR/3 x 3 min breaks, or combined 12 x 30-s sprint/30-s breaks and 6 x 2 min HIIR/5 x 2 min breaks) in the development of running performance in young soccer players.

Aerobic endurance

The improvement of $\dot{V}O_{2max}$ observed in three of five players *(subjects A, B and D)* following HICR in the present study is similar to that found (7% increase in $\dot{V}O_{2max}$) following five weeks of various HIIR (two–three weekly sessions of e.g. 4 x 4 min HIIR/3 x 3 min breaks, or combined 12 x 30-s sprint/30-s breaks and 6 x 2 min HIIR/5 x 2 min breaks, 90–95% HR_{max}) in U14 youth soccer players[7] and those reported (7–8% increases of $\dot{V}O_{2max}$) following four–eight weeks of two weekly sessions of 4 x 4 min HIIR (90–95% HR_{max})/3 x 3 min breaks (50–70% HR_{max}) in U17–U19 junior soccer players.[5,6] Furthermore, the enhancement of running economy (decreased oxygen cost) found in three of five players *(subjects B, C and E)* following HICR in this study points in the same direction as that reported by Helgerud et al.,[6] who found a 7% decrease in oxygen cost of U17–U19 junior soccer players, following eight weeks of two weekly sessions of 4 x 4 min HIIR (90–95% HR_{max})/3 x 3 min breaks (50–60% HR_{max}). It is, therefore, not unreasonable to believe that the five players *(subjects A–E)* in the present study also could have achieved similar running performance improvements during soccer match-play as those observed in the U17–U19 junior soccer players in the studies by Impellizzeri et al.[5] and Helgerud et al.[6] However, this issue remains to be investigated.

Given that the submaximal RER in the present study actually reflected the respiratory quotient of aerobic metabolism, the declines in submaximal RER (0.01–0.04 units) in *subjects B, C, D* and *E* of this study indicate increases of fat oxidation from 36% to 39%, 66% to 70%, 39% to 53% and 29% to 39%, respectively, of the total energy turnover.[14(p.188)] As blood glucose concentration appears to decline during soccer match-play[15(p.51)] (indicating depletion of the glycogen stores), such increases in fat oxidation, which may have a glycogen-saving effect,[16] can also induce running performance gains (e.g. increase the number of high-intensity runs and total distance covered) during a 90-min soccer match. The increase of submaximal RER (0.04 unit) in one of five players *(subject A)* may have been due to the increase of $\dot{V}_E/\dot{V}O_2$ in this player.

Anaerobic endurance

The increase in BLC in four of five players *(subjects A, B, C and E)* following HICR in this study indicate that the buffering capacity of H^+ from lactic anaerobic metabolism/HLa, and thus the anaerobic capacity, improved in these four players. However, although this improvement points in the same direction as that observed following high-intensity low volume training in well-trained male middle-distance runners,[12] further studies are necessary to verify these observations, as increased BLC from pre- to post-test can be, quite simply, a result of a learning effect rather than an improvement of H^+ buffering capacity. Another reason for caution is the fact that BLC is related to the distribution volume in the body. During exercise, the distribution volume changes, thus making comparison of BLC difficult.[17] Nevertheless, as typical sprint and high-speed running in soccer last ~2 s,[15(p.47),18] and BLC during soccer matches is thus generally moderate (~4–7 $mmol \cdot L^{-1}$),[15(p.49)] any improvement of anaerobic capacity, through increased H^+ buffering capacity, probably has little impact on running performance during soccer match-play.

Practical application

HIIR is certainly time-efficient training in soccer players who want to improve endurance and running performance.[5–7] However, compared to e.g. 4 x 4 min HIIR/3 x 3 min breaks, or combined 12 x 30-s sprint/30-s breaks and 6 x 2 min HIIR/5 x 2 min breaks (90–95% HR_{max}), which are total exercise durations of ~25–30 min, the 10-min HICR modality examined in the present study is considerably less time-consuming; about 60–70% less total time is spent on running exercise when the session takes place immediately following soccer training. In practice, therefore, we recommend performing 10 min of HICR (90–95% HR_{max}) two to three times/week, for six to eight weeks, in the pre-season preparation period, in an attempt to improve the endurance and running performance of youth soccer players. When performing this HICR modality as self-training, we recommend a 7-10-3 session, i.e. 7 min of progressive warm-up (from ~60% to ~85% HR_{max}), followed directly by 10 min of HICR (90–95% HR_{max}), and finally 3 min of jogging at a low speed corresponding to ~60–70% HR_{max}, which is a total duration of 20 min.

