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RESEARCH ARTICLE / ARAŞTIRMA MAKALESI

Running Momentum as a Potential Complement to Aerobic Speed in Evaluating Performance in Male Football Players

Erkek Futbolcularda Performansın Değerlendirilmesinde Aerobik Hıza Tamamlayıcı Bir Ölçüt Olarak Koşu Momentumu

Fahri Safa Cinarli[1], Caner Aygoren[2], Aytek Hikmet Guler[3], Cíntia França[4,5], Élvio Rúbio Gouveia[4,5], Monira Aldhahi[6]

[1]*Faculty of Sport Sciences, Inonu University, Malatya, Türkiye*
[2]*Health Sciences Institute, Munzur University, Tunceli, Türkiye*
[3]*Beşiktaş Football Club, İstanbul, Türkiye*
[4]*Department of Physical Education and Sport, University of Madeira, Funchal, Portugal*
[5]*LARSyS, Interactive Technologies Institute, 9020-105 Funchal, Portugal*
[6]*Department of Rehabilitation Sciences, College of Health and Rehabilitation Sciences, Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia*

ABSTRACT

Objective: This study aimed to investigate the relationship between commonly observed performance variables in football and aerobic-based test outcomes, with a particular focus on the role of running momentum as a complementary measure.

Materials and Methods: Sixteen elite youth male football players (age:17.88 ± 0.61 years) were assessed for acceleration, agility, lower limb one-repetition maximum (1-RM) strength, and estimated VO_2max. Correlation and regression analyses examined the relationships between final running velocity, running momentum, and key performance indicators.

Results: Final running velocity correlated positively with acceleration (r = 0.55, p < 0.05) and VO_2max (r = 0.78, p < 0.001), and negatively with agility time (r = -0.67, p < 0.05), while no significant association was found with leg press strength (r = 0.43, p > 0.05). In contrast, running momentum displayed large positive correlations with acceleration (r = 0.70, p < 0.01) and leg press strength (r = 0.78, p < 0.01), and a strong negative correlation with agility time (r = -0.78, p < 0.01). Regression analyses showed that VO_2max was the strongest outcome explained by running velocity, accounting for 60% of its variance, while momentum explained 28%. Furthermore, velocity accounted for 19-44% of the variance in acceleration, agility, and strength outcomes, whereas momentum explained 52-61%.

Conclusions: Running momentum demonstrated stronger associations with agility, leg press strength, and acceleration, while final running velocity was more closely related to VO_2max. These findings suggest that running momentum serves as a complementary and strength-oriented indicator to aerobic speed in evaluating the neuromuscular and mechanical performance of youth football players.

Keywords: Acceleration, athletic performance, football, oxygen consumption, running

ÖZ

Amaç: Bu çalışma, futbolda sık gözlenen performans değişkenlerinin aerobik temelli test sonuçlarıyla ilişkisini incelemeyi ve özellikle tamamlayıcı bir ölçüt olarak koşu momentumunun rolünü araştırmayı amaçladı.

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Correspondence: Fahri Safa Çınarlı · Faculty of Sport Sciences, Inonu University, Malatya, Türkiye · safa.cinarli@inonu.edu.tr

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n ve regresyon analizleriyle incelendi.

Bulgular: Son koşu hızı; hızlanma ($r = 0.55$, $p < 0.05$) ve VO_2max ($r = 0.78$, $p < 0.001$) ile pozitif, çeviklik süresi ile negatif ($r = -0.67$, $p < 0.05$) ilişkili bulundu; ancak alt ekstremite 1-RM kuvveti ile anlamlı bir ilişki saptanmadı ($r = 0.43$, $p > 0.05$). Buna karşılık koşu momentumu, hızlanma ($r = 0.70$, $p < 0.01$) ve alt ekstremite 1-RM kuvveti ($r = 0.78$, $p < 0.01$) ile güçlü pozitif, çeviklik süresi ile güçlü negatif ($r = -0.78$, $p < 0.01$) ilişkiler gösterdi. Regresyon analizleri, VO_2max'ın son koşu hızındaki varyansın %60'ını, momentumun ise %28'ini açıkladığını ortaya koydu. Ayrıca, son koşu hızı hızlanma, çeviklik ve kuvvet varyansının %19-44'ünü; momentum ise %52-61'ini açıkladı.

Sonuç: Koşu momentumu, çeviklik, bacak itme kuvveti ve ivmelenme ile daha güçlü ilişkiler göstermiştir; buna karşılık, son koşu hızı VO_2max ile daha yakından ilişkilidir. Bu bulgular, koşu momentumunun genç futbolcuların nöromüsküler ve mekanik performansını değerlendirmede aerobik hıza tamamlayıcı ve kuvvet odaklı bir gösterge olarak hizmet edebileceğini göstermektedir.

