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Can Running Speed and Aerobic Endurance Be Affected after 4 weeks of In-season Running-based HIIT of Different Modes?

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Abstract The purpose of this study was to investigate the effect of 4-weeks high-intensity interval training with short interval 15s/15s in three modes - linear (straight-line runs), shuttle and combined. Each group performed 2 x 4 minutes runs at 95-105% of VIFT. Eighteen male young soccer players participated in the present study. Before commencing the experiment, the participants were randomly divided into three HIIT groups: linear (n=6), combined (n=6) and shuttle (n=6). Players completed the 30 m sprint test, 505 COD test and the 30-15 Intermittent Fitness Test (30-15 IFT) before and after the experiment. Results show significant improvements from pre- to post-training only in the 505 COD test (left) ($p < 0.05$) and 30-15 IFT test ($p < 0.05$) in the combined and shuttle group. No significant differences were observed between the groups in any measured outcome. In conclusion, all HIIT modes performed in 4-weeks period led to improvements in aerobic endurance, speed performance and change of direction speed. In the combined group, we observed the most significant improvement in aerobic endurance and speed performance and in change of direction speed we noticed the best progress in the shuttle group.

Keywords High-intensity Interval Training, Football, Straight-line, Shuttle Runs

1. Introduction

Soccer nowadays can be characterized as a high-intensity intermittent team sport [23,30]. It is more physically demanding, intensified and for this reason players need to cover about 30% greater distance above the high-intensity threshold than in the past [4]. Some studies clarify that during a competitive soccer match, elite players cover a distance from 10 to 12 km and high-intensity actions contain 3-7% [7,11,17,18]. Physical requirements in soccer can be described as a combination of high-intensity running at different speed zones, changes of directions ability (CODs), sprints, jumping, passing, shooting and controlling the ball under pressure with game intensity from 80 to 90% of individual players' maximum heart rate (HR_{max}) [22,35]. Moreover, players' technical and tactical skills are closely related to players' fitness-level [5,34]. It means that those players with less aerobic endurance and anaerobic capacity are not able to perform their technical and tactical skills in the game as if they were at well fitness-level [5,34]. This suggests that players need to be well-trained in terms of aerobic-anaerobic endurance to cope with the match demands.

High-intensity interval training (HIIT) is one of the methods that could improve some physical demands mentioned above, and in addition, it can shorten the recovery after the match and reduce the risk of injury [8,27,31]. Likewise, HIIT improves aerobic endurance and ability to perform anaerobic capacity in high-intensity actions and CODs, and to reform physical demands of a match [6,14,15]. Further, using HIIT as a method, the maximum oxygen consumption (VO_{2max}) can be improved from 5 to 11% with intensity >85% HR_{max} [25]. To reach an optimal intensity for players, it is necessary to spend certain minutes in a very high intensity zone, which means >90 – 95% of players' VO_{2max} or HR_{max} [29].

Some studies investigate HIIT straight-line runs [5,19,32,33] and shuttle runs [16,24] training effects (4-8 weeks) separately. In fact, there are a lot of studies dealing with comparison between HIIT and SSG, but to the best of our knowledge we did not find studies comparing straight-line runs versus shuttle runs and their combination of improvements or maintenance of aerobic endurance and sprint times during the season. Hence, in this article we aimed to investigate the effects of 4 weeks straight-line runs, shuttle runs and combination of these two. CODs during HIIT decreases the amount of high-speed running but conversely increases mechanical work [28]. In COD (shuttle runs) particularly biarticular locomotor muscles are more activated, increased systemic O_2 demands (with a possibly greater upper-body muscle participation), and increased absolute anaerobic energy contribution [1,21]. During high-intensity runs with CODs may be a lower percentage contribution to total energy expenditure when the intensity of the work intervals was adjusted for the time loss during CODs. Blood lactate values during HIIT with CODs were higher when compared to HIIT straight-line runs [10,13]. During typical short-interval HIIT additional energy requirements from oxidative and anaerobic systems when comparing shuttle runs versus straight-line runs is estimated to be around 5 to 6%. Inclusion of COD was associated with a greater physiological load, as evidenced by increased cardiorespiratory, muscular O_2 consumption, blood lactate and RPE responses [10,26]. Due to that, we hypothesized that shuttle runs and its combination with straight line runs will result in greater improvements in physical capacities than solely straight-line runs.

