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ORIGINAL ARTICLE

Assessment of explosive force and agility in U19 soccer players following a high-intensity interval training program utilizing plyometric exercises

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ABSTRACT

Aims: This study aimed to assess the impact of a high-intensity interval training (HIIT) program incorporating plyometric exercises on explosive force and agility performance in U17 soccer players. Methods: Twenty healthy male soccer players from the G.S.M team volunteered for the study and provided informed consent. Participants were randomly assigned to two groups: a Control Group (CG) comprising 10 players who continued regular soccer training (Age: 17.6 ± 0.52 years; Height: 183 ± 0.055 m; Body mass: 73.3 ± 4.9 kg; BMI: 23.20 ± 4.07), and a High-Intensity Interval Training Group (HIIT) with the same number of players (Age: 17.7 ± 0.5 years; Height: 1.80 ± 0.313 m; Body mass: 70.9 ± 6.6 kg; BMI: 22.27 ± 2.94). The CG did not participate in any HIIT program, while the HIIT group undertook a weekly plyometric-focused HIIT session for ten consecutive weeks. All subjects underwent two tests: the Squat Jump Test and the T-agility Test, along with the Kinovea software to measure jump flight time to calculate jump height in the SJ test. Results: The intervention group exhibited significant improvements in both the Squat Jump and T-agility test results, indicating enhanced explosive force following the ten-week HIIT program (Squat Jump: t = -3.163, *p* = .012; T-agility: t = 4.960, *p* = .000) compared to the control group. These results suggest that the HIIT program effectively enhanced both explosive power and agility performance, thereby potentially improving performance during matches and reducing injury risk among U17 players. Conclusions: The findings of this study provide valuable insights for coaches looking to enhance vertical jump height and agility through HIIT programs featuring plyometric exercises. The positive effects on explosive force and agility performance may lead to improved match performance and injury prevention among recreational soccer players.
Keywords: Health, Team sports, HIIT, Plyometric exercises, Explosive force, Agility performance.

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INTRODUCTION

Football is a game that includes high speed runs at full or sub-normal speeds, high power projections, quick changes in ball direction. Sports coaches often design a training regime for sports coaching and performance research that covers a range of physiological and mechanical requirements. The training regime is, therefore, ready to use by athletes and coaches for their everyday sports activities. Many team sports (such as football, netball, martial arts and baseball) include intermittent, dynamic and ballistic movement. This requires advanced conditions, along with high aerobic and intermittent sprinting capacity, strong muscles and strength, speed flexibility, speed and adaptability.(Bin Shamshuddin et al., 2020).

Football places substantial demands on the lower body's strength, agility, and explosiveness, which are critical for performance (Ozbar et al., 2014); (Chelly et al., 2010). Although explosive actions constitute a small fraction of match duration, they significantly influence game success (Reilly et al., 2000). High-level soccer performance relies on physical fitness, psychological resilience, and technical skills, especially during small-sided games. To enhance the physical and technical capabilities of young players, innovative training methods are essential (Arslan et al., 2021). Soccer players need focused training regimens to meet the sport's physical challenges (Reilly et al., 2000). While much research addresses the training needs of adult athletes, it is also crucial to develop explosive capabilities in young soccer players. Athletic trainers are vital in creating training systems that cater to the diverse physiological and mechanical demands of athletes, thereby enhancing daily training regimens. When training young athletes, trainers must consider their unique physiological development, as their responses to training can differ markedly from those of adults (Oliveira-Junior et al., 2017). Research indicates that growth spurts are associated with improvements in physical performance (Aouichaoui et al., 2012); (Oliveira-Junior et al., 2017). A promising method for enhancing football fitness is Optimum Power Load (OPL) training, which focuses on loads that optimize muscle strength production. Studies show that OPL squats lead to significant improvements in football-specific activities like running, jumping, and agility, thereby positively affecting well-trained athletes' performance (Ribeiro et al., 2020). By tailoring training programs to the physiological changes experienced by young athletes, trainers can facilitate optimal development and enhance performance outcomes.

Muscle strength is essential for daily activities and performance in competitive sports (Ruiz et al., 2008). Exercise intensity significantly impacts physiological adaptations and athletic performance (Rosenblat et al., 2020). This intensity typically involves short bursts of strength training at levels close to VO2max (above 80% VO2max), interspersed with rest or low-intensity recovery periods, depending on the training method utilized. In team sports, muscle power is crucial, particularly in soccer, where rapid, short-duration movements significantly influence an athlete's fitness and skills. Agility—the ability to maintain balance and quickly change direction without losing control or speed—is a critical component for all athletes, including professional and tactical competitors (Alricsson et al., 2001). Agility encompasses balance, coordination, strength, and speed, offering benefits such as enhanced body stability during quick movements, improved intramuscular control, and a reduced risk of injury or re-injury. The Agility T-Test is one assessment used to evaluate athletes' agility, requiring movements forward, sideways, and backward (Raya et al., 2013).

Interval training (IT) consists of repeated bouts of high-intensity exercise followed by rest or low-intensity activity. The duration of these intervals can vary from seconds to minutes, depending on factors such as exercise mode, intensity, recovery time, number of intervals, and frequency (Buchheit & Laursen, 2013a); (Buchheit & Laursen, 2013b). IT has been utilized for decades for various objectives, including health improvement (Wisløff et al., 2009); (Kemi & Wisløff, 2010); (Weston et al., 2014), performance enhancement, and weight loss. High-Intensity Interval Training (HIIT) and Sprint Interval Training (SIT) are two popular forms of IT (Naves et al., 2018). HIIT typically targets near-maximum intensity, reaching between 80% to 100% of maximum heart rate (HRmax) or maximum oxygen consumption (VO2max) for intervals lasting no more than 60 seconds (Gillen & Gibala, 2014). Recovery periods, which may include low-intensity exercise or rest, can extend up to 4 minutes (Burgomaster et al., 2005); (Burgomaster et al., 2006); (Jiménez-Maldonado et al., 2018). HIIT is widely used to enhance performance in sports such as football, helping teams prepare for competition. Generally, HIIT sessions are structured within a 30-minute timeframe, incorporating warm-up and cool-down phases (Gibala & Jones, 2013); (Gillen & Gibala, 2014). Despite a growing body of literature, proper regulation of HIIT has not been thoroughly studied (Tschakert et al., 2015), ostensibly due to the numerous manipulable variables, such as intensity, duration of effort and rest, work-to-rest ratios, and recovery types (Martínez-Rodríguez et al., 2021).

