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EFFECTS OF PLYOMETRIC TRAINING IN SAND OR RIGID SURFACE ON PHYSICAL-PERFORMANCE RESPONSES AND TESTOSTERONE CONCENTRATION IN FOOTBALL PLAYERS

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Abstract:
Background: This study aimed to assess the effects of 8 weeks of plyometric training (PT) conducted on sand or a rigid court surface on physical-performance responses and testosterone concentration in football players. **Methods:** Twenty participants were randomly assigned to either the sand (n = 10) or rigid (n = 10) surface groups. Both groups engaged in identical indoor-football training regimens. Assessments included 20 m sprint times, change-of-direction tests (modified Illinois test and modified change-of-direction T-test), jumping ability, a repeated sprint T-test (countermovement, squat, and five jump tests), and static and dynamic balance. Plasma testosterone concentrations were measured concurrently with fitness assessments at the onset of the training period, following an 8-week interval, and at the conclusion of the training. **Results:** After the intervention, PT showed significantly increased sprint speed relative to PT. Change-of-direction scores also improved for PT relative to PT. Sand and rigid surfaces increased vertical jump performance (counter movement jump $p < 0.001$; ES = 0.247; squat jump, $p = 0.005$; ES = 0.170). Repeated sprint T-test scores improved in PT and sand surface compared with the rigid surface, with best times of PT > sand surface ($p < 0.05$). Both plyometric groups improved their dynamic balance ($p < 0.05$), with three parameters of PT and only one of sand surface being significantly greater than the rigid surface. Static balance was also enhanced in both experimental groups (sand surface > rigid surface). **Conclusions:** For reasons that remain to be clarified, physical-performance responses measures in football players increased more by 8 weeks of sand surface than by rigid surface, whereas at the end of the training, its concentration decreased in testosterone concentrations (33.5 ± 2.8 µg/dL). In conclusion, a significant correlation ($p < 0.0001$) was observed between testosterone concentration and maximal oxygen consumption. In the preliminary examination, a statistically significant correlation was observed between the concentration of testosterone and the results of the physical-performance responses test ($p<0.001$). Players' endocrine alterations maintained bodily homeostasis during training. Coaches and sports scientists must continually monitor players' endocrine changes to maximise player performance and prevent overtraining.
Keywords: Plyometric Training, Sand Surface, Physical-performance responses, Testosterone.

INTRODUCTION

Football is the most popular and presently most played sport in the world (Unanue et al., 2020). It is attracting an ever-increasing number of researchers interested in its myriad facets. Notably, the majority of research has focused exclusively on the performance of football athletes (Nicholson et al., 2021). Given that football games tend to have few goals scored, physical-performance reactions have major implications on the results of games

