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ORIGINAL RESEARCH

Bidirectional sprint interval training: A better alternative to plyometric training for football players? A randomized clinical trial

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Abstract

Background: The aerobic adaptations of sprint interval training (SIT) and anaerobic adaptations of plyometric training (PT) are well documented in the literature. Bidirectional SIT (including forward and backward "all-out" runs with change of direction) is a new approach to target aerobic and anaerobic traits in football players. **Objective:** This study intended to evaluate and compare the efficacy of bidirectional SIT versus PT on aerobic parameters, anaerobic parameters and sport-specific skill in university-level football players. **Methods:** In this two-arm randomized clinical trial, 26 university-level male football players (age 20.88 ± 1.69 years, height 173.70 ± 6.17 cm, mass 66.41 ± 7.60 kg, body mass index 22.04 ± 2.62 kg/m^2) were divided into two groups, bidirectional SIT (n = 13) and PT (n = 13, dropout of 1 subject during intervention) groups, respectively. Lower limb power (vertical jump height), sport-specific skill (wall volley), speed, agility, maximum oxygen consumption and running economy at 8, 10, and 12 km/h were analysed before and after four weeks of training. **Results:** The result revealed that the time effect was significant for all the parameters, while time × group interaction was significant for all variables except running economy, speed and wall volley. However, there is no significant group effect for all variables. **Conclusions:** Findings suggest that four weeks of bidirectional SIT results in significant improvement in aerobic as well as anaerobic parameters in football players. Therefore, bidirectional SIT can be used as a substitute for PT for anaerobic adaptations with added aerobic benefits in football players.

Keywords: maximal oxygen consumption, running economy, agility, vertical jump height, speed, wall volley

Introduction

Football is one of the world's most popular team sports. It is a complex, intermittent and long-duration sport which requires low and high intensity activities intermittently during a match as the football players are required to repeatedly and intermittently perform strides, turns, sprints and jumps, which places considerably high aerobic and anaerobic demands on their body (Bangsbo et al., 2006). Strength, power and their derivatives (acceleration and velocity) required for turning, sprinting and jumping make an important contribution to the performance potential and success of football players (Stølen et al., 2005). Footballers also require high aerobic fitness or high endurance for prolonged energy production throughout the game (Hoff & Helgerud, 2004). High aerobic fitness helps in recovery during high-intensity intermittent activities (Helgerud et al., 2001). Apart from the anaerobic and aerobic traits, a footballer also requires sport-specific skills to succeed (Stølen et al., 2005).

Sprint interval training (SIT), defined as "all-out" short-duration sprints with long, almost complete recovery in between, is a form of maximal or supramaximal high-intensity interval training (Buchheit & Laursen, 2013). In a recent meta-analysis, SIT was concluded to be a beneficial training methodology to improve maximal oxygen consumption (VO_{2max}) among healthy and young people (Gist et al., 2014). Also, adaptation in two weeks (six sessions) had shown that training with SIT is proven to be a time-efficient way to improve aerobic fitness (Barnes & Kilding, 2015). In a study by Jakobsson et al. (2020), it was suggested to combine "fatigue-resistant drill" (like SIT) and change of direction (COD) training into the same sessions to combat the effect of fatigue on COD performance and also analyse the effect of "fatigue-resistant drill" on sports-specific skills. Similarly, A running-based protocol of bidirectional SIT (involving backward running with COD) was concluded to be a time-efficient training method for improving aerobic capacity and high intensity endurance capacity, and maintaining indices of running economy (RE) and lactate threshold in team sport athletes in the work of Kelly et al. (2018) but no anaerobic parameters were taken into account. There is a paucity of literature working on bidirectional SIT, moreover, there is no study working on aerobic parameters. Backward running in the

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context of this paper is defined as running in a reverse direction where movement is accomplished via a single leg of support throughout foot–ground contact and both feet simultaneously in the air between contralateral foot strikes. During backward running, an athlete must rely on alternative sensory information due to a lack of visual guidance, which can in turn lead to better performance (Uthoff, Oliver, Cronin, Harrison, & Winwood, 2018).