Plyometric training (PT) is particularly popular among athletes in dynamic sports, and involves activities such as jumping, hopping, and bounding to enhance dynamic muscular performance (Váczi et al., 2013). In these exercises, muscles undergo a rapid lengthening followed by a shortening (known as the stretch-shortening cycle), utilizing elastic energy stored during the stretching phase (Cavagna, 1977). Plyometric training has been shown to improve muscle coordination and synchronization in sports like football, volleyball, and basketball (MH et al., 2021). Various training protocols, including sprint drills, speed training, and weighted exercises, have been proposed to enhance speed, jumping ability, and agility. Both plyometric training alone and in combination with strengthening exercises yield positive results in sprint performance (Monteiro et al., 2008). High-intensity plyometric training, involving sprints, accelerations, decelerations, and directional changes, is recommended to develop agility in football players. Specific sprint training programs have demonstrated significant improvements in sprint times for distances of 10 and 100 meters (Delecluse et al., 1995).

Given the conflicting and limited data in previous studies, we aimed to evaluate the effectiveness of high-intensity interval training (HIIT) featuring plyometric exercises. Specifically, we sought to assess the impact of a 10-week HIIT program on explosive force and agility in male U17 soccer players. We hypothesized that this training would enhance vertical jump performance and change-of-direction capability.

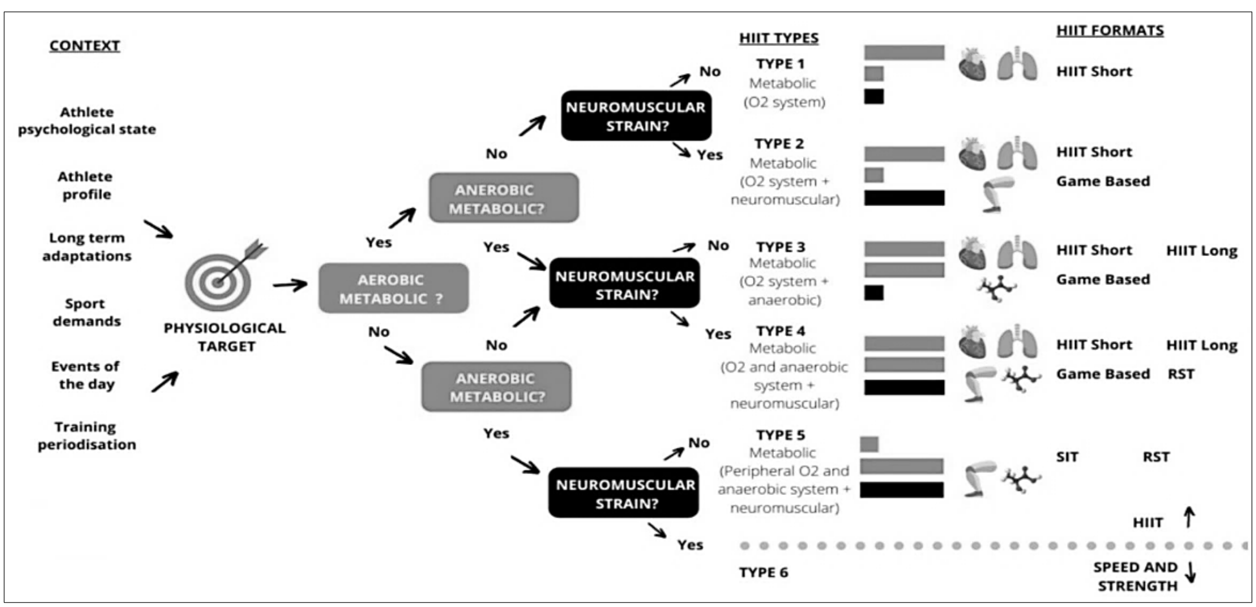

Figure 1. The key figure of HIIT Science. (Laursen & Buchheit, 2019).