(Kołodziejczyk et al., 2020). Thus, coaches must diligently monitor the physical-performance responses of football players to prevent injuries and ensure compliance with game regulations (Galdino, Lesch & Wicker, 2023). Football players must possess a high level of physical fitness comparable to that of football global levels to ensure optimal positioning and effective decision making during critical moments (Otte, Millar & Klatt, 2020). However, a limited body of research has specifically examined the physical-performance responses of athletes during matches. Notably, players' high-speed running distances tended to decrease during the latter stages of the match, which may indicate the accumulation of fatigue resulting from the high physical and physiological demands of the game. This result is supported by findings related to testosterone concentration and sprint performance decrement (Wing et al., 2021). Developing a football training methodology is a significant physical challenge particularly owing to the varying skill levels of players (Bradley et al., 2019). The football players of a team are subjected to physical and psychological stress owing to the intricate decision making involved in facing opponents, coaches, and spectators. This is particularly evident in high-intensity and physically demanding sports (Deuker et al., 2023). According to Kim et al. (2022), plyometric training (PT) was observed to have a positive impact on the physical performance and skill development of football players. Nonetheless, whether the aforementioned benefits can be further augmented through the implementation of training on a sand or solid surface remains a matter of interest. Previous studies have conducted a comparative analysis on the efficacy of PT on unstable surfaces, specifically on sand or rigid surfaces. Glossop-von Hirschfeld (2021) reported that prepubertal male football players exhibit similar improvements in their physical-performance measures regardless of whether they train on sand or rigid surfaces. Hammami et al. (2020) noted similar enhancements in vertical jumps, standing long jumps, and leg press in relation to sand and land-drop training. Similarly, the authors observed similar reductions in relative responses following PT on either a wooden gymnasium floor or a thick, unstable athletic mat, as assessed by strength measures. However, their results regarding the impact of training surface are inconclusive (Hammami et al., 2020; Ramirez-Campillo et al., 2020; Peitz, Behringer & Granacher, 2019). Several studies have reported limited benefits associated with the utilisation of unstable surfaces. Nevertheless, research comparing the effects of sand and firm surfaces on physical-performance responses is limited (Ramirez-Campillo et al., 2020). Marzouki et al. (2022) found that agility and strength improve to a greater extent through sand-based training compared with standard plyometrics. Similarly, Pereira et al. (2021) reported that training on sand enhances sprinting, jumping, and sprinting abilities with reduced muscle soreness compared with training on grass. The capacity of an athlete to utilise this PT is a crucial factor in achieving peak athletic performance, impacting proficiencies in activities such as sprinting, directional changes, and sport-specific manoeuvres like executing a football kick (Cormier et al., 2020). PT is a form of physical conditioning that involves a variety of targeted exercises, including drop jumps which place stress on the musculo-tendinous unit. This type of training is widely acknowledged as an effective means of improving athletic performance in skill-related activities whilst also promoting overall health and reducing the risk of injury (Chomani et al., 2021). The safe and effective implementation of plyometric programmes depends on several key factors, including the nature of the jump drills, the quantity and intensity of jumps, the surface utilised for training, the order of drills within a training session, the duration of rest periods between sets, and the frequency of rest periods between training days (Bin Shamshuddin et al., 2020). The physical-fitness adaptations to exercise in young players may be influenced by their training status. This lends support to the notion of the existence of certain methods during which physical-performance responses are accelerated (Tomporowski & Pesce, 2019). PT is important in improving the physical-performance responses of soccer players, and published results on the effects of testosterone concentration are conflicting. Thus, the respective effects of physical-performance responses and testosterone concentration on the response to PT require further research. Accordingly, the present study aimed to provide data to answer this question. Based on literature, we hypothesised that PT enhanced the physical-performance responses and testosterone concentration of male youth soccer players, and that this effect was modulated by maturity status and inter-set recovery interval.

Methods

Procedures

This study analysed the effects of an 8-week physical preparation period on testosterone blood concentrations and physical-performance responses in football. Results of physical-performance responses tests evaluating linear sprint, 20 m sprint tests, change-of-direction tests, jumping ability, a repeated sprint T-test, and static and dynamic balance in football players during the competitive season 2021/2022 were also assessed. Testosterone blood concentrations and physical-performance responses tests were performed at beginning of the training period. After 8 weeks, blood samples were collected at 7:30 am in the fasting state.

Participants

This investigation was structured as a prior examination conducted on individuals who played football. Twenty-four football players voluntarily participated in the study during the 2021/2022 season. The age range of the players was 18–22 years. A cohort of eight participants aged 18–23 years were voluntarily recruited to form the control group. The control group was not subjected to any particular exercise regimen and was permitted to maintain their customary training routine. Throughout the study, participants were directed to adhere to their typical exercise regimen and consume solely water within the hour preceding data collection. None of the individuals exhibited a history of smoking or any notable medical or health conditions. The participants refrained from consuming any medication, supplements, or corticoids prior to or during the course of the study. The research received approval from the coach and the president of the club. Prior to the commencement of any procedures, all participants were provided with a comprehensive explanation of the purpose and nature of the study and were required to provide written informed consent.

Anthropometric Characteristics

Standard techniques were utilised to obtain body weight and height. The resting heart rate (HR) was assessed using a HR monitor manufactured and the resulting data were analysed using specialised software. The same researcher conducted all measures at 7.30 a.m. for all time periods. Table 1 displays the anthropometric characteristics of participants determined prior to the start of the training period (mean standard deviation).

Table 1: Physical characteristics of control and experimental groups (mean ± SD) of the study participant

Variables	Unit of measurement	M	SD	Torsion coefficient
Age	Year	16.4	0.8	0.356
Weight	kg	70.8	6.4	0.582
Height	cm	1.72	0.08	0.126
Body fat		20.04	2.26	0.342
VO2max (ml·Kg−1 min−1)		48.7	1.80	0.234
BMI (Kg m−2)		20.90	0.71	0.383

Experimental design

Prior to participating in a study that involved 24 football players, written informed consent was obtained from all participants. The study was approved by the coach and club president. The team physician conducted a thorough examination of all individuals, with a specific emphasis on orthopaedic and other potential health

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issues that can hinder resistance training. We determined that all individuals were in satisfactory health and that the initial physical characteristics of the three groups were well matched.