Plyometric training (PT) is a form of explosive strength training using explosive movements to develop power involving stretch-shortening cycle (SSC; Markovic et al., 2007). PT contributes to improvement in vertical jump performance, acceleration, agility, leg strength, muscular power, an increase in joint awareness and overall sport-specific skills (Wang & Zhang, 2016). However, although PT has been shown to increase performance variables in many sports, little scientific information is currently available to determine whether PT actually enhances skill performance in football players, considering that football is an extremely demanding sport (Wang & Zhang, 2016). Plyometric training does not always necessarily show improvement in VO_{2max}. Still, some studies show that plyometric training led to the improvement of endurance performance that could be attributed to the improved RE, which is a result of improved musculotendinous stiffness (Sedano et al., 2013).

SIT is explosive, involves SSC and has shown similar neuromuscular adaptations as PT (Lum et al., 2019), while in combination with COD and backward running, the authors expected it to be more efficient in providing the anaerobic adaptation along with the aerobic adaptations. Though literature exists regarding the comparison between the PT and intermittent sprint training on the endurance performance (Lum et al., 2019), no study empirically compares bidirectional SIT against PT on various aerobic parameters, anaerobic parameters and sport-specific skills in football players. Therefore, the study proposes a performance-based analysis of the effect of bidirectional SIT and PT on aerobic parameters, anaerobic parameters and sport-specific skills in university football players after four weeks of training. The authors hypothesized that there will be a statistically significant difference between the effect of bidirectional SIT and PT on aerobic parameters, anaerobic parameters and sport-specific skills.

Methods

Participants

The numbers of participants were determined using G*Power (Version 3.1.9.2; https://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower) based on the data representing the changes in running economy following PT in the study of Lum et al. (2019). Thirteen participants per group (including 10% drop out) were shown to be necessary based on the given effect size of 0.3, α level of .05 and power (1 – β) of .80. A sample of 26 male collegiate university-level football players (age 20.88 ± 1.69 years, height 173.70 ± 6.17 cm, mass 66.41 ± 7.60 kg, body mass index 22.04 ± 2.62 kg/m^2) with VO_{2max} more than 45 ml/kg/min were recruited. Players (aged 18–28 years) with a background of two or more years of systematic football training (> 11 hours per week) and competitive experience and fulfilling basic criteria for lower extremity plyometric pre-training requirements (Davies et al., 2015) with no musculoskeletal injury in the lower limb within six months were included in the study. Exclusion criteria included Physical Activity Readiness Questionnaire Plus score of more than 1, bidirectional SIT or PT experience in the previous six months, participation in other competitive sport activity aside from football during the intervention period, history of lower limb or spine surgery and/or systemic or inflammatory diseases, acute systematic infection, concussion, head trauma or spine injury.

Research procedures in the present study were performed in conformity with the Declaration of Helsinki, 1964 and its later amendments. Participants were explained the purpose, methodology, and possible risks of the study, and they were given and signed the informed consent form explaining their rights as research participants. The study is also approved by the Institutional Ethics Committee of Jamia Millia Islamia (proposal no. 31/10/187/JMI/IEC/2018).

Protocol

For this, two-arm comparative randomized clinical trial, the authors examined and compared the effects of four weeks of bidirectional SIT and PT in university-level football players, as there are only healthy participants and the effects of PT and directional SIT are well documented in literature, each group served as a comparative control for the other. This design allowed for a direct evaluation of the relative effects of each intervention. The participants were randomly assigned into two groups, bidirectional SIT (*n* = 13) and PT (*n* = 13), using computer-generated block numbers, and the participants were trained 2–3 times weekly. There was a total of 10 exercise sessions performed under supervision with at least a 36–48 hour gap between two consecutive sessions. The aerobic performance parameters (running economy and VO_{2max}), the anaerobic performance parameters (vertical jump height, speed, agility) and sport-specific skills (wall volley) were investigated in both groups at baseline and after four weeks of training. One participant dropped out of the PT group due to noncompliance with no study-related reason, whereas all the SIT group participants completed the study. All tests were done at the same time of the day to give participants time to rest properly and recover. The study was performed at the human performance laboratory and the university sports complex.

Outcome measures

Running Economy

RE was evaluated at 8, 10, and 12 km/h. Participants performed a standardized warm-up, consisting of 5 min of running at 8 km/h followed by a 5 min passive recovery. RE was recorded and measured breath by breath via an open circuit metabolic system (PowerLab/8M Metabolic System, ADInstruments, Dunegin, New Zealand) with an incremental graded treadmill-based test. The responses were recorded continuously using Lab Chart (Version 8; ADInstruments, Dunegin, New Zealand)m sampling at 1000 Hz. They were later analysed as 10-s averages at 8, 10, and 12 km/h for 3 min each, in order to measure the RE. RE was defined by averaging the oxygen uptake values during the last 30 s.