2. Material and Methods

Participants

Eighteen male young soccer players participated in the present study. Before commencing the experiment, the participants were randomly divided into three HIIT groups: linear (n=6, age: 17.3 ± 1.0 years, body mass: 70kg, body height: 178.5 ± 4.0cm), combined (n=6, age: 17.3 ± 2.2 years, body mass: 77 ± 4.2kg, body height: 181,5 ± 6.0cm) and shuttle (n = 6, age: 18.1 ± 1.5 years, body mass: 72 ± 7.5kg, body height: 177.6 ± 7.4 cm). All players were selected from a single soccer team competing in the first domestic league (U16 - U21). Before commencing the experiment, all subjects signed a written informed consent form after being informed of the potential risks and benefits of participating in the study. All procedures were approved by a local research ethics committee, and the study was approved by local soccer academy and University Ethic Committee (registration number: UKF-2020/1355-1:191013) to comply with the Declaration of Helsinki.

Procedures

Field Testing

30m sprint – 30-m sprint time was recorded using Witty single beam wireless training timer (Microgate, Bolzano, Italy). Participants had three trials, from which the best time was recorded. Three minutes of resting time was allowed to each participant between the trials. The starting position was standardized to a still split standing position with the toe of the preferred foot positioned 0.3 m behind the starting line. Once ready, they sprinted as fast as possible until crossing the stop line. Measurements were completed under similar standardized conditions on artificial pitch with similar weather conditions (e.g., temperatures range: 15-20°C; not during rainy days) and requiring (to coaches) not to provide intense exercise 48h before measurements.

505 COD test - The flying start was allowed by the subject with a 10-meter start before crossing the starting line and running the timer. The photocells turned on after crossing the starting line, sprint for five meters, turning 180° and sprint another five meters. The time was recorded to the nearest 0.01 second. The participants were allowed 3 attempts. Test 5-0-5 (COD) is a change of direction that assesses the ability to accelerate and decelerate. In the 505 COD test, players run and change direction on the dominant and/or nondominant leg (preferred/nonpreferred leg). The time started when a participant first passed through the timing gate and stopped when the participant passed through them again upon their return. One minute of recovery time was given between each attempt.

The 30-15 Intermittent Fitness Test (30-15 IFT) - After a 30 m sprint test and 5-0-5 COD test, the players had a 15- to 20-minute rest, then performed a 30-15 IFT test. The 30-15 IFT test consisted of 30-second shuttle runs interspersed with 15-second passive recovery periods. Starting velocity was set at 8 $km \cdot h^{-1}$ for the first 30-second run and was increased by 0.5 $km \cdot h^{-1}$ every 45-second stage thereafter. The players had to run back and forth between two lines (point A - C) set 40 m apart at a pace governed by a pre-recorded beep at appropriate intervals [10]. The test was completed on an artificial soccer pitch. Subjects were instructed to complete as many (30-s) "stages" as possible, and the test ended when player could no longer maintain the required running speed (i.e., when players were unable to reach a 3-m zone near each marked line at the moment when the audio record signaled on 3 consecutive occasions) (Fig. 1). The last stage reached during the 30-15IFT is considered as maximal intermittent running velocity (VIFT) by each individual player. The reliability of this test has already been investigated (ICC r = 0.96; n = 19) [6].

Test-retest reliability of our tests (from our laboratory) was examined in the previous study held by the same research group [3].

Training Design

The training period included six microcycles, with each microcycle lasting one week (7 days). In the first and last microcycle there were pre-testing and post-testing. The second, the third and the fourth microcycle consisted of four training sessions with one HIIT training and one non-official match (2x35 min) (non-official match was considered as a substitution of real match during the season because of the COVID-19 pandemic situation).

The fifth microcycle consisted of three training sessions and one training session was HIIT training. The participants were divided into 3 HIIT groups: linear, shuttle and combined group. Players completed a general low-intensity warm-up, and technical/tactical training (10 vs. 10).

HIIT intervention consisted of two sets of four minutes of activity which were interspersed with four minutes of rest. Participants in the HIIT groups performed 8 repetitions of 15-second runs and 15-second rest in all three groups (linear, shuttle and combined). We also applied COD time loss of 0.7 seconds per 180 degrees turn in the shuttle and combined group [6,12]. The HIIT training consisted of 15-second runs and 15-second rest in all HIIT groups with an intensity set at 95% of VIFT in the second and third week. In the fourth and fifth week the intensity was increased at 100% and 105% of IFT, respectively. All training sessions were performed on artificial turf. Average training time (mean ± SD) in the training process in Tuesdays (Tec/Tac) lasted 113.25 ± 2.49 min, in Wednesdays (HIIT) 100.50 ± 3.35 min, in Thursdays (SSG) 97.50 ± 12.03 min and in Fridays (Tec/Tac) 93.33 ± 1.25 min. Detailed information about each program is presented in Fig. 2.