Testing Procedures

Throughout the physical preparation phase until the conclusion of the trial, all participants were involved in training sessions under the supervision of the team coaches. The training regimen comprised four to five football training sessions per week and one friendly game per week. The typical duration of training sessions was between 90–100 min, with a focus on skill development at varying levels of intensity, as well as instruction on offensive and defensive strategies. Additionally, a period of 25–30 min of uninterrupted play with minimal intervention from the coach was typically implemented.

Details Of Plyometric Training

Both groups engaged in a uniform plyometric programme on Tuesdays, Thursdays, and Saturdays for a duration of 7 weeks. The programme involved performing plyometric exercises on a rigid gymnasium floor and sand. During these days, 25 min of their typical routine, which focused on technical–tactical skill development, were replaced by the plyometric intervention. The sand and rigid surface PT regimen comprised four primary workshops, as outlined in Table 2.

Table 2: Components of plyometric training for the two experimental groups.

Week	Workshop one	Workshop two	Workshop three	Total contacts
1	6×2	6×2	6×2	36
2	6×3	6×3	6×3	54
3	6×3	6×3	6×3	54
4	6×4	6×4	6×4	72
5	6×4	6×4	6×4	72
6	6×5	6×5	6×5	90
7	6×5	6×5	6×5	90
8	6×6	6×6	6×6	108

Workshop 1 = 6 lateral (0.3 m) hurdle jumps (3 to left and 3 to right), then sprinting 10 m; workshop 2 = 6 horizontal jumps (3 to left and 3 to right), then sprinting 10 m; and workshop 3 = 6 × 0.4 m hurdle jumps, then sprinting 10 m.

The workshop sessions were initiated with plyometric exercises, specifically the modified change-of-direction and modified Illinois test. They were followed by a repeated sprint and assessments of jumping ability through the Squat, Countermovement, and Five Jump techniques. Additionally, static and dynamic balance were evaluated. The workshop concluded with a 20 m linear sprint. The training sessions were initiated with a 10 min warm-up and had a duration of 35 min, as indicated in Table 2. The sessions were consistently monitored by a single coach and comprised 54 to 108 ground contacts per session. The provision of verbal encouragement was found to maintain a heightened level of motivation throughout the task.

Sprint Performance

The practise of sprinting commenced with a uniform warm-up session lasting for a duration of 20 min. The study's subjects performed a 20 m run starting from a stationary position, and their performance was measured using paired photocells placed at 5, 10, and 20 m. The experimental protocol involved conducting three trials with an inter-trial recovery period of 6–8 min. The optimal outcome was selected for analysis. This study aimed to assess the test–retest reliability of measurements taken at distances of 5, 10, and 20 m. Additionally, 95% confidence intervals were calculated to provide a measure of the precision of the estimates.

Vertical Jumping

Following a 15 min warm-up period, flight durations were measured with a high level of precision (0.001 s) by using an infrared photocell mat and digital computer to determine corresponding jump heights. The technique for performing squat and counter-movement jumps were previously expounded upon in a publication by Hammami et al. (2022). The test–retest reliability and 95% confidence interval values for the two measures were 0.919, 0.920 and 0.823–0.933, 0.829–0.960, respectively.

Five-Jump Test

The study's participants were instructed to perform a series of five forward jumps with the goal of covering the maximum distance possible. The measure in question exhibited a test–retest reliability of (95% confidence intervals for this measure were 0.833 and 0.762– 0.887 respectively.

Modified Change-Of-Direction T-test

The modified change-of-direction test was used to evaluate speed whilst incorporating directional changes such as forward sprinting, left and right shuffling, and backward running. Paired photocells were utilised to record performance times. The test–retest reliability and 95% confidence interval were determined to be 0.939 and 0.842–0.960, respectively.

Modified Illinois test

The agility test in question has been previously documented and made available to the public by Rouissi et al. in 2016. The measurement of performance times was conducted using paired single beam photocells manufactured. The reliability of this measure was assessed through test–retest analysis, resulting in a reliability coefficient of a 95% confidence interval ranging for this measure were 0.911 and 0.792–0.930, respectively.