Maximal oxygen consumption

Maximal oxygen consumption was evaluated with two methods, directly via breath by breath via an open-circuit metabolic system (Powerlab/8M Metabolic System, ADInstruments Pty Ltd, Castle Hill, Australia) with an incremental graded treadmill-based test and indirectly derived by Yo-Yo I Recovery Test 1 (YYIR1). The values derived from YYIR1 are used for analysis, as they include the intermittent performance aspect of football. The total distance covered during the YYIR1 (including the last incomplete shuttle) was considered as the test score, and this distance was utilized to estimate VO_{2max} by the equation proposed by Bangsbo et al. (2008):

VO_{2max} (ml/kg/min) = YYIR1 distance (m) * 0.0084 + 36.4.

Vertical jump height and peak power

Participants were instructed to jump upright from a 90° knee flexion and perform a vertical jump with arm swing as high as possible. The height of the jump (VJH) was determined using a measuring tape attached to a graph paper on which the ink prints of the middle finger during the jump were recorded. Each subject performed three jumps, and the best score was used to analyse the VJH. This test is considered reliable with intra-class correlation coefficient of .97 (Christou et al., 2006). Peak power was determined by the formula proposed by Lara et al. (2006) using the VJH and body mass of each athlete:

$$\text{Peak power (W)} = (62.5 * \text{VJH (cm)}) + (50.3 * \text{body mass (kg)}) - 2184.$$

Sprint time

Two 30-m trials were conducted by the participants, with a 3-min recovery period between them, and the best attempt was used for analysis. The player assumes a staggered stance with the front knee bent at 90°, weight shifted forward, arms positioned oppositely to the legs, and the body leaning slightly forward for an explosive push-off at the command. The sprints started with the command "Go" and timed with a high-precision stopwatch (Seiko S141, Seiko, Tokyo, Japan) by the assessor standing on the finish line.

Agility

The Illinois Agility Test was used to analyse the agility. The participants started the test face down with their hands at the level of their shoulders. The trial began with the "Go" command, and the participants started running as quickly as possible. The trial was completed when the players crossed the finish line without disturbing the cones. The time taken to complete the test was recorded. Every subject performed three trials, and the best score was used for analysis. This test is considered reliable with an intra-class coefficient of .85 (Katis & Kellis, 2009).

Sport specific skill

Wall volley was used as the sport specific skill. Participants were asked to kick a ball from a distance of 1.83 m from a wall and then trap or kick the ball as many times as possible in a period of 30 s toward a marked box of 1.22 × 2.44 m on the wall. Participants were instructed to avoid the use of their hands. Three repetitions of this test were performed by each subject, and the best attempt was utilized for analysis. This test is a highly reliable standard test (intra-class correlation coefficient of .97) for evaluating the skill and accuracy of football players in sport-specific skill assessment (Reilly & Holmes, 1983).

Training

Participants completed 15 min of warm-up, including jogging, active stretching, side shuffles, high knee exercises and butt kicks at the beginning of every training session. At the end of every training session, 10–15 min of cool-down sessions comprising jogging and stretching were also mandated for players. For PT, participants were instructed to perform exercises to maximum effort for each repetition. The protocols used for PT are shown in Table 1, adapted from Wong et al. (2010) and Lum et al. (2019) with duplication avoided.

The directional SIT protocol used in this study was adapted from Kelly et al. (2018). The bidirectional SIT consisted of three sets of high-intensity sprints with short recovery periods in between. Each sprint interval covered a total distance of 110 m, incorporating both forward and backward sprints over distances ranging from 5–20 m, with multiple changes of direction (COD). A single set comprised three 110 m sprints, with a 20 s recovery period between runs and a 3 min recovery period between sets (Figure 1; Kelly et al., 2018). Although it was not possible to match the overall training volume due to the differing nature of the training protocols, the authors ensured consistency in training frequency (10 sessions in total, performed 2–3 times per week over four weeks), total session duration for both groups, and rest intervals between sets. All other training activities and participation levels were balanced between the groups.