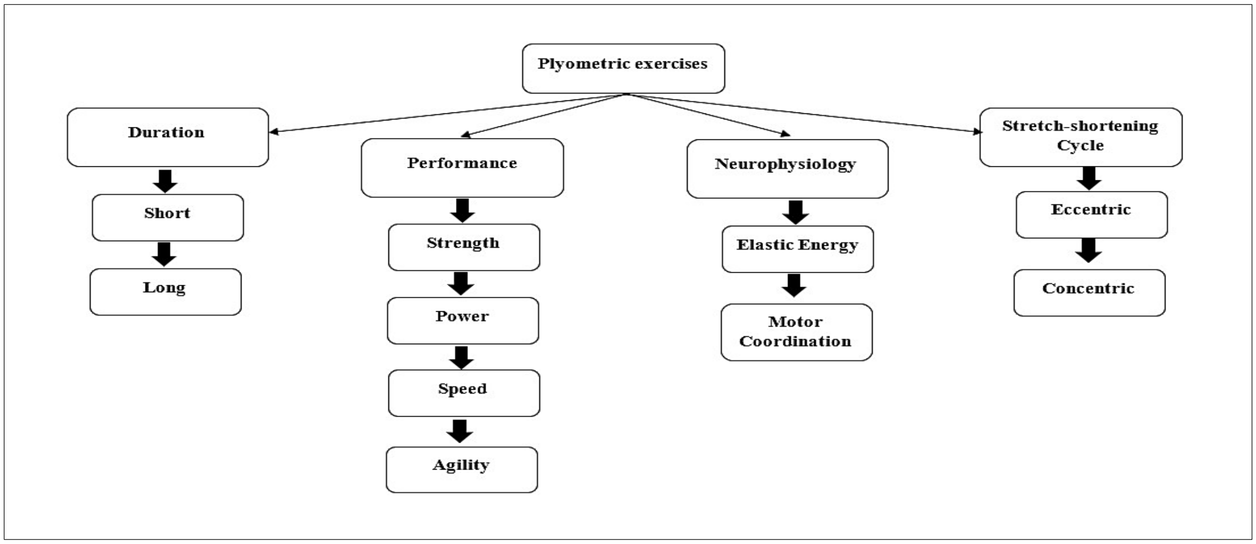

Figure 2. Theoretical framework of plyometric exercises.

MATERIALS AND METHODS

Study area and duration

This study aimed to examine the impact of a 10-week high-intensity interval training (HIIT) program using plyometric exercises on explosive power and agility in U19 football players. Following a quasi-experimental pre-posttest design, the research was conducted over 10 weeks, beginning with the recruitment of participants.

Research design

An experimental randomized pre-test and post-test control group design was employed to test the hypothesis of this study. This design was chosen for its ability to compare the subjects' initial conditions (pre-test) with the outcomes of the post-test after they underwent training. Additionally, this design facilitated the examination of how the independent variable influences the dependent variable. The inclusion of a control group enabled the attribution of differences in post-test results to the treatment itself rather than to extraneous variables.

Participants

The Ethics Committee at the Institute of Science and Technology of Physical and Sports Activities, Mohamed Boudiaf University of M'sila, Algeria, approved the protocol (Date: 15/10/2024). Twenty healthy male soccer players from the G.S.M team were randomly divided into two equal groups (Table 1). A brief medical history was collected from each participant to confirm their eligibility, and none reported any prior surgeries or pain during the testing period.

The study consisted of two groups: a control group (G2) and an experimental group (G1), each comprising 10 participants. The mean ages of the two groups were comparable, with the control group having a mean age of 17.6 years (SD = 0.52) and the treatment group having a mean age of 17.7 years (SD = 0.5), indicating no significant difference. The control group had a mean height of 1.83 cm (SD = 0.055), while the treatment group had a slightly lower mean height of 1.80 cm (SD = 0.3). In terms of body weight, the control group had a mean weight of 73.5 kg (SD = 4.9), which was slightly higher than the treatment group's mean weight of

70.9 kg (SD = 6.6). However, the body mass index (BMI) values of the two groups were similar, with mean BMI values of 23.20 (SD = 4.07) and 22.27 (SD = 2.94) for the control and treatment groups, respectively. This similarity in BMI suggests that the weight difference between the two groups may not be accompanied by a significant difference in body composition when height is taken into account.

Overall, these features suggest that the control and experimental groups are comparable in age and physical attributes, supporting the conclusion that there is no significant difference between them as indicated by the study's results.

Table 1. Participants Characteristics (Mean ± SD)

Variables	**Control (G2)**	**PT (G1)**
	10 players	10 players
Age	17.6 ± 0.52	17.70 ± 0.5
Height (cm)	1.83 ± 0.055	1.80 ± 0.3
Weight (Kg)	73.5 ± 4.9	70.9 ± 6.6
BMI	23.20 ± 4.07	22.27 ± 2.94

Procedure

The study was conducted during the winter of the 2024/2025 competitive season, with a 10-week training program that included technical, tactical, and high-intensity interval training program (HIIT) using plyometric exercises. Each testing session began with a 5-minute conventional run, followed by 10 minutes of body-weight strength and flexibility exercises, 2 minutes of dynamic stretching, and a 5-minute sprint-specific warm-up. There was a 5 to 10-minute break between tests, with each test consisting of three trials per participant, recording the best results. Participants tested outdoors on a synthetic turf field, dressed in their usual training attire and soccer boots. Throughout the study, subjects participated in 3 to 5 soccer training sessions per week, each lasting 90 to 105 minutes. The program training took place once a week for 90 minutes, including a 30-minute warm-up, 30 to 40 minutes of HIIT with plyometric exercises, and 20 to 25 minutes of stretching.

Measures

Squat jump

The Squat Jump (SJ) test is primarily used to assess an athlete's explosive lower-body power, which is an indicator of speed-strength ability. It is often combined with the Countermovement Jump (CMJ), leveraging the stretch-shortening cycle, where muscles are pre-stretched before contracting for the jump. There are two common SJ test variations: the Static SJ and the Dynamic SJ. The Static SJ requires the athlete to hold a flexed semi-squat position for a few seconds before initiating the jump. (Endab, 2024)

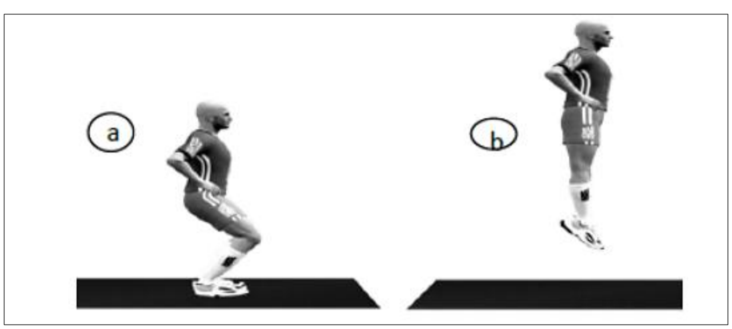

Figure 3. How to perform the Squat jump test.

Participants initiated the Squat Jump with their knees at a 90-degree angle, avoiding any downward movement, and performed a vertical jump with straight legs. They rested for one minute between three trials, with the highest jump recorded for analysis.