Repeated Sprint Test

Multiple sprint tests were administered according to Fessi et al. (2016). This assessment provided a dependable and sound evaluation of the capacity to execute swift directional alterations, emulating a contest involving brief, strenuous exertions, intervals of recuperation, and multidirectional movements. The measurements considered were best time, mean time, total time, and a fatigue index that was computed as total time / (best time × 7) × 100) – 100 according to Spencer et al. (2006).

Stork Test of Static Balance

The Stork test was executed using the conventional procedure, wherein individuals stood on their non-dominant leg and placed their other foot against the inner side of the supporting knee, as described by Kranti Panta (2015). The test–retest reliability scores for measurements conducted on the right and left legs were found to be 0.790 and 0.781, respectively. The corresponding 95% confidence intervals were 0.422–0.852 and 0.631–0.822.

Dynamic Balance

The Y-balance test (Bulow et al., 2019) was used to evaluate dynamic balance on the dominant leg. The experiment consisted of conducting three trials in both directions, with a 2 min inter-trial rest period. Test–retest reliabilities for the three reach directions ranged from 0.871 to 0.920, with respective 95% confidence intervals of 0.791–0.922, 0.809–0.903, 0.793–0.933 for the left, back and right side respectively (right support leg); and 0.850–0.961, 0.880–0.934, 0.811–0.921 for the left, back, and right side, respectively (left support leg).

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Statistical Analyses

Statistical analyses were conducted using the Statistical Package for the Social Sciences version 24 software programme.

Read Aloud

The effects related to training were evaluated using two-way analyses of variance, specifically examining the interaction between group and time. If a statistically significant F value was observed, Tukey's posthoc procedure was utilised to identify pairwise differences. A significance level of $p \leq 0.05$ was adopted as the threshold for determining statistical significance regardless of whether a positive or negative difference was observed. The determination of effect sizes was conducted by converting partial eta-squared values to the scale proposed by Correll, Mellinger, and Pedersen (2021). The effect sizes were categorised as small ($0.00 \leq d \leq 0.49$), medium ($0.50 \leq d \leq 0.79$), and large ($d \geq 0.80$). Percentage changes were claculated using the following formula: ([post-training value – pre-training value]/pre-training value) × 100. The authors of the study conducted an assessment of measurement reliabilities by using intra-class correlation coefficients (Chenani & Madadizadeh, 2021). All measurements were found to exhibit a satisfactory level of reliability, with correlation coefficients exceeding 0.80.

Results

The test results are outlined in Tables 3 and 4. After the intervention, sand surface showed significant improvements in all sprint times relative to sand or rigid surface, with no significant differences between sand surface and rigid surface. PT resulted in reduced change-of-direction times compared with training on sand or a rigid surface, as indicated in Table 3. The rigid surface also exhibited improvement compared with the rigid surface. Both groups engaged in plyometric exercises demonstrated comparable improvements in vertical jump performance (PS: SJ: A 30.1%, p≤0.001; CMJ: A 39.7%, p < 0.01; P: SJ: A 30.9%, ps 0.001; CMJ: A 39.7%, p ≤ 0.01). Scores on the five-jump test remained unchanged for all groups. RSTT scores showed gains for sand surface and rigid surface with respect to best time, mean time, and total time, but sand surface demonstrated a greater improvement in best times than the rigid surface (Table 4, p < 0.05). Stork balance scores increased in PT relative to sand or rigid surface, with sand surface also showing a gain compared with the rigid surface (left leg, p≤ 0.01), PT yielded gains of Y-balance in 2 of 3 scores for the right leg and 1 of 3 scores for the left leg test compared with the rigid surface, whereas only scores for the right leg/back (RL/B, p≤ 0.001) increased on the sand surface compared with the rigid surface.

Table 3: Presents a comparison of sprint, change of direction, and jump performance between groups before and after the 8-week trial.