Data analysis

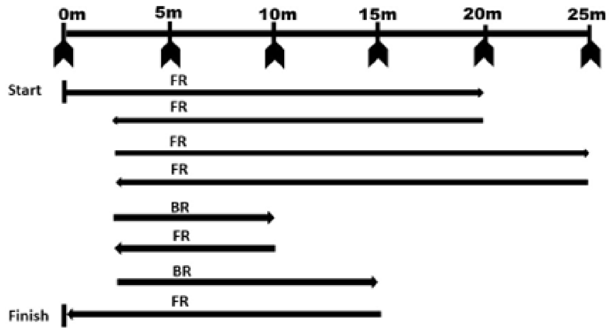
IBM SPSS Statistics for Windows (Version 21; IBM, Armonk, NY, USA) was used for all analyses. The data was assessed by the Shapiro-Wilk test for the normality of the distribution scores. The demographic characteristics and the baseline criterion measures were compared between the

Table 1 Plyometric training protocol

Exercise	Sets	Repetitions
Alternate leg bounding	4	10
Single-leg hurdle hop	2	10 per side
Double-leg hurdle hop	3	10
Depth jump	3	15
Weighted squat jump	3	15
Double leg lateral hop over hurdles	2	25
Plyo sit ups (from the second week)	3	10

Note. Rest (passive) intervals between sets were 3 min.

Figure 1 Setup for sprint interval training



Note. FR = forward running; BR = backward running.

two training groups using an independent *t*-test. To test for the difference between the groups after training, a 2 × 2 mixed-model analysis of variance (ANOVA) with group (SIT × PT), time (baseline × post-training) and interaction effect (group × time) was employed. The effect size (ES) for the main effect of trial is reported as partial eta-square statistic (η^2) with values of .01, .06, and .14 representing small, medium, and large effects, respectively. The data was also analysed using a paired *t*-test to analyse the pre to post changes in the various parameters. The ES was calculated using Cohen's *d*, with values of < 0.2, 0.2, 0.5, and 0.8 representing small, trivial, and large effects respectively. The level of significance was set at $\alpha < .05$. The formula used for change was:

Change (%) = ((post – pre)/pre) * 100.

Results

At the baseline, there was no significant difference in the demographic characteristics between the groups and all the variables were found to be normally distributed (Table 2). Both groups were comparable in terms of age, height, mass, and body mass index. No significant difference was found between the groups in VJH, leg power, wall volley, speed, VO_{2max}, agility, RE at 8, 10, and 12 km/h at baseline thus making the groups comparable. The results of 2 × 2 mixed model ANOVA (exact *p* values are depicted in Table 2), showed significant main effect for time for all the parameters. Group × time interaction effect was significant for VJH, leg power, and VO_{2max}; no significant group effect was found for any variable (Table 2).

The paired *t*-test showed a significant difference in bidirectional SIT in all variables, while the PT group showed significant effect in all variables except VO_{2max}; however, the ES was different for both groups in all variables, but they were not significantly different from one another, as shown in Table 3. The improvement was calculated to be 13.06% for VO_{2max} in the bidirectional SIT group. The improvement was calculated to be 10% for the PT and 6.95% in bidirectional SIT for sport-specific skill. The improvement in sprint was calculated to be 10.12% and 6.54% for the bidirectional SIT and PT groups, respectively. The improvement in RE at 8, 10 km, and 12 km/h was calculated to be 15.66%, 10.78% and 11.47% for SIT and 16.43%, 13.18% and 9.59% for the PT group, respectively. The improvement in agility was calculated to be 7.81% for the bidirectional SIT and 5.74% for the PT group. The improvement in VJH and leg power was calculated to be 3.82% and 2.74% for bidirectional SIT and 5.46% and 3.92% for PT group, respectively.

Discussion

The present study was designed to investigate the effects of two high-intensity training protocols (i.e., bidirectional SIT versus PT) on anaerobic parameters (VJH, leg power, speed, agility) and aerobic parameters (VO_{2max} and RE), and sport-specific skill in university football players. The results showed that there was a significant improvement in the majority of the variables in both the training groups (bidirectional SIT and PT), meanwhile, VO_{2max} showed improvements only after the SIT.