Agility T-test

The Agility T-Test was conducted on a 10m x 10m area. Participants began at the central cone and, upon hearing the "*go*" command, sprinted forward to it. They then moved sideways 5m to the right cone, sprinted 10m to the far-left cone, returned to the right cone, and finally backpedalled to the finish line (Bin Shamshuddin et al., 2020). A stopwatch (Skmei) was started when the participant began and stopped when they crossed the finish line. Completion times were recorded in seconds.

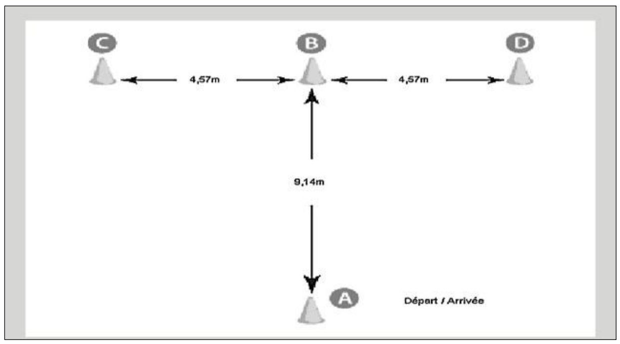

Figure 4. How to perform the T-agility test.

Kinovea two-dimensional motion analysis software

The use of Kinovea version 0.8, an advanced 2D motion analysis tool, greatly improved the post-acquisition phase of the study. This software facilitated a detailed analysis of player movements captured on video. By calibrating the optical jump bar to 90 cm, Kinovea was used to assess jump distance and flight time. This calibration, combined with the software's advanced features, enabled precise calculations of jump height and flight time, allowing for accurate evaluations of the participants' movements.

All jumps were filmed using a Realme 8 phone camera positioned 4 meters from the side of the athlete, as shown in Figure 1. Vertical jump performance was assessed using Kinovea software (Boston, MA, USA). Data were collected at a multi-sports stadium in M'sila Province, Algeria, by researchers from the MLC Laboratory.

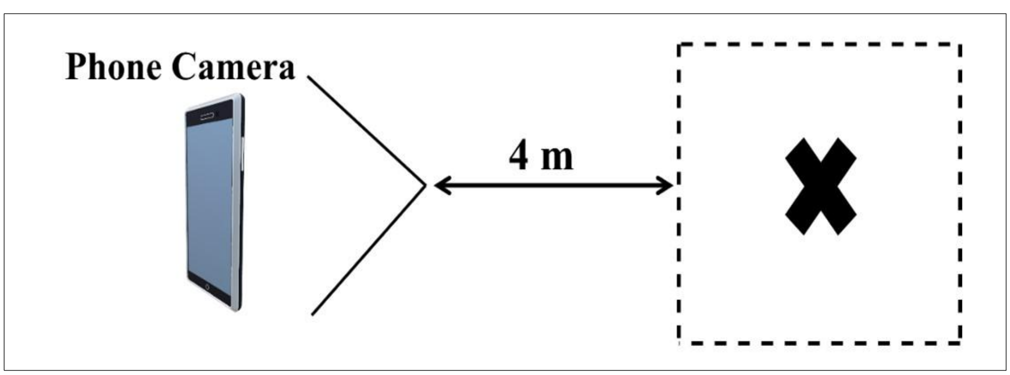

Figure 5. Distance measurements for phone camera setups in video capture.

The high-intensity interval training program with plyometric exercises

Both groups underwent regular soccer training for 10 weeks, which focused on fast footwork, technical skills, positional games (both small and large), as well as offensive and defensive 1 vs. 1 drill, and tactical games with different objectives. The experimental group incorporated high-intensity interval training (HIIT) and plyometric exercises into their routine, replacing a portion of the standard soccer training immediately after the regular sessions (Table 2-3).

Table 2. The high intensity interval training program for experimental group.

Week	Duration	Recovery	Intensity	%Heart Rate
Week 01	2 × 10s	10s	Low	70-75%
Week 02	2 × 15s	10s	Low	75-80%
Week (03+04)	3 × 10s	10s	Medium	80-85%
Week (05+06)	4 × 15s	10s	Medium	85%
Week (07+08)	4 × 20s	10s	High	90%
Week 09	4 × 25s	10s	High	95%
Week 10	4 × 30s	10s	High	100%

Note. *HR: Heart rate. *Duration: Sets x Time.

Table 3. The plyometric exercises for experimental group.

Weeks	Plyometric exercises							
	Squat jump		Side jump		Countermovement jump		Double bound leg jump	
	Rep	Sets	Rep	Sets	Rep	Sets	Rep	Sets
Week 01	06	02	06	02	06	02	06	02
Week 02	06	02	06	02	06	02	06	02
Week 03	08	02	08	02	08	02	08	02
Week 04	08	02	08	02	08	02	08	02
Week 05	06	03	06	03	06	03	06	03
Week 06	06	03	06	03	06	03	06	03
Week 07	08	03	08	03	08	03	08	03
Week 08	08	03	08	03	08	03	08	03
Week 09	06	04	06	04	06	04	06	04
Week 10	06	04	06	04	06	04	06	04

Analysis

Data are expressed as mean ± SD. A two-way repeated-measures analysis of variance (ANOVA) was conducted to evaluate the main effects of time and group (HIITG vs. CG) between baseline and post-intervention assessments. Changes over time in the HIITG were analysed using an ANOVA with repeated measures for all variables, which indicated significant time effects in the 2 × 2 ANOVA. To compare baseline and post-intervention results within each group, paired sample t-tests were performed to assess differences between pre-test and post-test for both the HIITG and CG groups. The significance level was set at $\alpha = .05$. All statistical analyses were performed using PASW Statistics version 25.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Normality of distribution

The normality test results detailed in Table 4 examine the distribution of data for the Squat Jump and T-agility test before and after the intervention in both experimental (EG) and control groups (CG).