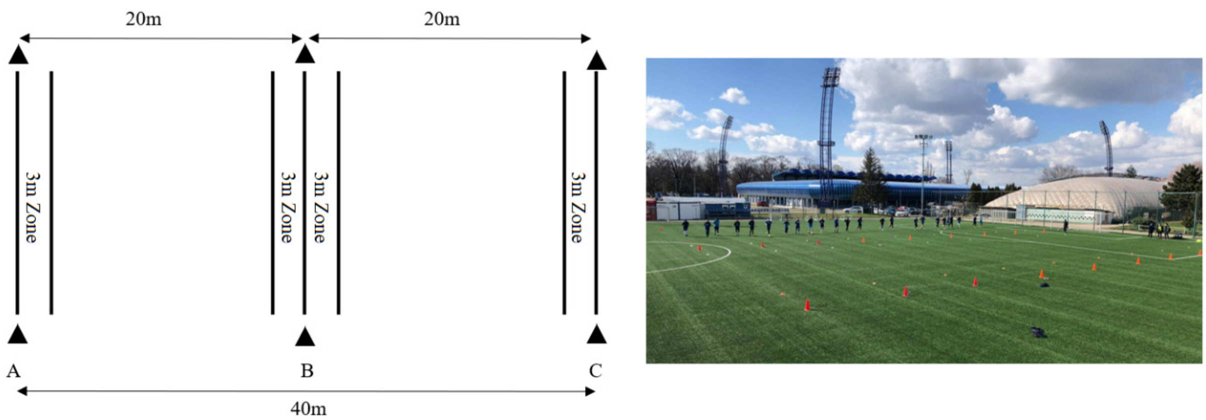

Figure 1. Shows 30-15 Intermittent Fitness Test (30-15 IFT) testing session and schematic representation