Anaerobic parameters

VJH and leg power

Although improvement was seen in both groups, the ES and the percentage difference have shown greater improvement after PT. The findings are consistent with those of Ozbar et al. (2014), who reported similar results following 8 weeks of training in female football players. Wang and Zhang (2016) noted that the increase in leg power and jump performance following PT is due to improvements in the SSC, elastic components of muscle, tendon, and stretch reflex. Conversely, Markovic et al. (2007) showed a larger improvement in power after sprint training compared to the PT group. Various neuromuscular adaptations could have induced the observed improvement, such as increased neural drive to the agonist muscles, improved intermuscular coordination, changes in the mechanical stiffness of the muscle-tendon, changes in muscle size or architecture, and changes in single-fibre mechanics (Kisner et al., 2017). The authors also speculate that there may be a greater improvement in PT due to the specificity of the training (Faude et al., 2014).

For bidirectional SIT, the results were novel to this study as this protocol (bidirectional SIT) has not been used before to analyse anaerobic power, to the best of our knowledge. If backward running or bidirectional SIT is considered, the results are consistent with those of Uthoff, Oliver, Cronin, Harrison, and Winwood (2018) and Lum et al. (2019), respectively. Studies indicate that backward running increases eccentric loading and posterior chain activation, leading to improved sprint acceleration and power output (Frost et al., 2008). Cronin et al. (2011) demonstrated that stepping backward before sprinting forward optimizes force application, enhancing sprint performance. Research by Uthoff, Oliver, Cronin, Winwood, and Harrison (2018) and Uthoff et al. (2021) highlights the acute and long-term benefits of backward sprint training, including increased speed, jump performance, and leg stiffness.

Additionally, multidirectional sprint training has been found to significantly improve COD speed and agility in athletes, supporting its role in optimizing anaerobic adaptations (Nygaard Falch et al., 2019). These findings suggest

Table 2 Means, standard deviations, and results of analysis of variance

Variable	Mean ± *SD*		Analysis of variance			
	SIT (*n* = 13)	PT (*n* = 12)	Effect	*F* ratio	*p*	η^2
VJH (cm)						
Pre	45.76 ± 4.40	49.25 ± 6.90	T	178.10	< .001	.88
Post	47.51 ± 4.50	51.94 ± 7.10	G	2.84	.10	.11
			T × G	7.99	.01	.25
LP (W)						
Pre	3981.4 ± 479.5	4272.8 ± 554.0	T	178.10	< .001	.88
Post	4090.5 ± 492.1	4440.7 ± 568.3	G	2.35	.13	.09
			T × G	7.99	.01	.25
WV						
Pre	21.00 ± 3.60	22.50 ± 4.20	T	23.12	< .001	.50
Post	22.46 ± 3.20	24.75 ± 5.00	G	1.42	.24	.05
			T × G	1.04	.31	.04
SP (s)						
Pre	3.16 ± 0.50	3.21 ± 0.50	T	22.03	<. 001	.48
Post	2.84 ± 0.50	3.00 ± 0.40	G	0.32	.57	.01
			T × G	0.92	.34	.39
AT (s)						
Pre	18.04 ± 1.20	17.92 ± 0.90	T	165.48	< .001	.87
Post	16.63 ± 1.30	16.89 ± 0.70	G	0.03	.86	.001
			T × G	3.98	.05	.14
VO_{2max} (ml/kg/min)						
Pre	48.90 ± 3.60	51.34 ± 4.70	T	22.72	< .001	.49
Post	52.29 ± 3.30	51.38 ± 4.50	G	0.22	.63	.01
			T × G	21.63	< .001	.48
RE@8 (ml/kg/min)						
Pre	25.03 ± 2.90	26.17 ± 3.00	T	121.69	< .001	.84
Post	21.11 ± 2.90	21.87 ± 2.20	G	0.80	.37	.03
			T × G	0.27	.60	.01
RE@10 (ml/kg/min)						
Pre	32.64 ± 3.6	34.05 ± 2.7	T	63.09	< .001	.73
Post	29.12 ± 3.5	29.56 ± 4.0	G	0.48	.49	.02
			T × G	0.92	.34	.03
RE@12 (ml/kg/min)						
Pre	39.66 ± 3.4	40.94 ± 3.1	T	70.24	< .001	.75
Post	35.11 ± 3.5	37.01 ± 3.9	G	1.50	.23	.06
			T × G	0.50	.48	.02

Note. SIT = sprint interval training group; PT = plyometric training group; VJH = vertical jump height; LP = leg power; WV = wall-volley; SP = sprint time; AT = Illinois Agility test; VO_{2max} = maximal oxygen consumption; RE@8, RE@10, RE@12 = running economy at 8, 10, and 12 km/h; T = time; G = group.