For the Squat Jump, the Shapiro-Wilk test indicates a normal distribution in pre-intervention measurements, with the EG scoring 0.884 (p = .146) and CG scoring 0.821 (p = .126). Both p-values exceed the .05 threshold, suggesting that there is no significant deviation from normality. Post-intervention results show improved normality for the EG (0.960, p = .781) and a slightly lower statistic for CG (0.878, p = .125), yet all p-values remain above .05, confirming sustained normality. The T-agility test results mirror these findings, indicating normality in pre-intervention results with the EG at 0.926 (p = .411) and CG at 0.977 (p = .944). Post-intervention, the EG scored 0.948 (p = .641) while the CG scored 0.979 (p = .958), with all p-values again greater than .05, reinforcing the conclusion of normal distribution. Finally, the Shapiro-Wilk test results support the notion that data from both the Squat Jump and T-agility tests conform to normality assumptions in both the pre- and post-test phases for all groups. This finding is vital for justifying the application of parametric statistical methods in evaluating the intervention's effects.

Table 4. Normality test.

Variables	**Test**	**Shapiro-Wilk**			
		Statistic		Significant	
		EG	CG	EG	CG
Squat Jump	Pre	0.884	0.821	0.146	0.126
	Post	0.960	0.878	0.781	0.125
T-agility test	Pre	0.926	0.977	0.411	0.944
	Post	0.948	0.979	0.641	0.958

Validity and reliability

Table 5 presents the reliability and validity outcomes for the squat jump test (SJ) and the T-agility test among under-17 football players. The squat jump test exhibited moderate reliability with a coefficient of 0.608 and a strong Pearson correlation of 0.779 (p < .001), suggesting that it possesses significant reliability and validity. In contrast, the T-agility test demonstrated exceptional reliability, indicated by a coefficient of 0.994 and a nearly perfect Pearson correlation of 0.996 (p < .001), confirming its high reliability and validity. These findings underscore the robust psychometric properties of both tests.

Table 5. Reliability and validity of the SJ and T-agility test among retired physical education teachers.

Variables	**Reliability**		**Validity**
	Pearson correlation	Sig	$\sqrt{\boldsymbol{reability}}$
Squat Jump	0.608	.000	0.779
T-agility test	0.994	.000	0.996

Paired Sample t-Test examination of explosive power and agility performance among both group

Table 6 summarizes the results of a paired-sample t-test comparing pre- and post-performance metrics for vertical and horizontal jumps in both the experimental group (EG) and control group (CG). The experimental group showed significant improvements in several key areas: flight time, jump height, and T-agility test scores. Specifically, flight time increased from a mean of 0.006 seconds (SD = 0.004) before the intervention to 0.014 seconds (SD = 0.006) afterward, with a significant t-statistic of -9.204 (df = 9, p = .004). Jump height also rose notably from a mean of 0.130 meters (SD = 0.107) pre-test to 0.327 meters (SD = 0.097) post-test, resulting in a highly significant t-statistic of -9.978 (df = 9, p < .000). Furthermore, T-agility scores improved, decreasing from 6.549 seconds (SD = 0.099) to 6.013 seconds (SD = 0.085), with a significant t-statistic of 4.960 (df = 9, p = .0003). In contrast, the control group did not demonstrate any significant changes in the measured performance metrics. The standing jump showed minimal variation, with means of 0.322 meters (SD = 0.113) pre-test and 0.310 meters (SD = 0.111) post-test (t = -1.198, df = 9, p = .261). Flight times remained relatively stable, reported at 0.012 seconds (SD = 0.007) pre-test and 0.010 seconds (SD = 0.005) post-test (t = -9.204, df = 9, *p* = .515). Height measurements similarly indicated no significant change, with means of 0.230 meters (SD = 0.098) pre-test and 0.200 meters (SD = 0.063) post-test (t = -9.978, df = 9, *p* = .132). Lastly, the control group's T-agility test scores slightly worsened from 6.213 seconds (SD = 0.049) to 6.500 seconds (SD = 0.051), but this difference was not statistically significant (t = -5.085, df = 9, *p* = .102).

Table 6. Conduct paired-sample t-test to compare the pre- and post-performance of vertical jump and agility test in the experimental and control groups.

Groups	Variables	Test	Statistic	Paired-sample t-test		
			Mean ± SD	t-value	df	Sig
EG	SJ (m)	Pre	0.318 ± 0.073	-3.163	09	.012
		Post	0.332 ± 0.073		09	
	Flight time (s)	Pre	0.006 ± 0.004	-9.204	09	.004
		Post	0.014 ± 0.006		09	
	Height (m)	Pre	0.130 ± 0.107	-9.978	09	.000
		Post	0.327 ± 0.097		09	
	T-agility test (s)	Pre	6.549 ± 0.099	4.960	09	.000
		Post	6.013 ± 0.085		09	
CG	SJ (m)	Pre	0.322 ± 0.113	-1.198	09	.261
		Post	0.310 ± 0.111		09	
	Flight time (s)	Pre	0.012 ± 0.007	-9.204	09	.515
		Post	0.010 ± 0.005		09	
	Height (m)	Pre	0.230 ± 0.098	-9.978	09	.132
		Post	0.200 ± 0.063		09	
	T-agility test (s)	Pre	6.213 ± 0.049	-5.085	09	.102
		Post	6.500 ± 0.051		09	

Note. Statistical decision: EG: there are statistically significant differences; CG: there are no statistically significant differences.

