

The effects of high-intensity training on aerobic capacity of football players

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Published online: September 30, 2023

(Accepted for publication September 15, 2023)

DOI:10.7752/jpes.2023.09263

Abstract

Football is characterised by varying pace and acyclical movements that are influenced by game situations. To meet these locomotive demands in football, players need to generate energy from different sources via aerobic and anaerobic metabolism. Currently, teams are limited by small preseason windows to improve technical, tactical and physiological performances. Through the use of High Intensity Intermittent Training (HIIT), athletes may derive cardiorespiratory improvements in a short period. As such, this study aimed to determine whether HIIT could provide a practical field-based method to improve the aerobic fitness of male football players. Eighteen sub-elite football players (21 ± 1.8 years, height 1.76 ± 5.7 cm, and mass $62.7 \text{ kg} \pm 7.2 \text{ kg}$), were recruited for this study. Pre- and post-experimental period, maximum oxygen uptake was measured through a modified Heck protocol test on a treadmill until volitional fatigue. A progressive overload approach was used to make the players run at intensities greater than their recorded $\text{vVO}_{2\text{max}}$. Progressive overloading was implemented by increasing the $\text{vVO}_{2\text{max}}$ prescription percentage, along with the manipulation of the work-to-rest ratios, repetitions, sets and high-speed running total distances. The intervention was applied during the first four weeks of the pre-season, with a total of 8 specific HIIT sessions. Results obtained showed improvement in aerobic fitness metrics (pre- versus post-measurement). Specifically, statistically significant increases ($p < 0.0001$) were noted for: $\text{VO}_{2\text{max}}$ (pre: 43.9 ± 4.6 ; post: $50.5 \pm 3.4 \text{ mlO}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$); $\text{vVO}_{2\text{max}}$ (pre: 13.8 ± 1.5 ; post: $16.3 \pm 1.49 \text{ km} \cdot \text{h}^{-1}$); and vVT_2 (pre: 9.2 ± 1.3 ; post: $11.6 \pm 2.0 \text{ km} \cdot \text{h}^{-1}$) as a result of the intervention. Application of the four-week intervention programme was guided by the progressive overload principle, to systematically increase the demands placed on the cardiorespiratory responses and ensure that players reach greater aerobic adaptations. Overall, the results indicate that HIIT is a time-effective training method that can efficiently improve the cardiorespiratory dynamics of football players in a limited time.

Keywords: modified Heck protocol test, aerobic capacity, field-based training, $\text{vVO}_{2\text{max}}$

Introduction

Modern football is physically demanding and requires players to have the ability to repeat high-intensity actions during the match as these are of paramount importance for success (Reilly *et al.*, 2000; Owen & Wong, 2009). Variability in the methods physical preparation coaches use for developing aerobic capacity has led to investigations into more effective aerobic capacity development methods for intermittent sports (Jovanovic, 2018).

Until recently, the approach has been to implement long slow distance (LSD) training; however, compelling evidence now shows that HIIT has greater performance-based physiological benefits. Moreover, HIIT is time-efficient, particularly in the condensed training phase where training focuses on other aspects such as technical and tactical preparation (Rodgers, 2010).

The relative duration of repetitions and rest is also important to consider when programming HIIT, because of their influence on immediate physiological responses and subsequent adaptations (Rodgers, 2010).

It has been reported that HIIT produces greater fitness benefits than steady-state training (Gibala & Jones, 2013). However, the implementation of HIIT cannot occur without practical considerations such as determining how fast the run needs to be, how long each interval should last, how much rest is required in between the repetitions and sets plus how many intervals to be done (Gibala & Jones, 2013). Additionally, using generalised training approaches in cohorts with different fitness levels may result in ineffectual stimulus for adaptations or overloading, which may result in injuries (Buchheit, Vassallo and Waldron, 2021b).

Prescribing training intensity according to different velocities/intensities may result in a significant positive increase in aerobic capacity. Indeed, HIIT training prescribed at 100% of the velocity at the maximum rate of oxygen consumed during exercise ($\text{vVO}_{2\text{max}}$) provides significant increases in dynamic aerobic variables compared to a prescription of 95% $\text{vVO}_{2\text{max}}$ (Dendai, Ortiz, Greco & de Mello, 2006).

Additionally, supramaximal intensities (100%–120% vVO_{2max}) have been reported to improve aerobic capacity (Laursen & Buchheit, 2019). The manipulation of rest intervals and repetitions influences the ability to repeat the given exercise at a set intensity, and consequently the aerobic variables (Laursen *et al.*, 2019).