Table 3 Results of paired *t*-test and effect sizes

Variable	SIT (*n* = 13)			PT (*n* = 12)		
	t	*p*	Cohen's *d*	*t*	*p*	Cohen's *d*
VJH (cm)	−7.27	.001	−0.05	−11.80	.001	−1.12
LP (W)	−7.27	.001	−2.01	−11.80	.001	−3.40
WV	−2.87	.010	−2.01	−3.88	.003	−3.40
SP (s)	3.76	.003	1.04	2.88	.010	0.83
AT (s)	10.73	.001	−1.52	7.53	.001	−0.03
VO_{2max} (ml/kg/min)	−5.50	.001	2.97	−0.12	.900	2.17
RE@8 (ml/kg/min)	6.72	.001	1.86	9.54	.001	2.75
RE@10 (ml/kg/min)	5.02	.001	1.39	6.19	.001	1.78
RE@12 (ml/kg/min)	7.63	.001	2.11	4.69	.001	1.35

Note. SIT = sprint interval training group; PT = plyometric training group; VJH = vertical jump height; LP = leg power; WV = wall-volley; SP = sprint time; AT = Illinois Agility test; VO_{2max} = maximal oxygen consumption; RE@8, RE@10, RE@12 = running economy at 8, 10, and 12 km/h.

that incorporating bidirectional SIT into training programs can effectively enhance anaerobic power and athletic performance. The possible mechanisms for enhancing leg power and jump performance after bidirectional SIT could be attributed to an increase in the strength and power of the leg muscles, as well as to the addition of backward running and its effect on biomechanical variables like total muscle activation, average muscle force per unit ground force, utilization of the contractile element of the motor unit, lower knee joint loads, and higher rate of force development (Uthoff, Oliver, Cronin, Winwood, & Harrison, 2018). In contrast, Faude et al. (2014) found deteriorations in countermovement jump height after maximal high-intensity interval training (SIT; according to Buchheit & Laursen, 2013), but the training was given during the preseason, so the decrease could be due to fatigue from increased training load and competitive demands.

Speed

Our results were similar to those of Markovic et al. (2007), who found sprint training to be superior to PT in improving sprint performance time. Rimmer and Sleivert (2000) also compared SIT and PT and found a better effect of SIT on sprint performance in male rugby players. Our study states that bidirectional SIT was better at improving speed than PT, possibly due to the improved muscle function suggested by Markovic et al. (2007) and the fact that the players were trained with bidirectional SIT. Higher stride frequency displayed during backward running might help improve the neurophysiological functions of the body to increase sprint performance. This is further supported by the fact that greater vertical leg stiffness is associated with backward running compared to forward running, as high vertical leg stiffness is known to be concomitant with greater maximal forward sprinting speed (Uthoff, Oliver, Cronin, Winwood, & Harrison, 2018).

Significant improvements were observed following PT by Ozbar et al. (2014) in female soccer players. The PT group significantly improved sprint performance after eight weeks of PT, but these improvements did not differ significantly from those observed in the sprint group (Rimmer & Sleivert, 2000). The increase in sprint performance in the PT group can be explained as acceleration is dependent on a slower SSC and power output rate similar to the countermovement jump (Cronin & Hansen, 2005). Sprinting is a multidimensional movement skill that requires a number of lower-limb muscles to produce explosive concentrate and SSC force, thus improving speed after PT.

Agility

In this study, the better improvement in the bidirectional SIT group can be due to the specificity of the training, as this training included COD and backward running. Similarly, better improvement in agility with bidirectional SIT compared to the PT group was recorded by Markovic et al. (2007) in male physical education students. Improvement in agility with backward running was shown by Swati et al. (2012). In our study, we used bidirectional SIT, which enhances power output and balance (providing more proprioceptive inputs), thereby improving agility (Uthoff, Oliver, Cronin, Winwood, & Harrison, 2018). Therefore, the improvement in agility following bidirectional SIT can be due to improvements in strength, body control and awareness (balance), recognition and reaction, starting and acceleration speed, complex footwork, dynamic flexibility, and directional change. However, this study also showed improvement after PT, which is supported by a study in which improvement in agility following six weeks of PT in young football players was observed (Thomas et al., 2009). A review by Wang and Zhang (2016) corroborates improvements in agility following PT. Power development (Randell et al., 2010), reactive strength, and eccentric strength may have contributed to agility performance improvements (Cronin & Hansen, 2005). Literature also suggests that agility increases are due to either improved motor recruitment or neural adaptations (Markovic & Mikulic, 2010).