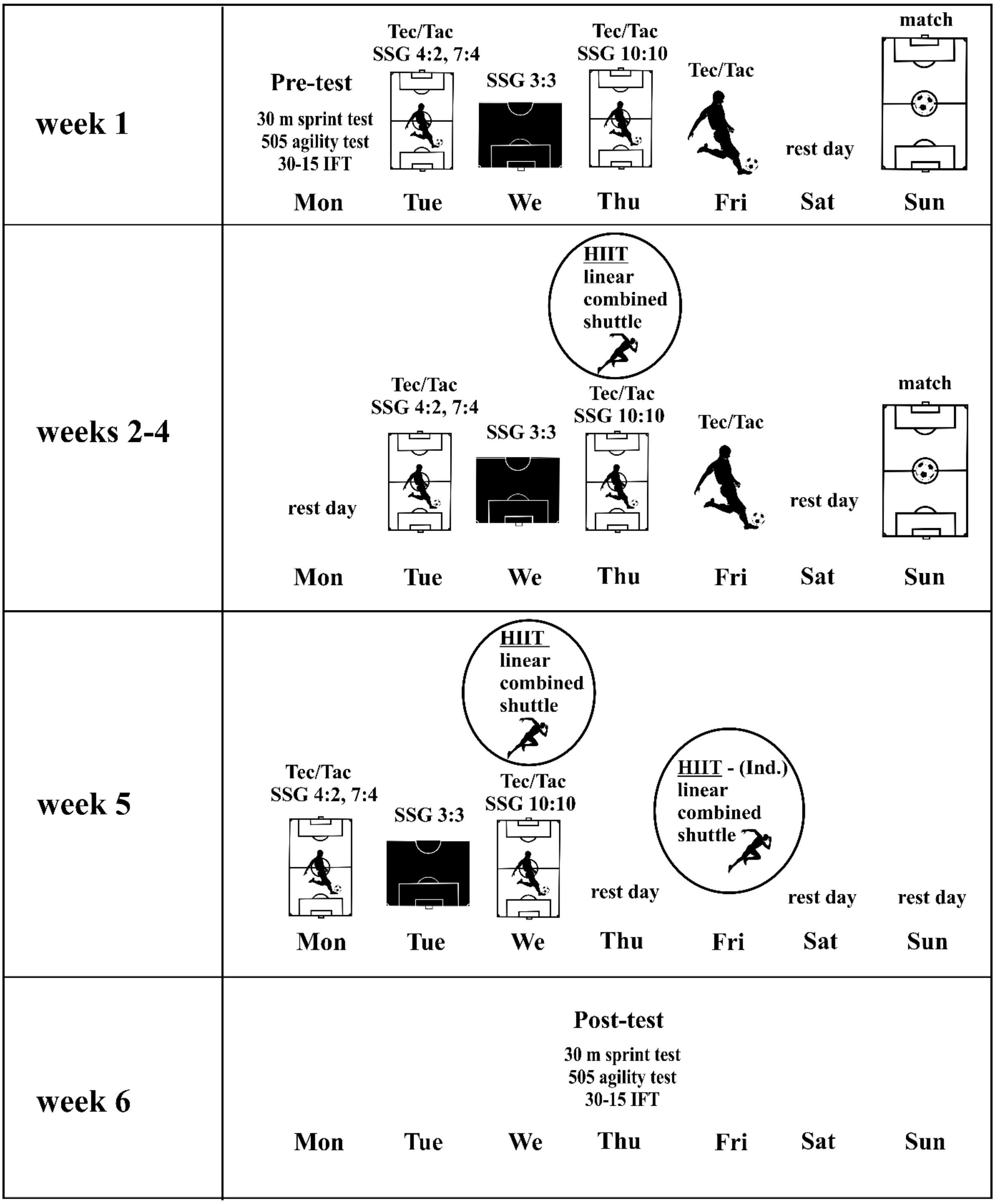

Figure 2. Schematic illustration of training program across each microcycle across the 6-week training cycle. Tec/Tac = technical-tactical training, SSG = small sided games, HIIT = high intensity interval training, Ind. = individual HIIT training

Individual HIIT Session

Due to the COVID-19 pandemic situation, we were forced to undergo individual training in the fifth week. The individual training consisted of a 15-minutes warm-up and players performed HIIT according to the program as they were divided into groups with interval (2x4 min.) in intensity of (105% VIFT).

External Load

During each match and training session, athletes wore a global positioning system (GPS) (Titan 2 Sensor) sampling at 10 Hz. The GPS devices were used only during the experimental stimulus (4-weeks). Pre- and post-testing were performed without GPS devices. The unit was worn in a custom tight-fitting vest, with athletes assigned the same unit throughout the season. The GPS device was placed in a way that it would stay between the scapulae. Every player wore the vest 15 minutes before training or the game started and took it off when finished. External load variables selected to reflect total weekly volume were: total distance (m), sprints (>25.2 m·min-1), zone 4 (moderate intensity 14.4 – 19.8 km/h), zone 5 (very high intensity 19.8 – 25.2 km/h), acceleration (>3 m/s²), deceleration (>-3 m/s²). The main goal of inclusion of GPS devices into our training or experimental study was to control for external load between different HIIT groups. In that sense, we were able to better compare training effects related to the overall training volume in the specific intensity and be sure that the results are related to our experimental program.

Statistical Analyses

Standard statistical computing was performed for data analysis. Median and median absolute deviation was calculated due to non-normal data distribution of some parameters (30-15 IFT test) and low sample size in each experimental group (n=6). Shapiro-Wilk test was performed to gather the normality of distribution. Non-parametric one-way Anova Kruskall-Wallis H test was performed to compare absolute changes between the groups in each outcome. Wilcoxon signed-rank test was used to compare pre- and post-training measurements. All data analyses were performed using Excel and the Jamovi software (*jamovi* version 1.6, computer software, retrieved from https://www.jamovi.org).

3. Results

Results of this study are shown in Table 1. Significant improvements from pre- to post-training were noted only in the 505 COD test (left) in the combined group (*Wilcoxon W* = 18.5; p = 0.036; d = 1.000) and shuttle group (*Wilcoxon W* = 21.0; p = 0.031; d = 1.000) and 30-15 IFT test (figure 3) in the combined (*Wilcoxon W* = 0.0; p = 0.031; d = -1.000) and shuttle group (*Wilcoxon W* = 0.0; p = 0.034; d = -1.000).

No significant differences from pre- to post-training (figure 4) were observed in the 30 m sprint test in linear, shuttle group (*Wilcoxon W* = 12.5; p = 0.752; d = 0.190) and combined group (*Wilcoxon W* = 17.5; p = 0.171; d = 0.667) and in 505 COD test (right) in linear (*Wilcoxon W* = 14.0; p = 0.106; d = 0.867), shuttle (*Wilcoxon W* = 18.5; p = 0.115; d = 0.762) and combined group (*Wilcoxon W* = 18.5; p = 0.115; d = 0.762).

Selected external load characteristics from experimental stimuli and the whole 4- week training period are shown in Table 2 and Table 3, respectively.