Overall, studies have shown positive effects of using HIIT; however, the variability in methods of applying HIIT influences the significance of the increase in athletes' respective aerobic capacities (Dendai *et al.*, 2006, Hellsten, Mandrup, Egelund, Nyberg, Slingsby, Andersen, Løgsttrup, Bangsbo *et al.*, 2017). However, data on the effectiveness of using field-based training protocols remain scarce and conflicting. This study aimed to evaluate the effectiveness of a field-based HIIT protocol for improving the aerobic fitness of sub-elite football players. Additionally, the study sought to provide a practical method of implementing individualised high-interval training as an endurance training tool.

Material & Methods

Participants

A sample of 18 male footballers (age: 21.0 ± 1.8 years; height: 1.76 ± 0.06 m; mass: 62.7 ± 7.2 kg) free of injury, volunteered to participate in this cross-sectional intervention study. All participants completed an informed consent sheet prior to any procedures. The study was approved by the Faculty of Health Science Research Ethics Committee (REC-172-2019).

Testing was conducted at two points in time, separated by a four-week intervention. Data were collected in the post-pre-season change-over period.

Procedure

Anthropometrical measurements:

Body mass was measured using a calibrated electronic scale (Seca Robusta 813, Germany) to the nearest 0.01 kg and stature (height) was measured using a stadiometer (Seca 213, Seca, Germany) taken to the nearest 0.1 cm.

Aerobic capacity:

The football players underwent two maximal oxygen consumption (VO_{2max}) tests within five weeks; in between these two testing points, the players underwent a HIIT intervention programme. The aerobic capacity tests were conducted between the hours of 08:00 and 14:00. The tests were carried out at room temperatures between 20 °C and 24 °C, relative air humidity between 45% and 65%, and barometric pressures between 698 mm Hg and 705 mm Hg. The players were advised to avoid high caffeine content or alcoholic beverages 24 hours before evaluation, to have a light meal two hours before the test and to be dressed in a vest, short pants and running shoes.

The Cortex metalyzer (Metalyzer 3B, Cortex, Germany) was calibrated before and after performing each test, using a known gas mixture ($O_2 = 14.97\%$; $CO_2 = 4.96\%$), balanced with nitrogen ($N_2 = \pm 0.02\%$) and then verifying the calibration against the ambient air. Calibration and exchange of the pneumotachograph were performed before each test, using a syringe (Cortex calibration gas syringe 31, Germany) with a capacity of 3 L. A 100 mL of dead space was used as a correction factor in determining the flow and respiratory volume readings. The subject's heart rate was continuously monitored during the test with a heart rate band around their chest with a Polar S-810 (Polar Electro Oy, Finland). A motorised treadmill (4 Front Woodway, USA) was used for the maximal oxygen uptake (VO_{2max}) protocol.

A continuous stepped protocol with a fixed grade inclination of 3% (the modified Heck protocol) was used in this study (Howley, Bassett & Welch, 1995). Specifically, players spent one minute at rest and warmed up for three minutes at velocities of 4.8, 6.0, and 7.2 $km \cdot h^{-1}$ for one minute each. The test then began at 8.4 $km \cdot h^{-1}$, and the velocities increased with velocity increments of 1.2 $km \cdot h^{-1}$ every two minutes.

The ventilatory threshold was determined from VT_1 and VT_2 speeds which were derived from the rate exchange ratio (RER) being at a value of 0.85 for VT_1 and 1.00 for VT_2 (Aziz, Tan & Teh, 2005). The O_2 consumption, CO_2 production and respiratory quotient ($RQ = VCO_2/VO_2$) were calculated from the measured values using a computerised breath-by-breath gas exchange analysis system (MM3B Cortex, Germany).

VO_{2max} and the tests termination criteria were reached when the rate of exchange ratio between metabolic CO_2 produced and O_2 used ($RER \geq 1.15$) attained at least 90% of the predicted heart rate max (which is $220 - age$) (She, Nakamura & Makino, Yasuhiro & Hiroshi, 2015; Howley, Bassett & Welch 1995). The vVO_{2max} was determined from the metabolic cart measurements as the first running velocity at which VO_{2max} was reached, which was at volitional fatigue or $RER \geq 1.15$.

The running-based HIIT intervention was carried out twice a week, for four weeks, which resulted in eight HIIT sessions being held in total. Following the first week, there was progressive overloading whereby the vVO_{2max} prescription percentage was increased, along with the manipulation of the work-to-rest ratios, repetitions, sets and high-speed running total distances to increase the physiological demands of the HIIT sessions (Table 1).

Table 1: The four-week high-intensity interval training (HIIT) programme.