Limitations

The number of participants in the present study was limited. Furthermore, time to exhaustion protocols lasting 6–7 min (approximately the same duration as the ramp test procedure of this study) have shown a coefficient of variation corresponding to ~15%.[19] Moreover, BLC and RER are indirect assessments of anaerobic capacity and substrate oxidation, respectively. Therefore, the outcomes of this study must be interpreted and generalized with caution.

CONCLUSION

HICR of short exercise duration, as a supplement to regular soccer training, can help improve the running performance and endurance of youth soccer players.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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This study did not receive any funding.

AUTHORS' CONTRIBUTIONS

Study concept and design: Even Jarstad, Arne Christian Tysland

Acquisition of the data: Even Jarstad, Arne Christian Tysland

Analysis and interpretation of the data: Even Jarstad, Asgeir Mamen

Drafting of the manuscript: Even Jarstad

Critical revision: Even Jarstad, Asgeir Mamen

All authors read and approved the final version of the manuscript: Even Jarstad, wife of the late Arne Christian Tysland, Asgeir Mamen.

In memory of

We dedicate this paper to the second author, the late Arne Christian Tysland, MD. Rest in peace, Arne Christian, your memory will never be forgotten.

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Table I. Anthropometric variables of the five soccer players at pre- and post-training.

	Subject A		***Subject B***		***Subject C***		***Subject D***		***Subject E***	
Variables	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Body mass *(kg)*	66.1	68.5	61.8	62.2	55.0	54.0	62.7	62.4	56.9	57.7
BMI $(kg \cdot m^{-2})$	20.6	21.4	18.7	18.8	20.5	20.1	19.1	19.1	19.5	19.7

BMI = body mass index.

Table II. Running performance variables of the five soccer players at pre- and post-training.

	Subject A		***Subject B***		***Subject C***		***Subject D***		***Subject E***	
Variables	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Time to exhaustion (*s*)	248	273	304	420	274	335	278	309	315	424
Peak velocity ($km \cdot h^{-1}$)	13.0	14.0	15.0	16.5	13.5	14.5	14.0	14.5	16.0	16.5

Table III. Physiological variables that determine endurance of the five soccer players at pre- and post-training.

	Subject A		***Subject B***		***Subject C***		***Subject D***		***Subject E***	
Variables	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
$\dot{V}O_{2max}$										
$L \cdot min^{-1}$	3.38	3.63	3.83	4.32	3.11	3.00	3.68	3.98	3.76	3.81
$mL \cdot kg^{-1} \cdot min^{-1}$	51.1	52.9	62.0	69.5	56.6	55.5	58.7	63.7	66.1	66.0
$mL \cdot kg^{-0.75} \cdot min^{-1}$	145	152	174	196	154	151	165	179	182	182
HR_{max} *($s \cdot min^{-1}$)*	196	200	203	203	212	209	206	205	211	212
RER_{peak} *($\dot{V}CO_2/\dot{V}O_2$)*	1.08	1.09	1.09	1.10	1.01	1.08	1.05	1.04	1.12	1.11
BLC *($mmol \cdot L^{-1}$)*	10.0	10.9	8.8	11.6	9.4	10.9	10.0	9.4	10.2	13.5
$\dot{V}_E/\dot{V}O_2$	35	39	39	40	34	35	31	31	38	36
$BORG_{6–20}$	17	18	17	19	18	17	18	18	18	19
Running economy										
$\dot{V}O_2$ *($mL \cdot kg^{-0.75} \cdot m^{-1}$)*	0.60	0.68	0.66	0.63	0.67	0.63	0.74	0.79	0.68	0.66
$\%\dot{V}O_{2max}$	62	67	57	48	65	62	68	67	56	54
HR *($s \cdot min^{-1}$)*	163	167	145	134	175	166	167	163	144	144
Substrate oxidation										
RER *($\dot{V}CO_2/\dot{V}O_2$)*	0.86	0.90	0.89	0.88	0.80	0.79	0.88	0.84	0.91	0.88
$\dot{V}_E/\dot{V}O_2$	28	29	27	28	22	22	23	22	26	27

$\dot{V}O_2$ = oxygen consumption, $\dot{V}O_{2max}$ = maximal oxygen consumption, HR = heart rate, HR_{max} = maximal heart rate, RER = respiratory gas-exchange ratio, RER_{peak} = peak respiratory gas-exchange ratio, BLC = blood lactate concentration, $\dot{V}_E/\dot{V}O_2$ = ventilatory equivalent for oxygen, $BORG_{6-20}$ = the BORG 6 to 20 rate of perceived exertion-scale.