Variables	Group	Pre-trial		Post-trial		*p* value	d (Cohen)
Sprint		M	SD	M	SD		
5 m (s)	PS	1.19	0.12	0.98	0.11	0.001	1.20
	P	1.20	0.07	1.15	0.09	0.001	1.33
	C	1.20	0.06	1.23	0.06	0.001	1.13
10 m (s)	PS	2.19	0.15	1.66	0.21	0.001	1.42
	P	2.15	0.13	2.03	0.12	0.001	1.52
	C	2.14	0.08	2.16	0.11	0.001	1.53
20 m (s)	PS	3.49	0.23	3.11	0.13	0.005	0.92
	P	3.55	0.20	3.44	0.14	0.001	1.19
	C	3.2	0.21	3.53	0.19	0.002	0.99

Change-of-direction							
T-Half (s)	PS	7.02	0.31	6.39	0.26	0.001	1.25
	P	7.19	0.38	6.77	0.29	0.001	1.18
	C	7.15	0.34	7.17	0.31	0.007	0.89
Illinois-MT (s)	PS	13.3	0.4	11.11	0.5	0.001	1.36
	P	13.3	0.5	12.6	0.7	0.001	1.56
	C	13.2	0.3	13.4	0.3	0.001	1.18
Jump tests							
SJ (cm)	PS	28.7	4.1	36.7	3.4	0.001	1.14
	P	27.4	3.9	35.8	2.6	0.001	1.99
	C	27.5	3.2	29.7	2.8	0.005	0.91
CMJ (cm)	PS	29.4	3.6	40.5	5.4	0.002	0.99
	P	30.8	3.5	39.1	3.2	0.001	1.94
	C	30.5	3.6	31.8	3.1	0.001	1.15
5JT (cm)	PS	10.4	0.7	11.2	0.3	0.199	0.49
	P	9.8	1.3	11.2	1.5	0.013	0.68
	C	10.1	1.2	10.3	1.2	0.239	0.46

PS = plyometrics on sand; P = standard plyometrics; C = control group.

Table 4: Presents a comparison of the repeated sprint T-test and balance performance between groups before and after the 8-week trial.

Variables	Group	Pre-trial		Post-trial		*p* value	d (Cohen)
Repeated sprint T-test		M	SD	M	SD		
Repeated sprint T-test– Best time (s)	PS	12.3	0.6	10.3	0.7	0.001	1.48
	P	12.3	0.4	11.3	0.6	0.001	1.98
	C	12.3	0.7	12.2	0.6	0.001	1.44
Repeated sprint T-test- Mean time (s)	PS	12.6	0.6	10.6	1.1	0.003	0.98
	P	12.5	0.4	11.1	1.2	0.001	1.59
	C	12.5	0.8	12.4	0.7	0.001	1.05
Repeated sprint T-test– Fatigue index	PS	−4.5	2.2	−2.5	0.7	0.001	1.41
	P	−4.1	2.2	−3.8	2.4	0.006	0.77
	C	−8.1	3.6	−5.7	3.1	0.198	0.49
Repeated sprint T-test– Total time (s)	PS	87.6	3.10	73.8	7.2	0.003	0.98
	P	86.8	2.4	77.1	8.2	0.001	1.59
	C	87.1	4.9	86.6	4.4	0.001	1.05
Y Balance Test							
Right support leg							
RL/L (cm)	PS	83.7	6.7	98.2	12.8	0.024	0.76
	P	83.7	7.9	94.1	9.4	0.000	1.14
	C	82.3	6.3	84.10	6.2	0.088	0.61

RL/B (cm)	PS	106.4	6.5	123.6	7.1	0.001	1.56
	P	105.7	5.1	123.6	8.10	0.001	1.99
	C	103.1	6.2	106.3	5.6	0.001	1.04
RL/R (cm)	PS	51.5	9.10	55.8	9.4	0.895	0.13
	P	52.4	10.9	55.6	11.1	0.336	0.27
	C	52.2	12.2	52.7	12.2	0.844	0.16
Left support leg							
LL/L (cm)	PS	48.10	8.8	53.4	7.6	0.703	0.23
	P	51.2	12.3	54.10	9.7	0.113	0.44
	C	51.8	9.5	55.2	9.2	0.988	0.000
LL/B (cm)	PS	111.8	5.9	123.2	8.8	0.001	1.13
	P	104.4	3.6	119.6	8.2	0.001	1.28
	C	105.8	9.10	108.6	9.8	0.049 c	0.68
LL/R (cm)	PS	86.6	6.8	90.8	6.6	0.170	0.52
	P	84.4	6.9	90.8	5.6	0.014	0.69
	C	82.3	9.6	86.4	9.7	0.866 c	0.15
Stork Balance Test							
Right leg (s)	PS	3.26	1.37	15.13	2.08	0.001	1.50
	P	5.12	5.45	6.77	5.57	0.001	1.14
	C	3.19	1.32	3.55	1.63	0.001	1.62
Left leg (s)	PS	4.42	3.08	15.19	3.08	0.001	2.27
	P	4.44	3.39	5.43	4.55	0.001	1.45
	C	2.08	0.54	2.42	0.73	0.001	1.74