WEEK 1 (frequency: 2 sessions)							
Group	WORK: REST	INTENSITY	REPS	SETS	SHUTTLE DISTANCE (m)	RUNNING SPEED (km/h)	Total Distance (m)
1	1:1 15s:15s	120% vVO _{2max}	8	2	70.83	17.28	1133
2					75	18.72	1200
3					84	20.16	1344
4					87	20.6	1392
WEEK 2 (frequency: 2 sessions)							
1	1:1 12s:12s	140% vVO _{2max}	8	2	67.2	20.16	1075
2					70.53	21.84	1128
3					74.6	22.4	1193
4					83	25.2	1328
WEEK 3 (frequency: 2 sessions)							
1	1:0.5 12s: 6s	140% vVO _{2max}	8	2	67.2	20.16	1075
2					70.53	21.84	1128
3					74.6	22.4	1193
4					83	25.2	1328
WEEK 4 (frequency: 2 sessions)							
1	1:0.5 6s:3s	170% vVO _{2max}	6	2	40	24.48	480
2					44.2	26.52	530.4
3					46.6	28.56	559.2
4					51	30.6	612

The HIIT intervention programme was prescribed based on the running velocity values obtained at vVO_{2max}. Players with similar VT velocities were grouped and given the same running distances. The players performed shuttle runs in their assigned groups based on average velocity. Each of the groups was assigned a set of distances and velocities to run; the players were put into their unique groups according to the same and similar vVO_{2max}.

Data analysis

All the data were presented using means and standard deviations and the data distributions were analysed using Shapiro-Wilk tests. A Wilcoxon signed test was used to compare pre- and post-test results to assess any changes in cardiorespiratory variables. ANOVA test was used with the post hoc analysis to determine if there was statistically significant difference between groups. Effect sizes were calculated as Cohen's *d* and qualitative descriptors from Hopkins, Marshall, Batterham & Hanin (2009) were used (trivial: 0 – 0.2; small: 0.2 – 0.6; moderate: 0.6 – 1.2; large: 1.2 – 2.0; very large: 2.0 – 4.0; nearly perfect: >4.0.) All statistical calculations were processed through the Statistical Program for the Social Sciences (SPSS) version 25 (IBM) with the level of significance set at $p < 0.05$.

Results

The 18 participants were made up of one goalkeeper, five defenders and six attackers. The 18 participants completed all the HIIT sessions for the 4-week intervention.

Table 2: The pre- and post-test results of the cardiorespiratory variables for the football players after a 4-week HIIT intervention.

Variable	Pre	Post	p-value	effect size <i>d</i>
VO _{2max} (ml O ₂ .kg ⁻¹ .min ⁻¹)	43.9 ± 4.6	50.5 ± 3.4	0.0001	1.65
vVO _{2max} (km.h ⁻¹)	13.8 ± 1.5	16.3 ± 1.49	0.0001	1.67
Speed (km.h ⁻¹) @ VT ₁	6 ± 0.0	7.5 ± 1.2	0.001	1.77
Speed (km.h ⁻¹) @ VT ₂	9.2 ± 1.3	11.6 ± 2.0	0.001	1.42
HRmax (beats.min ⁻¹)	169 ± 7.3	180.5 ± 6.4	0.0001	1.68
HR @ VT ₁ (beats.min ⁻¹)	97.7 ± 12	122.7 ± 10	0.0001	2.26
HR @ VT ₂ (beats.min ⁻¹)	140.2 ± 16	163.1 ± 12	0.0001	1.62
Time to VO _{2max} (min:s)	0:10:06 ± 18	0:13:10 ± 14	0.0001	11.41
Time to VT ₁ (min:s)	0:01:50 ± 0.93	0:03:49 ± 1.1	0.0001	116.83
Time to VT ₂ (min:s)	0:05:47 ± 1.5	0:08:14 ± 2.13	0.0001	79.80

A large increase in VO_{2max}, vVO_{2max}, velocity at VT₁, VT₂, HRmax and HR at VT₂ was noted following the HIIT intervention. A very large increase in HR at VT₁ was evident and a perfect increase in the time it took to reach VO_{2max}, VT₁ and VT₂ was noted in the post tests following the HIIT intervention.

Aerobic capacity test results

The pre- and post-test results for the cardiorespiratory variables for the football players after a 4-week HIIT intervention are presented in Table 2. The VO_{2max} pre-test and post-test results revealed that the HIIT intervention programme led to large significant improvements in the players' VO_{2max}, ($p = 0.0001$). Figure 1

displays the 18 individual responses for $\text{VO}_{2\text{max}}$ following the four-week HIIT intervention. All but two players showed improvement in their $\text{VO}_{2\text{max}}$ (Figure 1). Similar significant ($p = 0.0001$) improvements were noted in the $\text{vVO}_{2\text{max}}$ (Table 2 and Figure 2). The T-test indicates that there was a significant increase in HR_{max} at $\text{VO}_{2\text{max}}$ ($p = 0.0001$), HR at VT_1 ($p = 0.0001$) and HR at VT_2 ($p = 0.0001$), between the results found in the pre-test and post-test (Table 2). The velocities at which VT_1 ($p = 0.001$) and VT_2 ($p = 0.001$) occurred significantly improved when comparing the pre-test and post-test (Table 2). The results indicated that there was a significant improvement ($p = 0.0001$) in the time at which $\text{VO}_{2\text{max}}$ ($p = 0.0001$), VT_1 ($p = 0.0001$) and VT_2 ($p = 0.0001$) occurs when comparing the pre-test and post-test (Table 2).