Table 1. Performance characteristics across the groups after pre- and post-training measurements (Median ± MAD)

Group/Parameter	505L_Pre	505L_Post	505R_Pre	505R_Post	30m_Pre	30m_Post	30-15 IFT_Pre	30-15 IFT_Post
Linear	2.18 (0.03)	2.14 (0.04)	2.14 (0.03)	2.11 (0.04)	4.10 (0.12)	4.04 (0.09)	20.25 (0.30)	21.00 (0.75)
Combined	2.25 (0.02)	2.17 (0.04)*	2.17 (0.02)	2.10 (0.04)	4.20 (0.09)	4.12 (0.09)	20.00 (0.50)	21.50 (0.50)*
Shuttle	2.18 (0.05)	2.08 (0.02)*	2.15 (0.02)	2.08 (0.06)	4.10 (0.04)	4.09 (0.07)	19.75 (0.25)	20.75 (0.5)*

Note: *0.05 pre- to post-training, MAD = median absolute deviation, 505L_Pre = 505 COD test peroformed on left leg, 505R_Pre = 505 COD test peroformed on right leg, Pre = pre-testing, Post = post-testing, IFT = Intermittent fitness test

Table 2. External load characteristics across the groups during HIIT trainings (Median ± MAD)

Group/Parameter	TD (m)	Sprints (m)	Zone 4 (m)	Zone 5 (m)	ACC [3 m.s-2] (n)	DC [-3 m.s-2] (n)
Linear (n = 3)	5586.0 (97.50)	117.0 (69.0)	2066.1 (81.0)	1313.0 (122.7)	3 (3)	0 (0)
Combined (n = 3)	4739.0 (332.0)	0.0 (0.0)	1686.3 (32.0	1041.0 (271.4)	37 (22)	60 (22)
Shuttle (n = 3)	3253.3 (499.4)	0.0 (0.0)	1476.9 (857.1)	378.7 (83.7)	53 (8)	81 (22)

Note: TD – Total distance, m = meter, Sprints (> 25.2 km/h), Zone 4 (14.4 – 19.8 km/h), Zone 5 (19.8 – 25.2 km/h), ACC – acceleration (>= +3m.s-2), DC – deceleration (<= -3m.s-2), MAD = median absolute deviation, n = sample size, m.s = meters per second