Discussion

The primary empirical discovery of this study indicated that adolescent football players with prior experience who underwent a specific level of PT, exhibited improved performance in sprinting, change of direction, and static balance when the training was conducted on a sand surface as opposed to a rigid surface. Nevertheless, previous research conducted on various participant groups and varying intensities of PT has not consistently reported similar advantages. What impact does an unstable surface have on the outcomes of PT? According to Villalba et al. (2022), evidence suggests that decreased ground reaction times, accompanied by increased lateral movement and improved balance, may enhance biomechanical learning, neuro-muscular adaptations, and the strengthening of muscles involved in balancing. In turn, it can lead to improved training response when performing on stable surfaces, as indicated by Dos' Santos et al. (2019). In fact, when jumping onto a sandy surface, the foot sinks into the sand, requiring the athlete to exert additional force in making successive leaps, which over time is likely to increase strength. Several investigators have emphasised the potentially favorable influence of training on an unstable surface upon balance and agility (Hammami et al., 2020; Lichtenstein et al., 2020; Marzouki et al., 2022), offering as it does specific training in the challenges faced during actual play on uneven and soggy fields. The potential benefits of training on an unstable surface for improving balance and agility were noteworthy because it provided targeted practise for the difficulties encountered during real gameplay on uneven and wet playing fields. Nevertheless, the potential for sandy surface to mitigate overtraining may vary depending on the age, maturity, and training level of athletes. The

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observed enhancement in muscle strength resulting from the tapering of a conventional plyometric regimen may also indicate the likelihood of such correction according to Bonavolontà et al. (2021). They provided empirical evidence in favour of the aforementioned concept by demonstrating that the implementation of PT programmes on sand results in notably decreased muscle soreness. This finding is consistent with the research outcomes of Suresh and Patil (2023). If the presence of overtraining correction was indeed a contributing factor, the degree to which performance improvement was observed upon transitioning to a sandy surface would be contingent upon the time interval between the last training session and the subsequent post-test, which in this study was 7–10 days. This matter may be clarified by implementing diverse intensities of plyometric activity, accompanied by meticulous observation of muscle-soreness sensations and the intramuscular release of enzymes (Ahmadabadi et al., 2023; Ramirez-Campillo et al., 2021; Znazen et al., 2022). The observed improvements in sprint performance between both plyometric groups in our study can be attributed to concurrent enhancements in muscle strength and power, as indicated by previous research conducted by Aloui et al. (2022) and Berton et al. (2022). However, in contrast to the current data, Hammami et al. (2022) observed notable improvements in 10 m performance after 8 weeks of PT on either a stable floor or two extremely unstable surfaces. The gains were measured at (1.4%) and (1.8%), respectively, both of which were statistically significant ($p<0.05$). Additionally, their study indicated a tendency towards similar improvements in 30 m performance, with gains of 0.7% and 0.9%, respectively ($p=0.08$). Similarly, Negra et al. (2017) reported comparable enhancements in sprinting performance amongst pre-pubertal soccer players following an 8-week intervention of either unstable (0–10 m (46%), 0–20 m [A5%), $p<0.01$) or stable (0–10 m (A4%], 0–20 m [A4%], $p < 0.01$) PT. The observed distinction between PT and the sand surface and rigid surface groups can be attributed to the athletes being in a phase of physical preparation, specifically in the pre-season, during which they had not yet attained their optimal performance level. The current study observed that football players experienced more significant improvements in their capacity to rapidly change direction when training on sand surfaces (T Half A 8.9%; Illinois MT A8.3%) compared with stable ones (T-Half 5.8%A; Illinois MT A4.2%). In their recent study, Hammami et al. (2022) observed favourable outcomes associated with depth jump training on sand and land surfaces in terms of change of direction T test performance amongst a sample of participants. Conversely, Negra et al. (2017) observed comparable enhancements in the Illinois MT score after an 8-week period of PT on a stable (A3%, $p<0.01$) and an unstable surface (A3%, $p<0.01$). Granacher et al. (2015) reported similar enhancements in change-of-direction capabilities (A2.9 to 3.1%, $p<0.001$) amongst sub-elite adolescent male soccer players following an 8-week PT regimen conducted on either stable or unstable surfaces. The potential improvement in change-of-direction performance resulting from PT on a sand surface may be attributed to the increased force required by athletes to overcome hurdles during this type of exercise. During the act of leaping onto the sand, the foot experiences a sinking effect as it makes contact with sand particles. Consequently, the athlete is required to apply an additional force to execute a subsequent jump (Ahmadi et al., 2021; Mirzaei et al., 2014). The endocrine system is greatly stimulated by physical activity, and the hormonal response to exercise is influenced by a variety of factors, including the subject's training state, method of exercise, duration, and intensity (Athanasiou, Bogdanis & Mastorakos, 2023). The majority of studies performed at the beginning and conclusion of sports performance (pre and post) have evaluated the relationship between exercise and endocrine function (Fernández-Lázaro et al., 2021). Few studies have analysed the impact of many months of physical activity on hormonal changes. Conversely, no study has attempted to comprehend the result of exercise duration on blood-hormone concentrations in football players. However, engaging in competitive, consistent, and frequent physical activity is extensively recognised to significantly affect the regulation of hormones in the body, specifically those leading to alterations in the testosterone and cortisol levels in the