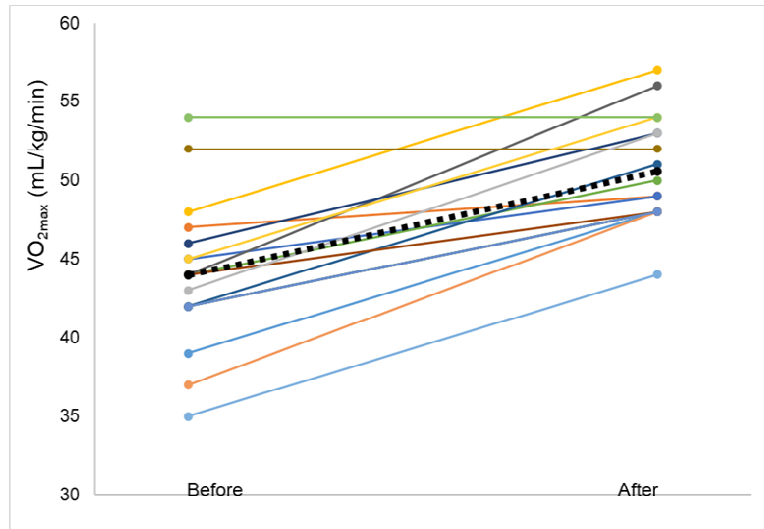


Figure 1: $\text{VO}_{2\text{max}}$ comparison of pre-tests and post-test results indicate that all the players had an improved $\text{VO}_{2\text{max}}$ following the 4-week HIIT intervention. Dashed line indicates the group mean of 18 football players.

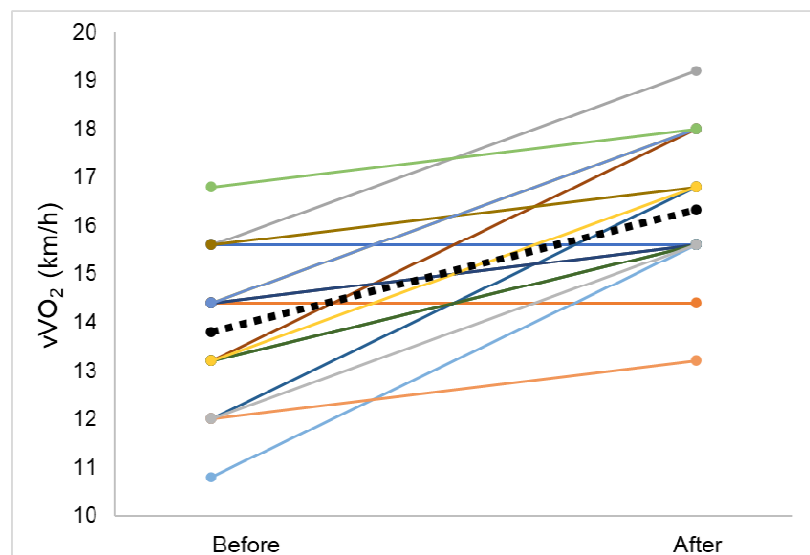


Figure 2: $\text{vVO}_{2\text{max}}$ comparison for pre- and post-test results indicates all the players experienced an improvement in the speeds at which $\text{VO}_{2\text{max}}$ occurred following the 4-week HIIT intervention. Dashed line indicates the group mean of 18 football players.

A large increase in $\text{VO}_{2\text{max}}$, $\text{vVO}_{2\text{max}}$, velocity at VT_1 , VT_2 , HR_{max} and HR at VT_2 was noted following the HIIT intervention. A very large increase in HR at VT_1 was evident and a perfect increase in the time it took to reach $\text{VO}_{2\text{max}}$, VT_1 and VT_2 was noted in the post tests following the HIIT intervention.

The ANOVA indicated a significant increase in $\text{VO}_{2\text{max}}$, ($p = 0.0002$) of the players, as well as a difference in the pre- and post-test values $p = 0.000$ and no interacting differences for the groups (Table 3). Post-hoc analysis revealed a significant difference in the $\text{VO}_{2\text{max}}$ ($p = 0.000$) of the interacting differences for the pre- and post-test values and no difference across the groups ($p = 0.160$) (Table 3).