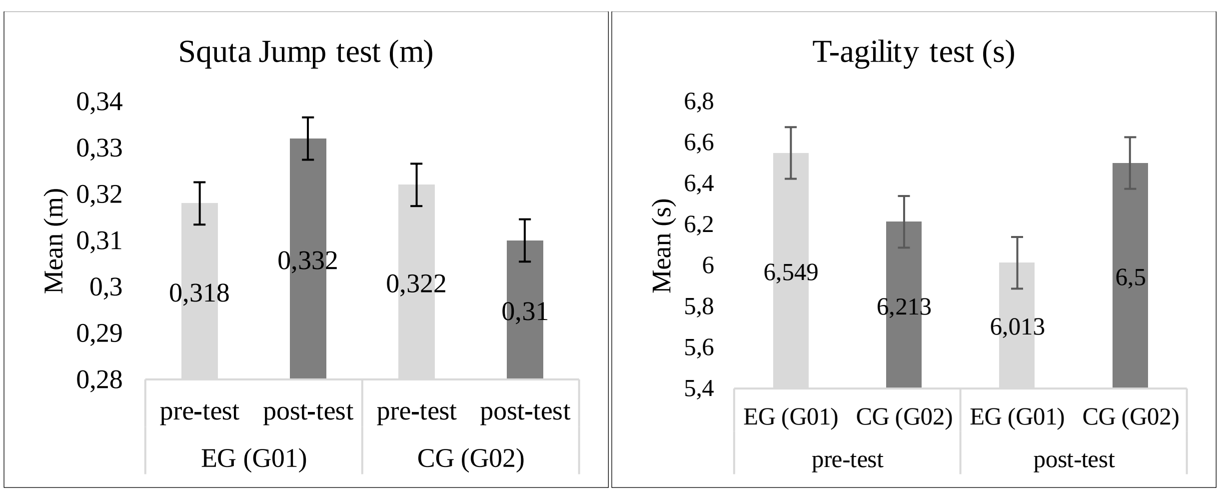

Figure 6. Comparison of pre- and post-test results of squat jump and agility tests for both groups.

In conclusion, the analysis indicates that the experimental group achieved significant enhancements in jump performance and agility following the intervention, while the control group exhibited no meaningful changes. This highlights the effectiveness of the experimental approach implemented in this study.

Two-Way ANOVA test for examining differences in explosive power and agility performance

This study examined the effects of a 10-week training program on vertical jump performance and agility in both experimental and control groups. Table 7 and Figure 7 after analysis of variance (ANOVA) revealed a significant interaction effect between group and time for squat jump performance (p = .003), showing that the experimental group improved their squat jump height from 0.318 ± 0.073 cm to 0.332 ± 0.073 cm, while the control group experienced a negligible change (0.322 ± 0.113 cm to 0.310 ± 0.111 cm). The experimental group also demonstrated a significant increase in flight time (p = .001), indicating enhanced explosiveness, with flight times rising from 0.006 ± 0.004 s to 0.014 ± 0.006 s. Additionally, vertical jump height improved significantly (p = .016) from 0.130 ± 0.107 cm to 0.327 ± 0.097 cm.

In terms of agility, the experimental group improved their T-agility test time from 6.549 ± 0.099 s to 6.013 ± 0.085 s, while the control group's time increased slightly from 6.213 ± 0.049 s to 6.500 ± 0.051 s. The statistical analysis confirmed this improvement with a p-value of .005, indicating that the experimental group performed better on change of direction tasks post-intervention. In summary, the findings indicate that the experimental group achieved significant enhancements in both vertical jump performance and agility measures compared to the control group, highlighting the effectiveness of the 10-week training program.

Table 7. Comparison of Changes in vertical jumps and change of direction performance between experimental and control groups before and after the 10 weeks.

Performance Tests	**Experimental Group**		**Control Group**		**ANOVA Group x Time interaction**
	Pre	Post	Pre	Post	p-value
Squat Jump (m)	0.318 ± 0.073	0.332 ± 0.073	0.322 ± 0.113	0.310 ± 0.111	.003
Flight time (s)	0.006 ± 0.004	0.014 ± 0.006	0.012 ± 0.007	0.010 ± 0.005	.001
Height Distance (m)	0.130 ± 0.107	0.327 ± 0.097	0.230 ± 0.098	0.200 ± 0.063	.016
T-agility test (s)	6.549 ± 0.099	6.013 ± 0.085	6.213 ± 0.049	6.500 ± 0.051	.005

Note. Statistical decision: There are statistically significant differences.

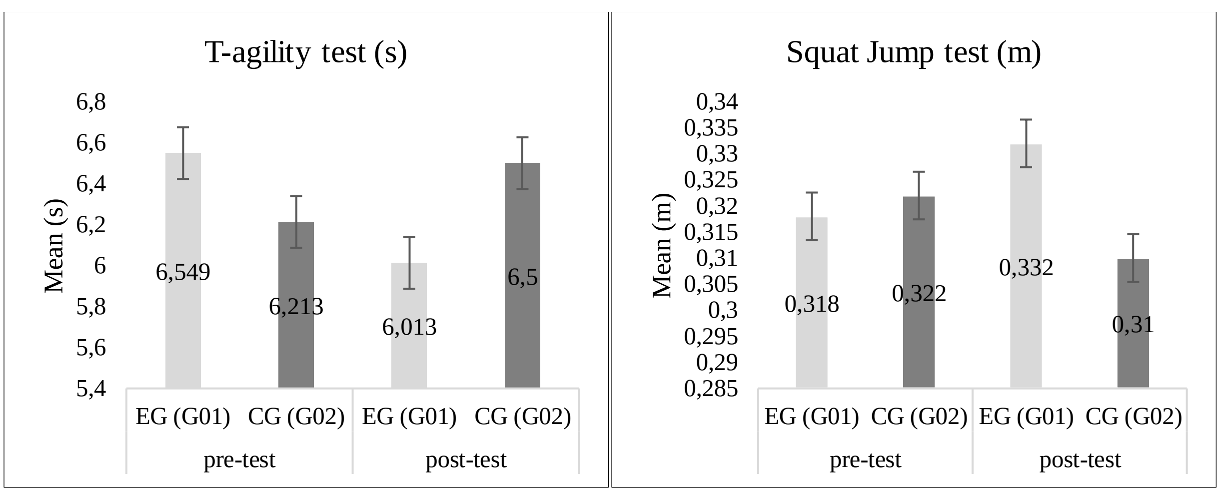

Figure 7. Comparison of the results of both groups (EG-CG) between the pre-test and post-test results in squat jump and agility performance.