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bloodstream. Physical exercise has the potential to impact an individual's physical performance, particularly in sports that rely on strength and endurance. This phenomenon is likely attributable to elevated levels of testosterone in the bloodstream, as suggested by previous studies (Wiciński et al., 2023). A previous study has examined the fluctuations in testosterone levels amongst football players throughout a training a duration of 8 weeks. In another work, Muscella et al. (2022), demonstrated that young footballers exhibit elevated levels of testosterone concentrations. This finding agrees with a previous one from a study conducted on various team sports (Rodrigues Lopes et al., 2022). In the current work, we observed an increase in testosterone levels during the initial phase of training, which was characterised by the implementation of high-intensity physical exercises as a prerequisite for commencing the training regimen. Subsequently, a modest reduction in the levels of circulating hormones was observed following the completion of the training session. As previously noted, physical exercise serves as a stressor, and the production of testosterone is influenced by the intensity and duration of exercise (Rao, Narnaware, & Giripunje, 2023). Testosterone is widely acknowledged for its robust anabolic impact on muscle tissue and its ability to stimulate competitive behaviour, rendering it advantageous for enhancing athletic performance (Hilton & Lundberg, 2021). The impact of elevated testosterone levels on athletic performance is found to be substantial (Hilton & Lundberg, 2021). However, available evidence regarding the effects of testosterone on athletic performance is limited and low quality (Muscella et al., 2022). Moreover, the matter at hand is subject to significant controversy owing to the existence of numerous rulings within the realm of professional sports. Notably, any direct link between testosterone concentrations and the type of training has not yet been established (Sabag et al., 2018). Therefore, we corroborated that testosterone was associated with athletic-performance responses. Our findings extended previous research such as that of Massini et al. (2018), who found that elevated testosterone is associated with improved performance in middle-distance runners based primarily on the aerobic energy pathway. According to Hilton and Lundberg (2021), testosterone has a positive impact on muscle mass by promoting its growth whilst simultaneously reducing body fat. Our own findings agreed with this notion, that is, we observed significantly decreased body-fat percentage compared with testosterone levels. All these outcomes indicated testosterone's significant role in carbohydrate and proteins metabolism by acting as competitive agonists at the receptor level of muscle cells.

Conclusions

The sport of football is becoming increasingly athletic and placing greater physical demands on participants. Players also require strength and power to outrun or outjump their opponents and capture the ball before others do. Our results regarding football players at a crucial juncture in their pre-competition preparation indicated that an 8-week training programme of either PT or sand surface improved physical-performance responses. Nevertheless, PT appeared to induce some additional improvements in athletic performance that were not observed with sand surface, particularly with regard to sprint, change of direction, repeated sprint test (best time), and static equilibrium. More investigations are warranted in this domain across a diverse range of sports to establish comprehensive hormone reference values. Therefore, promoting the incorporation of PT as a component of pre-season conditioning for coaches is advisable. Our findings indicated that the training sessions undergone by football players yielded favourable outcomes in terms of anaerobic and aerobic fitness, thereby rendering the players suitable for participation in matches. Training induced specific changes in endocrine function and thus maintained body homeostasis amongst football players. Coaches and sport researchers need to consistently differentiate between variations in hormones to enhance athlete performance. Further research involving a larger sample size of football players is necessary to validate these findings.

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