Table 3: $\text{VO}_{2\text{max}}$ and $\text{vVO}_{2\text{max}}$ values for 18 football players grouped by initial $\text{vVO}_{2\text{max}}$ before and after 4-week HIIT intervention.

	Pre		Post	
	$\text{VO}_{2\text{max}}$ ($\text{ml O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	$\text{vVO}_{2\text{max}}$ ($\text{km} \cdot \text{h}^{-1}$)	$\text{VO}_{2\text{max}}$ ($\text{ml O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	$\text{vVO}_{2\text{max}}$ ($\text{km} \cdot \text{h}^{-1}$)
Group 1*	42.2 ± 3.1	12.48 ± 1.9	50.8 ± 2.7	16.4 ± 1.2
Group 2	42.6 ± 6.3	13.6 ± 0.6	48.6 ± 3.2	16.4 ± 1.8
Group 3	45.5 ± 1.2	14.7 ± 0.6	51.75 ± 3.4	15.3 ± 0.6
Group 4	47.3 ± 5.0	15.2 ± 0.7	52.3 ± 4.5	18 ± 1.2

* Group 1 indicated a $\text{VO}_{2\text{max}}$ significantly different from Group 4

Discussion

This study aimed to evaluate the effects of a four-week field-based HIIT on the aerobic capacity of football players. The results indicated that aerobic capacity and its associated variables all improved following the HIIT intervention.

Physiological standards

The players in the current study compared to international players competing in the professional, semi-professional and amateur level indicated relatively lower height and body weight (Booyesen, Bentel & Harry *et al.*, 2018). The international players ranged between a height of 174.4 to 179.3 cm and a weight ranging from 69.0 to 76.3 kg (Rousopoulos *et al.*, 2021; Tourn, Tribolet, Watsford & Fransen, 2021).

The $\text{VO}_{2\text{max}}$ of the players in the current study ($43.9 \pm 4.6 \text{ ml/kg/min}$) is relatively low in comparison to semi-professional from a similar geographic location ($52 \pm 6 \text{ ml/min/kg}$) (Boer & Van Aswegen, 2016) and international professional players (55 to 65 ml/kg/min) (Rousopoulos *et al.*, 2021, Metaxas, Sendelides, Koutlianos and Mandroukas, 2006; Da Silva, Guglielmo, Carminatti, De Oliveira, Dittrich & Paton, 2011; Metaxas, 2021). This discrepancy can be attributed to better training approaches and greater availability of training time for professional athletes. Similarly, the $\text{vVO}_{2\text{max}}$ in the current study ($13.8 \text{ km} \cdot \text{h}^{-1}$) was lower than those reported by semi-elite and professional players ($14.4 \text{ km} \cdot \text{h}^{-1}$ - $17.0 \text{ km} \cdot \text{h}^{-1}$) (Marquezi, Agostinho, Aparecido & Cascapera, 2019; Slimani, Znazen, Miarka, & Bragazzi, 2019).

In the current study the speed at which VT_1 occurred was $6 \text{ km} \cdot \text{h}^{-1}$, which is lower than the speed at which VT_1 ($7.1 \text{ km} \cdot \text{h}^{-1}$) would generally occur for an active sample (Marquezi *et al.*, 2019); in the study by Cunha, Lopes, Geremia, Leites, Baroni & Voser *et al.* (2016), international elite youth academy players reached $9.9 \pm 1.1 \text{ km} \cdot \text{h}^{-1}$. The speed at which VT_2 occurred was $9.24 \text{ km} \cdot \text{h}^{-1}$, which is lower than the VT for elite international footballers ($13.0 \text{ km} \cdot \text{h}^{-1}$) (Slimani, Znazen, Miarka & Bragazzi 2019; Rousopoulos *et al.*, 2021). Youth amateur football players were reported to have a mean VT_2 of around 13.6 ± 0.3 and $14.7 \pm 0.2 \text{ km} \cdot \text{h}^{-1}$ (Rousopoulos *et al.* (2021)). The VTs of the players in the current study still do not come close to those reported in the literature. According to the study by Slimani *et al.* (2019) examining the physiological profiles of football players, they had an average VT threshold performance of $13.2 \text{ km} \cdot \text{h}^{-1}$ (1st league) to $12.3 \text{ km} \cdot \text{h}^{-1}$ (3rd league); the latter findings are also substantially higher than the findings of the current study, with the Slimani study having markedly higher VT values.