Aerobic parameters

Maximum oxygen consumption

The results of this study regarding VO_{2max} were in accordance with the metanalysis performed by Gist et al. (2014), suggesting SIT of being capable of improving aerobic fitness. Increase in VO_{2max} following two weeks of SIT has also been proven previously in football players (Kelly et al., 2018). In this study, SIT led to improvement in VO_{2max} as SIT is believed to induce large adaptive responses by enhancing cardiorespiratory signalling, anaerobic capacity gains and increase in stroke volume, increases in muscle oxidation, buffering capacities and enhancements of PGC-1α which plays an imperative role in mitochondrial gene transcription, biochemical changes are also seen following bidirectional SIT (Kelly et al., 2018).

In a study done by Michailidis et al. (2013), similar to our findings, PT in football players did not induce improvement in $VO_{2max,}$ but these changes corresponded to the younger generation. PT does not influence VO_{2max} as improvement in VO_{2max} requires aerobic physiological adaptations (Turner et al., 2003). However, an eight-week PT was found to produce improvements in VO_{2max} in physically active men by 13.8% (Potteiger et al., 1999). According to this study, the increase in VO_{2max} was likely the result of the high-intensity work and the short duration rest intervals, like in any interval training.

Running Economy

In our study, more improvement was observed in the SIT group in RE at 12 km/h; whereas at 8 and 10 km/h, the improvement in the PT group was slightly more than that of the SIT group. Similar to our study, Franch et al. (1998) compared interval training at near maximal and supramaximal velocities in recreational runners and found that RE significantly improved in the near maximal speeds (84% and 106% speed at VO_{2max}) groups. The improvement in bidirectional SIT has been theorized to be because of more running practice, which has been shown to affect RE (Helgerud, 1994). Furthermore, the improvement in this study was greater than in other studies, as in this study backward running was also used within the SIT protocol (backward running and SIT, both are related to improvement in RE, individually). In the case of PT, similar studies by Saunders et al. (2006) and Paavolainen et al. (1999) showed that the participants improved their RE following PT. The exact mechanism by which the improvement RE after PT occurs remains unclear; however, it has been theorized that this improvement results from enhancement in motor unit recruitment and reduced ground contact time (Saunders et al., 2006; Paavolainen et al., 1999).

Sport-specific skill

Similar to this study, the increase in skill via PT was reported by Lees et al. (2010). Also, replacement of low-intensity technical-tactical football drills by plyometric drills is suggested to be a practical approach in both male and female players (Ramírez-Campillo et al., 2015). Perhaps, it was the neuromuscular adaptations that had an effect on the kicking performance-related biomechanical factors such as maximum linear toe velocity, ankle, knee, and hip at ball contact (Lees et al., 2010). To the best of our knowledge, no other study has examined the effect of bidirectional SIT solely on footballers' skills, although this study also showed a significant trend. de Villarreal et al. (2015) confirmed the use of a combination of SIT and PT in increasing skill performance.

Study limits

The limitation of this study can be its duration, i.e., four weeks and therefore, future research should be conducted using long-term training regimes. The authors did not assess the follow-up following completion of the training programs, future research should address this limitation. The inclusion of only male football players limits the generalization of this study to all football players and makes this study a gender biased study. Also, a conventional control group can distinguish the effectiveness of each training protocol. It would have been better for the study to use timing gates in place of a stopwatch for recording time.

Conclusions

This study highlights and concludes that bidirectional SIT and PT are time-efficient and applicable training methods for increasing the anaerobic performance in collegiate football players. These training sessions may be used by the coaches to increase the efficiency of football players. This study provides knowledge for specific exercise prescription, as the results show that following a period of four weeks, there was a significant improvement in most of the variables in both training groups. While VO_{2max} only improved in the SIT group, other anaerobic parameters and running economy were improved in both groups. Future studies should explore more regarding the other physiological and performance-related physiological and biochemical effects of bidirectional SIT.

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Conflict of interest

The authors report no conflict of interest.

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