DISCUSSION

This research aimed to assess the impact of a HIIT program featuring plyometric exercises on the physical performance of junior soccer players. The results indicate a significant enhancement in both jumping ability and change of direction performance among the intervention group after 10 weeks of HIIT training. Brief training intervals support the effectiveness of HIIT (Gillen et al., 2014), particularly since exercise modalities that engage a higher proportion of muscle fibres—especially Type II motor units—may yield distinct and positive outcomes that warrant further exploration (Farland et al., 2015). The observed improvements in jumping performance can be attributed to the stretch-shortening cycles involved in plyometric training. Existing literature suggests that explosive exercises can effectively enhance power (Fajrin & Kusnanik, 2018); (Chu & Myer, 2013). Additionally, studies have demonstrated that plyometric training on hard surfaces positively impacts jumping abilities (Ramírez-Campillo et al., 2013).

This study emphasizes the significance of high-intensity interval training (HIIT) combined with plyometric exercises to enhance jump efficiency among U19 football players. Players in the intervention group demonstrated superior jump efficiency and change of direction abilities, while control group players exhibited the lowest performance in jumping and agility. The synergistic effect of various plyometric exercises (including squat jumps, lateral jumps, vertical jumps, stride jumps, and hurdle jumps) produced better results than any single exercise alone. Consistent training, particularly focusing on both vertical and horizontal jumps, is crucial for improving jump performance, which is vital during football matches.

Developing maximal strength is essential for enhancing performance. HIIT training, characterized by intense physiological loads similar to those experienced in actual soccer games, typically maintains heart rates at around 85% of HRmax, with peaks reaching 90–95% of HRmax (Rebelo et al., 2014); (Mendez-Villanueva et al., 2013). Consequently, vertical jump performance is closely tied to maximal speed, strength, and explosive strength (Sheppard et al., 2008). Youth soccer players can benefit from supplementary training targeting these abilities (Lloyd & Oliver, 2012), as they lead to improved neuromuscular adaptations, including better coordination and rapid movements, enhancing jumping power. Previous research supports the positive effects of HIIT on jump performance. For instance, Tottori et Fujita (2019) reported a significant 9.6% improvement in standing long jump performance among children aged 9.7 years after a 7-week HIIT program conducted twice weekly (Tottori & Fujita, 2019). Linebach (2014) also found that increased explosive force in the lower limbs from HIIT workouts correlates with enhanced vertical jump performance (BENELGUEMAR et al., 2020). While these findings are promising, direct comparisons with other studies are challenging due to variations in participants' training backgrounds.

The significant increase in maximal power observed in footballers after ten weeks of high-intensity interval training (HIIT) with plyometric exercises can likely be attributed to enhanced drive control, stretch-shortening capacity, and musculoskeletal rigidity resulting from improved explosive strength in the legs (Bin Shamshuddin et al., 2020). Research consistently indicates that varied plyometric frequency training is effective for enhancing leg power (Fajrin & Kusnanik, 2018). This plays a crucial role in the effectiveness of such training programs, as the principle of overload is essential for improving muscular strength. It is important to acknowledge that body weight alone may not provide adequate resistance for optimal standing long jump performance; strength and power are vital components of jump ability (Sheppard et al., 2008).

The intensity of the plyometric exercises utilized in the study likely increased motor unit excitability and led to greater recruitment of fast-twitch muscle fibres, thereby enhancing jump performance. Additionally, plyometric exercises raise muscle temperature, which further amplifies muscle activation and supports the storage and recoil of elastic energy in tendinous tissue (Ishikawa & Komi, 2004). Previous findings suggest that incorporating plyometric training can significantly improve key athletic performance components compared to traditional in-season training for young runners (Chelly et al., 2015). Furthermore, HIIT has been shown to markedly enhance power and performance in team sports (Iacono et al., 2015). Plyometric training over 16 weeks has also demonstrated improvements in power, as evidenced by tests such as the Multiple 5 Bounds and Standing Long Jump Test (Söhnlein et al., 2014). Researchers recommend the continuation of plyometric training to further develop explosive movements in athletes (Hammami et al., 2019). Given its efficacy, plyometric training is particularly relevant for sports requiring explosive jump movements (Söhnlein et al., 2014). When appropriately implemented, this type of training can yield benefits independent of an athlete's initial fitness level. In a related study, a short-term plyometric training program proved advantageous for high school male adolescents (age 16.89 ± 60.85) in enhancing explosive strength (SJ-testing). Plyometric exercises are widely recognized for their ability to improve explosive power (Ramírez-Campillo et al., 2013). Moreover, plyometric training is advantageous as it requires minimal space, time, and equipment. However, several studies have yet to definitively determine the optimal design for plyometric training, including considerations of frequency, volume, and landing height, to maximize muscle power enhancement (Ramírez-Campillo et al., 2013); (de Villarreal et al., 2009).

The current study highlights the significant enhancement in agility performance following a high-intensity interval training (HIIT) program that incorporated plyometric exercises in U19 football players. According to Cochrane et al. (2004), agility is primarily influenced by rapid movements, with power and strength playing a minimal role (Cochrane et al., 2004). Our findings support the hypothesis that plyometric exercises can effectively improve agility metrics. This is consistent with previous research indicating that HIIT programs featuring plyometric exercises result in improved agility times, as documented by (Chiu et al., 2004).