HR_{max} at $\text{VO}_{2\text{max}}$ was 169 bpm in the current study; however, the HR_{max} is said to be at 189 bpm for international football players, which suggests that the current study registered significantly lower HR_{max} (Modric, Sime, Sekulic & Liposek, 2019). HR at VT_1 was at 97 bpm, which is lower than the 130 bpm at VT_1 for sporadically active people; however, the comparison was not done with a football sample because of the limited data available (Marquezi *et al.*, 2019). In the current study HR at VT_2 was at 140.2 bpm which was considerably lower than the 180 bpm reported by Modric *et al.* (2019) and Rousopoulos *et al.* (2021). The time at which $\text{VO}_{2\text{max}}$ occurred was 10:06 minutes, VT_1 at 01:50 minutes and VT_2 at 05:47 minutes.

The numerous physiological differences between the current sample and those previously reported can be attributed to the playing status and level of the athletes (Slimani *et al.*, 2019; Schwesig, Schulze, Reinhardt, Laudner, Delank, & Hermassi, 2019; Rousopoulos *et al.*, 2021).

In the current study, a four-week HIIT intervention was designed to train the players above their $\text{vVO}_{2\text{max}}$. The players were made to run shuttles for pre-determined times and distances (known running speeds) followed by passive rest. For the duration of the four-week intervention, the intensity of the HIIT running programme was increased weekly, by ramping up the velocity of the runs, reducing passive rest times and manipulating the repetitions and sets. The manipulation of the different training variables was tailored to be as individual-specific as possible, whereby the players with the same or similar $\text{vVO}_{2\text{max}}$ were placed in the same groups and were given the same distances, rest, repetitions and sets to do.

Following the 4-week HIIT intervention in the current study, the sample improved their physiological parameters. Specifically, significant increases were noted in the $\text{VO}_{2\text{max}}$, $\text{vVO}_{2\text{max}}$, HR_{max} at $\text{VO}_{2\text{max}}$, HR , running speeds and times at VT_1 , VT_2 and the time at which $\text{VO}_{2\text{max}}$ occurs. Post-test data of the players was as follows: mass: 62.5 kg, $\text{VO}_{2\text{max}}$: 50.5 ml/kg/min , $\text{vVO}_{2\text{max}}$: $16.3 \text{ km} \cdot \text{h}^{-1}$, HR_{max} at $\text{VO}_{2\text{max}}$: 180.5 bpm, HR at VT_1 : 122.7 bpm, HR at VT_2 : 163 bpm, speed at VT_1 : $7.4 \text{ km} \cdot \text{h}^{-1}$, speed at VT_2 : $11.64 \text{ km} \cdot \text{h}^{-1}$. The time at which $\text{VO}_{2\text{max}}$ occurred was 13:10 min, VT_1 was at 03:49 min and VT_2 was at 08:14 min. These physiological improvements indicate that the players could cope with higher workloads and more intense efforts. In a football

context these improvements would mean players would have an improved ability to recover faster from high-intensity efforts and be more fatigue resistant (Hawley, Lundby, Cotter & Burke, 2018). These post-test findings were expected because the literature suggests that intensity plays a role in mediating the improvements of $\text{VO}_{2\text{max}}$ (Milanović, Sporis & Weston, 2016). Specifically, interval training with higher intensities results in greater aerobic improvements. Meta-analyses by Bacon, Carter, Ogle & Joyner (2013); Milanović *et al.* (2016) and Weston, Taylor, Batterham & Hopkins (2014) all reported a greater increase in $\text{VO}_{2\text{max}}$ for high-intensity training compared to values typically reported in large studies of moderate-intensity continuous training (MICT).

Effects of the HIIT intervention programme

The HIIT training intervention rests on scientific principles of training that include individuality, specificity, continuity and individuality. The application of these principles was facilitated by the frequency, intensity, training and type (FITT) guidelines (Barisic, Leatherdale & Kreiger, 2011). Sperlich, de Marées, Koehler, Linville, Holmberg & Mester (2011) reported similar to the current study, as they were able to yield significant improvements (7% improvements in $\text{VO}_{2\text{max}}$) over five weeks.

The data from this study indicate that a four-week HIIT intervention significantly improved the $\text{VO}_{2\text{max}}$, and this is in agreement with studies that hypothesised that HIIT can significantly improve $\text{VO}_{2\text{max}}$ (Belegišanin, 2017; Marquezi *et al.*, 2019; Miranda, Aliberti, Invernizzi, 2021; Clemente, Ramirez-Campillo, Nakamura & Sarmiento, 2021). The increase in $\text{VO}_{2\text{max}}$ is possibly related to factors including the time spent at $\text{VO}_{2\text{max}}$ during the HIIT exercises, insufficient rest time between running repetitions, the high intensity of the running exercises and the high volume of the running exercises prescribed (Tabata, Nishimura, Kouzaki, Hirai, Ogita, Miyachi & Yamamoto, 1996; Billat, Slawinski, Bocquet, Chassaing, Demarle & Koralsztein, 2001).