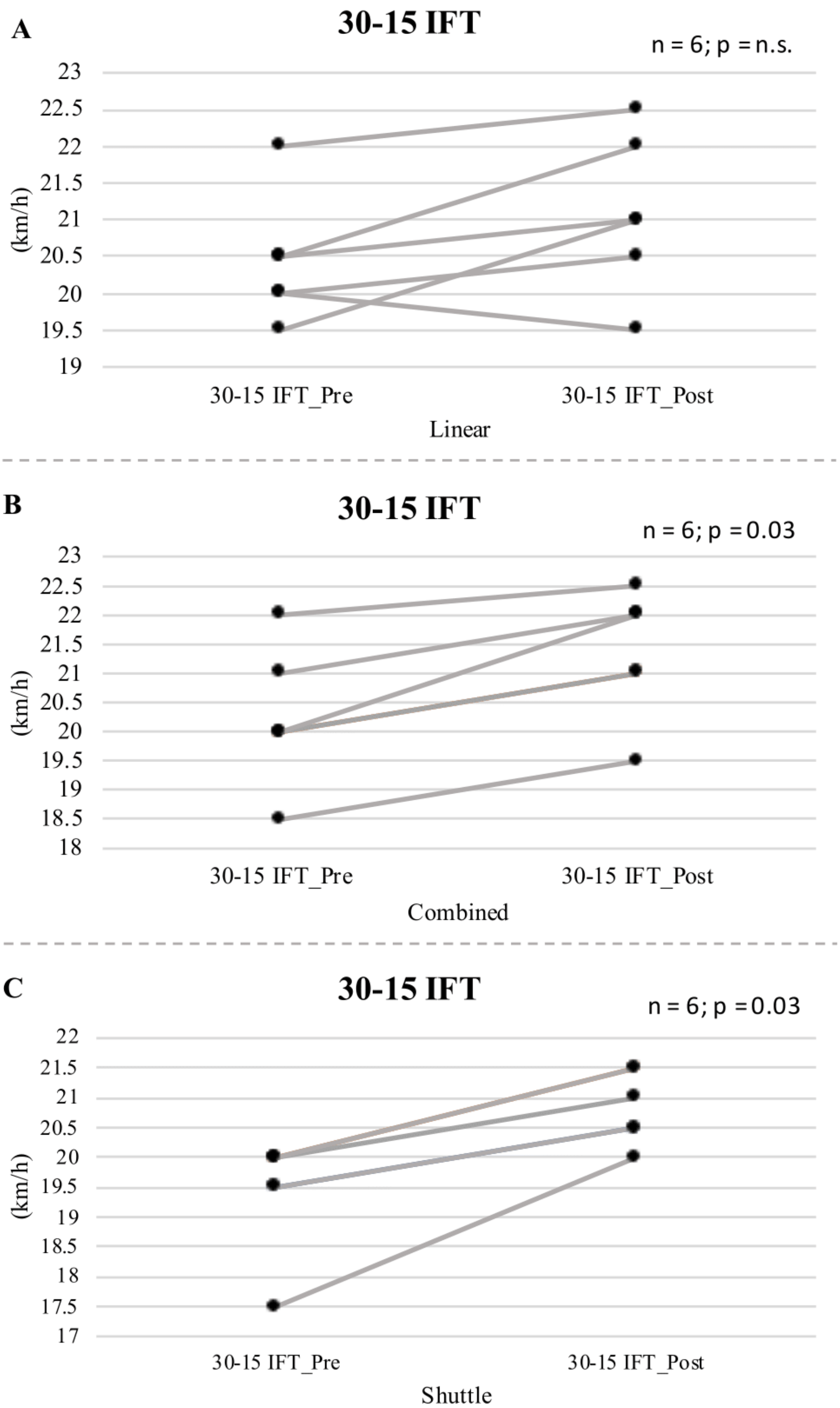

Figure 3. Shows individual results of 30-15 IFT test in the linear (A), combined (B), and shuttle group (C). n = sample size, p = alpha, n.s. = non-significant, km/h = kilometers per hour, Pre = pre-training, Post = post-training

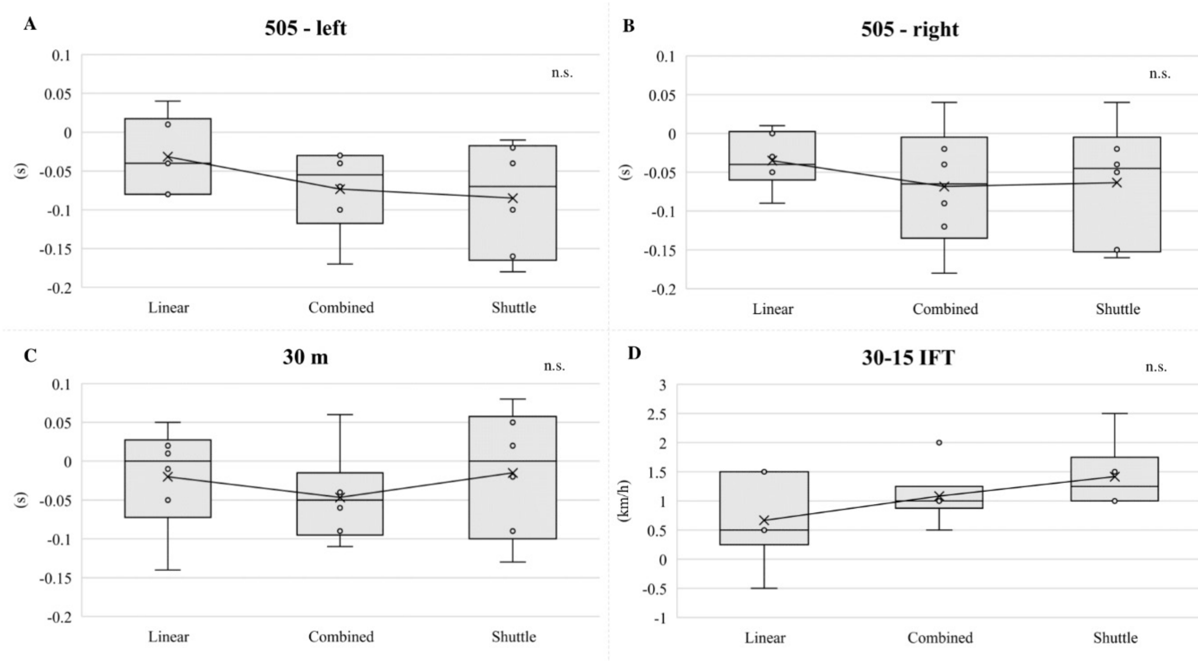

Figure 4. Shows results of 505 COD test (A, B), 30m sprint test (C), and 30-15 IFT test (D). n.s. = non-significant, s = seconds, km/h = kilometers per hour