Plyometric exercises are widely utilized to boost explosive actions in soccer, offering the advantage of easy integration into training sessions due to their minimal spatial and equipment requirements. They also mimic the neuromuscular demands present in essential soccer activities such as sprinting, jumping, and changing direction (Gehri et al., 1998). Prior studies have shown that high-intensity plyometric exercises, like drop jumps, are safe and effective for young athletes, as noted by (Ramírez-Campillo et al., 2013); (Thomas et al., 2009). Improvements in power development, reactive strength, and eccentric strength likely contributed to enhanced agility performance (Randell et al., 2010); (Sheppard & Young, 2006). Although acceleration may depend more on a slower stretch-shortening cycle and the rate of power production, Thomas et al. (2009) found that sprint times remained unchanged even as agility improved by 9% over six weeks of plyometric training in semi-professional adolescent soccer players (Thomas et al., 2009). In children, a study by Meylan and Malatesta (2009) recorded a 10% enhancement in agility after eight weeks of plyometric training (Meylan & Malatesta, 2009). Miller et al. (2006) also reported improvements of 5% and 3% in the T-agility and Illinois agility tests, respectively, after six weeks of plyometric training (Miller et al., 2006). The research by bin Shamshuddin MH et al. (2020) further indicated that six weeks of plyometric training enhanced agility in recreational football players, with significant improvements observed in the intervention group (p < .05) while the control group's agility remained largely unchanged (Bin Shamshuddin et al., 2020). This study demonstrated a reduction in time for the T-test agility, supporting the notion that plyometric training can positively influence agility. While fewer studies have focused on the effects of plyometric training on individual endurance, the evidence supporting its impact on agility remains strong. Notably, Thomas et al (2009) documented a significant improvement in agility in semi-professional adolescent footballers after six weeks of plyometric training, despite no change in sprint performance (Thomas et al., 2009).

In summary, the 10-week HIIT program focused on jumping exercises for U19 soccer players led to notable improvements in explosive power and change of direction performance. While both high plyometric volume and a hard training surface positively influenced jump and agility outcomes, it was primarily the combination of high-volume training on a hard surface that enhanced jumping ability and directional changes after intense exercise, demonstrating its effectiveness for performance gains. Conversely, excessive training volume or the use of harder surfaces may hinder adaptations in maximum jump height or pure concentric strength (e.g., squat jump) when fast stretch-shortening cycle (SSC) actions are involved.

CONCLUSION

The HIIT (High-Intensity Interval Training) program was consistently scheduled weekly for all participants, ensuring homogeneity in terms of academic commitments and eliminating bias related to training timing or variations in regimens. This study demonstrates that a well-structured exercise program, grounded in scientific principles, can significantly enhance key physical components. The commitment to effectively executing the training program is crucial for maintaining its success.

The findings reveal improvements in explosive strength and agility performance after a 10-week HIIT regimen that incorporated plyometric exercises among U19 football players. These attributes—explosiveness and agility—are critical for enhancing athletic performance in sports. It is also important to explore varying intensities and volumes within the HIIT framework to identify the optimal conditions for training. This can assist coaches and physical trainers in planning effective training sessions over the 10-week period, as established in this study. Overall, these results offer valuable insights for refining training routines, aimed at boosting players' explosive power and agility before competitive matches.

Practical application

This research highlights that a High Intensity Interval Training (HIIT) program incorporating plyometric exercises is crafted with a scientific foundation and rigorously implemented. It serves as a crucial element of training for elite football players, with evidence supporting its effectiveness in enhancing explosive power and agility. Consequently, integrating this combined training regimen can enhance players' performance during matches while also reducing the risk of injuries.

To sustain the interest of young athletes, it is important to frequently modify and update the workouts. This approach will keep athletes engaged and motivated to adopt effective training methods.

AUTHOR CONTRIBUTIONS

This study was conducted by a group of researchers from the laboratory of motor learning and control, Institute of Sciences and Techniques of Physical and Sports Activities, Mohamed Boudiaf University, Algeria; composed of:

Laidi Abderrahim: The study utilized the Statistical Package for the Social Sciences (SPSS) to address specific research questions. We significantly contributed to the design of physical tests as well as the acquisition, analysis, and interpretation of data. The original research team was responsible for preparing and presenting the findings, which included reviewing and discussing revisions. Our approach involved comprehensive data collection and analysis using statistical techniques, with a focus on effective data presentation. We collectively agree to take responsibility for all aspects of this research, ensuring the accuracy and integrity of the work.

Djerioui Makhlouf: The study utilized the Statistical Package for the Social Sciences (SPSS) to address specific research questions. We significantly contributed to the design of physical tests as well as the acquisition, analysis, and interpretation of data. The original research team was responsible for preparing and presenting the findings, which included reviewing and discussing revisions. Our approach involved comprehensive data collection and analysis using statistical techniques, with a focus on effective data presentation. We collectively agree to take responsibility for all aspects of this research, ensuring the accuracy and integrity of the work.

Saadaoui Fayssal: The study utilized the Statistical Package for the Social Sciences (SPSS) to address specific research questions. We significantly contributed to the design of physical tests as well as the acquisition, analysis, and interpretation of data. The original research team was responsible for preparing and presenting the findings, which included reviewing and discussing revisions. Our approach involved comprehensive data collection and analysis using statistical techniques, with a focus on effective data presentation. We collectively agree to take responsibility for all aspects of this research, ensuring the accuracy and integrity of the work.

Khalil Bourenane: The study utilized the Statistical Package for the Social Sciences (SPSS) to address specific research questions. We significantly contributed to the design of physical tests as well as the acquisition, analysis, and interpretation of data. The original research team was responsible for preparing and presenting the findings, which included reviewing and discussing revisions. Our approach involved comprehensive data collection and analysis using statistical techniques, with a focus on effective data presentation. We collectively agree to take responsibility for all aspects of this research, ensuring the accuracy and integrity of the work.

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No potential conflict of interest was reported by the authors.

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