A progressive overloading strategy was used, starting the players off at 120% $\text{vVO}_{2\text{max}}$ for week one, 140% $\text{vVO}_{2\text{max}}$ for week two, 140% $\text{vVO}_{2\text{max}}$ for week three and 170% $\text{vVO}_{2\text{max}}$ for week four. Progressive overloading used in the current study was applied to ensure that the volume of sets, intensity and reps were systematically manipulated to gradually increase the physical challenge of the exercises to avoid the stress of over-training too quickly.)

The highest adaptations in aerobic capacity are postulated to occur at intensities ranging between 90% and 100% of $\text{VO}_{2\text{max}}$ (Wenger & Bell 1986; Hellsten & Nyberg, 2016). In support of high-intensity exercises being a factor for increasing $\text{VO}_{2\text{max}}$, Dupont, Blondel, Lensel & Berthoin, (2002) suggest supra-maximal intervals also result in greater time spent training at intensities above 90% of $\text{VO}_{2\text{max}}$. Additional support for a prescription of very high intensity comes from Tabata *et al.* (1996) and Dupont, Millet, Guinhouya & Berthoin (2005) who suggested that training intensity at 120% of $\text{VO}_{2\text{max}}$ during intermittent high-intensity interval runs is more effective at maintaining intensities above 90% $\text{VO}_{2\text{max}}$ than MICT. Additionally, Buchheit and Laursen (2013) suggested that at very high intensities (such as $\text{vVO}_{2\text{max}}$ of 130%–140%), active adults.

The use of very high intensities (120%, 140% and 170%) and short rest periods (1:1 and 1:0.5) between each interval could be the possible explanation for why the current study was able to elicit high cardiopulmonary responses that led to significant improvements in $\text{VO}_{2\text{max}}$ over the four weeks. Exercise intensity is not the sole determinant of programmes designed to improve $\text{VO}_{2\text{max}}$. The rest or recovery period also forms part of the principles for manipulating HIIT to ensure more time is spent at $\text{VO}_{2\text{max}}$ during training. Two strategies regarding rest periods have been proposed, the first being the active recovery strategy that encourages recovery to be done at low to moderate intensities as a means to increase the oxidative recovery responses before the next interval (Spencer, Bishop, Dawson, Goodman & Duffield, 2006). The second strategy utilised in between intervals is passive rest or recovery. This strategy encourages athletes to recover without much activity (Spencer *et al.*, 2006). These larger cardiopulmonary responses will allow athletes to experience less oxygen debt and promote oxidative phosphorylation before the next interval. The use of passive recovery in the current study could explain why the players were able to perform for high-intensity intervals that could have promoted acute cardiopulmonary responses; the passive rests may have facilitated the ability to maintain the desired intensity for all the intervals, which led to significant $\text{VO}_{2\text{max}}$ improvements (Spencer *et al.*, 2006).

As in the current study, Esfarjani and Laursen (2007) investigated the effects of HIIT on cardiorespiratory variables. The results obtained indicated that there were significant improvements in the $\text{vVO}_{2\text{max}}$. HIIT prescription above basal or supramaximal $\text{vVO}_{2\text{max}}$ lead to heightened aerobic and anaerobic metabolism responses (Esfarjani *et al.*, 2007). Therefore, improvements of the $\text{vVO}_{2\text{max}}$ may occur through increases in the metabolic capacity of either the aerobic or anaerobic energy systems, or both (Laursen, Shing, Peake, Coombes & Jenkins, 2005). The increase in $\text{vVO}_{2\text{max}}$ could be because of the improved $\text{VO}_{2\text{max}}$ because when players can increase their $\text{VO}_{2\text{max}}$ capacity and efficiency they are most likely to be able to deal with higher workloads and in this case, it was the speed at which $\text{VO}_{2\text{max}}$ occurs (Esfarjani *et al.*, 2007; Marquezi *et al.*, 2019; Rousopoulos *et al.*, 2021).