Table 3. External load characteristics across the groups during week 2 - 5 (Median ± MAD)

Group/Parameter		TD (m)	Sprints (m)	Zone 4 (m)	Zone 5 (m)	ACC [3 m.s-2] (n)	DC [-3 m.s-2] (n)
Linear (n = 3)	week 2	29693.0 (1515)	280.0 (122.1)	1241.3 (61.1)	1272.8 (135.1)	131 (19)	152 (20)
	week 3	26741.0 (312)	236.8 (108.5)	1083.2 (121.3)	914.5 (191.5)	95 (12)	141 (36)
	week 4	26565.0 (371)	305.0 (110.4)	1060.9 (120.1	1424.1 (162)	67 (6)	139 (11)
	week 5	11875.0 (574)	66.2 (45.2)	316.7 (49.9)	494.9 (101.8)	19 (2)	35 (1)
Combined (n = 3)	week 2	29366.9 (198.1)	185.6 (1.3)	1003.1 (37.1)	1165.7 (109.5)	140 (17)	143 (26)
	week 3	26616.0 (395)	73.2 (1.1)	833.9 (152.1)	1010.0 (233.1)	89 (18)	101 (3)
	week 4	23717.0 (1764)	191.4 (15.6)	801.9 (112.9)	1160.0 (47.9)	70 (27)	115 (3)
	week 5	13960.0 (85)	85.8 (4.5)	457.2 (104.7)	467.0 (110.7)	16 (4)	38 (18)
Shuttle (n = 3)	week 2	29475.0 (370)	236.9 (57.6)	955.1 (146.6)	848.5 (141.3)	160 (17)	151 (24)
	week 3	26157.0 (29)	126.0 (39.4)	946.3 (24.1)	719.0 (28.8)	173 (44)	170 (52)
	week 4	30991.0 (868)	239.7 (88.9)	810.0 (23)	903.0 (155.6)	85 (39)	115 (8)
	week 5	14432.0 (55)	123.1 (0.6)	436.2 (45.6)	574.7 (29.7)	31 (1)	93 (1)

Note: TD – Total distance, m = meters, Sprints (> 25.2 km/h), Zone 4 (14.4 – 19.8 km/h), Zone 5 (19.8 – 25.2 km/h), ACC – acceleration (>= +3m.s-2), DC – deceleration (<= -3m.s-2), MAD = median absolute deviation, n = sample size, m.s = meters per second

4. Discussion

The purpose of this study was to investigate the effect of 4- week high-intensity interval training with short interval 15s/15s in three modes - linear (straight-line runs), shuttle and combined. Each group performed 2x4 min. of HIIT runs at 95-105% of VIFT. It was hypothesized that shuttle and combined runs will have better improvements in physical capacities than straight-line runs. Results showed no significant differences between the groups in any measured outcome. Significant improvements from pre- to post- training were only recorded in the 505 COD (left) ($p < 0.05$) and 30-15 IFT ($p < 0.05$) tests in the shuttle and combined group.

Speed performance was measured by 30 m sprint test and we did not record any significant improvements from pre- to post-training in the linear (p = 0.75, d = 0.19), shuttle (p = 0.75, d = 0.19) and combined group (p = 0.17, d = 0.66). In the linear group we observed improvement by 1.5%, the shuttle group improved by 0.2% and the combined group by 1.9%. From GPS devices during HIIT training, the linear group covered distance in sprint (>25.2 km/h) with 117±69 m. In the shuttle and combined group from GPS devices we did not observe any values in the sprint. Arslan et al. [2] in their study applied 5-weeks of HIIT straight-line runs with 2 training sessions per week with interval 15-15s with intensity at 90-95% of VIFT. In their results, they improved speed performance with an increase of 6.8%. Similarly, Faude et al. [19] performed 4-weeks with 2 training sessions per week of HIIT straight-line runs with intervals 15-15s at 140% of IAT (individual anaerobic threshold) velocity and they reached an improvement of 0.7%. Fernandez-Fernandez et al. [20] tested a 20 m sprint test during 8-weeks of HIIT shuttle runs over 20 to 30m and players improved their performance by 2.4%. Our results show that a combination of straight-line runs and shuttle runs had the best impact on improving speed performance, which is somewhat similar result as obtained from the above-mentioned studies. In fact, increased neuromuscular requirements such as accelerations during shuttle runs may improve acceleration phase whereas application of straight line runs which attack high-speed running zone (> 25 km/h) may improve maximal running speed. Hence the combined group reached the best improvement in the 30 m test between the groups.