In a performance context, HR could be considered a dependent variable because HR in exercise performance is largely influenced by workload among other factors, specifically, the increased demand for oxygenated blood. The more refined a player's cardiopulmonary system is, the more their HR can be increased to match the demands of exercise intensity of an increased $\text{VO}_{2\text{max}}$, VT_1 or VT_2 or greater intensities (Little, Safdar, Wilkin, Tarnopolsky & Gibala, 2010). In the current study, the pre-test HR results linked to $\text{VO}_{2\text{max}}$, VT_1

and VT_2 were lower compared to the post-test significant increases in HR linked to VO_{2max} , VT_1 and VT_2 . The possible reason for these significant increases in HR at the different performance markers is an indication that the player's cardiopulmonary system adapted to dealing with higher workloads due to the 4-week HIIT intervention programme and as a result, the HR of players was higher at the new workloads of where VO_{2max} , VT_1 and VT_2 were occurring at, similar to a 6-session HIIT study by Marquezi *et al.* (2019), that yielded increases of HR at VT_1 and VT_2 . It is suggested that an improved exercise performance post-HIIT intervention is not only owing to increased VO_{2max} but also the increased oxidative capacity of skeletal muscle and fat oxidation during exercise, resulting in less accumulation of intracellular metabolites (lactate, hydrogen ion, inorganic phosphate, adenosine diphosphate and adenosine monophosphate) and the sparing of glycogen stores (MacInnis & Gibala, 2017; Astorino & Schubert, 2018). In the current study, the improved fat oxidation system was marked by VT_1 , which is an indirect metabolic indicator for measuring or determining fat oxidation. VT_1 improved significantly after the 4-week HIIT intervention.

In the current study the AT (indicated by VT_2) of the football players had a significant improvement after the HIIT intervention programme. The data shows improvements in the speeds or intensity at which VT_2 occurred at, indicating better tolerance of higher intense exercises, whereby the amount of oxygen consumption had improved at higher workloads. Additionally, it is worth noting that AT also improves because of better utility of the glycolysis energy system (Astorino & Schubert, 2018). However, glycolysis efficiency was not directly measured in the current study, but existing literature indicates that improved AT is a by-product of an improved utility of the glycolysis energy system (Bangsbo, 2014).

The current study prescribed the HIIT intervention at intensities that were greater than ATs, which then could have had an effect in the improvements of VO_{2max} and the VT_2 . In support of this study, Hoshino, Kitaoka and Hatta (2016) also suggest that to improve anaerobic threshold, training should be prolonged or performed at an intensity that is greater than the AT. Higher exercise intensities performed over long intervals are most likely to produce a higher increase in blood lactate and could require a greater supply of anaerobic glycolytic energy. This in turn would result in an improved AT (Stepto, Martin, Fallon & Hawley, 2001; Seiler & Hetlelid, 2005). It is also suggested that increased duration of a HIIT session (without changing the rest interval duration) increases anaerobic glycolytic energy contribution, which provides a strong stimulus for improved AT adaptation (Buchheit & Laursen, 2013).

The higher speeds at which VT_1 and VT_2 occurred in the post-test compared to the pre-test suggest that these changes resulted from an improved ability to remove excess CO_2 and inspire more O_2 to support the demands of the exercise. In support of our finding, a study by Schaun, Pinto, Silva, Dolinski & Alberton (2018) and Marquezi *et al.*, 2019 indicated that a HIIT intervention performed at vVO_{2max} of 130% at a work-to-rest ratio of 10:20 led to improved speed at VT_2 .

Research limitations

Further, the study did not use GPS units to monitor any locomotive activity and the running velocities of the players during the shuttle runs could not have been accurate. As such, only calculated velocities through the displacement formula could be used to ensure that participants reached their prescribed speed of shuttle in the allocated time.

Future research

Future research can explore the optimal work: rest ratio that stresses more time spent at (or above) 90% VO_{2max} . Secondly, adaptations from vVO_{2max} HIIT prescription compared to anaerobic speed reserve should be investigated. Finally, HIIT prescription research should explore the difference in metabolic demands between straight-line running and maximal effort involving changes of direction.

Conclusion

This study aimed to critically evaluate the changes in the aerobic capacity of soccer players who underwent a field based HIIT intervention programme over four weeks. In this study, HIIT resulted in increased aerobic capacity, as reported by improved VO_{2max} , vVO_{2max} and vVT_2 . Specific to the HIIT protocol, the progressive overloading at very high intensities ($> 100\% vVO_{2max}$) was important for conditioning the athletes to be able to sustain high-intensity aerobic demands for longer periods. Consequently, this time spent at or above VO_{2max} could potentially be the stimulus for improved aerobic capacity. Overall, it is concluded that HIIT can be beneficial to training aerobic capacity. It is recommended that fitness trainers consider implementing field based HIIT at very high intensities, as an effective tool to improve the aerobic capacity of football players in a short period.

Conflicts of interest: The authors report there are no competing interests to declare.

Disclosure statement: The authors report there are no competing interests to declare.

Author contributions: KN, AL, AG: project conception, data collection, analysis, manuscript draft and review.

AL, AG: Supervision

All authors have read and approve the manuscript.

Data Availability Statement: The data that support the findings of this study are openly available in Figshare at <https://repository.uj.ac.za/> at <http://doi.org/10.25415/ujhb.23861247>.

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