The 505 COD test is a change of direction speed test and in our results we had not significant improvements in the 505 (left leg) test in the linear group (p = 0.202, d = 0.319) but we had significant improvements in the shuttle (p = 0.031, d = 1.000) and combined (p = 0.036, d = 1.000) group. The linear group improved with an increase of 1.8%, shuttle by 4.6% and combined group by 3.5%. GPS data during HIIT training in the linear group showed minimum number of accelerations and no decelerations. The shuttle group shows the highest number of accelerations and decelerations which can be caused by the changes of directions during running and turning. In the 505 (right leg) test we had no significant improvements in linear (p = 0.106, d = 0.867), shuttle (p = 0.115, d = 0.762) and combined group (p = 0.115 d = 0.762). The linear group improved at least 1.4%, shuttle and combined groups improved by 3.2%. In Fernandez-Fernandez et al. [20] study they used HIIT shuttle runs over 20 to 30 m with interval 15-15s and intensity at 90-95% of VIFT and change of direction speed was improved by 2.6%. We think that due to the largest number of changes of directions (mechanical work) we obtained improvement in these two groups (shuttle and combined group). The left leg was non-dominant and that's why we probably recorded significant improvement compared to 505 (right leg), which was mostly involved in the training process. It can be concluded that due to the most changes of directions (3 $m.s^{-2}$) in the shuttle group it was observed the best improvement.

The 30-15 IFT test as a measure of aerobic capacity, maximal HR and VO_2 in intermittent sports such as soccer is reliable and accurate for individualizing HIIT with changes of directions [28]. In our results we did not find significant improvements in the linear group (p = 0.105, d = 0.762). Conversely, in shuttle (p = 0.034, d = - 1.000) and combined (p = 0.031, d = - 1.000) groups we found significant improvements. In the linear group, players from pre- to post-training improved by 3.7%. The shuttle group improved by 5% and the combined group reached the best improvement by 7.5%. Arslan et al. [2] with their experimental approach mentioned that HIIT training increased aerobic endurance by 4.4%. Equally Belegišanin [5] used HIIT straight line runs method 30-30s and 15-15s twice a week for 8 weeks in season and increased aerobic endurance by 5.7%. Similarly, Dellal et al. [16] used 6-weeks training period shuttle runs over 40-m with 30-30s, 15-15s and 10-10s and players improved by 5.8%. Equally Fernandez-Fernandez et al. [20] with shuttle runs (8-weeks) over 20 to 30 m improved players' aerobic endurance by 6.3%. From the findings of our study, we can state that all 3 modes improve aerobic endurance, but by combining straight line runs and shuttle runs we have achieved greater improvement in this particular test. As a result of many accelerations, decelerations and reacceleration in the training process, we found out the best improvement in shuttle and combined group. In both groups, due to changes of directions they had to compensate for time loss on each change of direction and that could facilitate further improvements in these groups.

A limitation of the present study is the sample size (number of players) in all groups, but research was conducted in a real-world training environment with league players, so the results of this study are applicable and useful for couches. Another stimulus that may affect the results is using only one HIIT stimulus per week and for future research it would be better to choose at least 2 training stimuli per week. Using GPS devices for detecting external load would be better to use for all players. In our study we had a limited number of devices but despite that we managed to find out external load of players and thus check if the overall training volume was similar across all the groups, at least in selected players.

In conclusion, although not all results were statistically significant, only a small number of players have not improved. All HIIT modes performed in 4-week period led to improvements in aerobic endurance, speed performance and change of direction speed. In the combined group we observed the most significant improvement in aerobic endurance and speed performance and in change of direction speed we noticed the best progress in the shuttle group.

Practical Application

This study offers several practical applications for conditioning training in football. The study showed the effects of one popular training intervention with three design models, i.e. HIIT - linear, combined and shuttle, for young soccer players. Short intervals are often performed HIIT modality in team sports because they have similar competition requirements (short work and a short break). This study also showed a significant improvement ($p < 0.05$) in HIIT - combined and shuttle groups, in 30-15 IFT and COD test 505L in young football players after 4 weeks of HIIT. Implementing this approach can be especially useful when the pre-season period is short (4 weeks), when a short passive rest interval is applied with an emphasis on individual scores. Development of players who need to increase volume and / or intensity in a short time, these are players who did not receive full-time (reserves) in the match, or players who did not travel for the match or players who return after an injury (final phase of the rehab/after preparatory period). Practitioners can better prepare their athletes for the demanding requirements of the match. The presented study suggests that coaches can successfully use the time to improve the required physical condition of young football players, because the study consists of a 2x4 min HIIT program.

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