Anahtar Sözcükler: Hızlanma, atletik performans, futbol, oksijen tüketimi, koşu

INTRODUCTION

Maximal aerobic speed is defined as the lowest running velocity at which maximal oxygen uptake occurs or the oxygen consumption plateau is reached [1]. A higher maximal aerobic speed indicates an enhanced capacity to sustain physical activity effort over prolonged periods. While numerous treadmill-based protocols exist for determining maximal aerobic speed, the cardiopulmonary exercise test remains the gold standard [2,3]. However, its practical application is often limited owing to the requirement of specialized equipment and expertise. Consequently, indirect field-based methods have been developed to estimate maximal aerobic speed, among which the 30-15 Intermittent Fitness Test ($30\text{-}15_{IFT}$) is widely utilized [4].

The $30\text{-}15_{IFT}$ is a graded, intermittent, shuttle-based test designed to assess an individual's ability to sustain high-intensity intermittent running [5]. It has demonstrated excellent test-retest reliability, with intraclass correlation coefficients ranging from 0.80 to 0.99 for maximal velocity and from 0.90 to 0.97 for peak heart rate across various populations [6]. Furthermore, the $30\text{-}15_{IFT}$ has shown strong criterion validity compared to laboratory-based continuous treadmill tests, with large to very large correlations observed for maximal oxygen uptake, end-running velocity, and maximal heart rate [7]. A change as small as 1.0 km/h (two stages) in $30\text{-}15_{IFT}$ end-running velocity is considered both practically meaningful and statistically significant, as it exceeds the test's typical error (TE = 0.56 km/h) and represents a real improvement beyond measurement variability [7]. Additionally, a high correlation between V_{IFT} and maximal oxygen uptake has been observed in football players, reinforcing its applicability in team sports [8]. Several studies suggest that $30\text{-}15_{IFT}$ effectively estimates maximal aerobic speed and monitors aerobic fitness adaptations in athletes [9]. Athletes with superior VO_2max can maintain higher terminal speeds over longer durations due to better metabolic efficiency and fatigue resistance [10].

However, the accuracy of $30\text{-}15_{IFT}$ in determining maximal aerobic speed has been a subject of debate. The velocity IFT (V_{IFT}) may not perfectly reflect the maximal aerobic speed because of the multicomponent nature of intermittent running [11]. Physiologically, the test elicits a composite demand for aerobic (67%) and anaerobic (30%) energy systems, while the neuromuscular system is constantly challenged by repeated accelerations, decelerations, and changes in direction [12,13]. A key concern regarding using $30\text{-}15_{IFT}$ for estimating maximal aerobic speed is that it does not inherently account for individual physical characteristics, such as body mass, which could lead to potential inaccuracies in interpretation [14].

Indeed, the literature has reported that body mass is a crucial performance determinant, particularly for athletes in the developmental phase. For instance, in a professional rugby academy, V_{IFT} values remained relatively stable across age groups (U16 to senior), whereas body mass increased continuously [15]. Consistent with recent findings, running momentum in academy-level rugby players has been shown to be strongly associated that a 1 kg increase in body mass corresponds to approximately 5-6 kg·m/s increase in momentum, while a 1 m/s improvement in sprint speed results in more than 100 kg·m/s increase in momentum among backline players, confirming the sensitivity of momentum to both anthropometric and kinematic changes [17]. Similarly, in a four-year monitoring of elite male football players, sprint velocity fluctuated annually, whereas momentum consistently increased ($p < 0.01$) [18]. These findings highlight the necessity of incorporating body mass into performance assessments to better contextualize maximal aerobic speed in developing athletes. By normalizing V_{IFT} with body mass, the final running momentum may serve as a more individualized and insightful performance indicator, particularly during the early stages of sports development.

Physical performance characteristics, such as linear sprinting ability, agility, and lower limb strength, are considered crucial determinants of athletic success, including injury prevention [19]. Despite the existing evidence, little is known about how running momentum relates to football-specific performance metrics. Moreover, examining these relationships in young male football players may provide novel insights into age-specific performance profiles and could offer practical implications for individualized training and talent identification.

Therefore, this study investigated the associations between V_{IFT}, momentum IFT, and hybrid performance variables, specifically linear sprint performance, agility, and lower limb strength, in young male football players. Based on key studies [12,15, 16], it was hypothesized that maximal aerobic speed and running momentum would be positively associated with key performance determinants, such as speed (acceleration), lower limb strength, and aerobic capacity, and negatively associated with agility time in young male football players.

MATERIAL AND METHODS

Study Design

This is a cross-sectional study. Data were collected during a preparatory training camp to ensure a controlled and standardized testing environment. All the study procedures strictly adhered to the ethical principles outlined in the Declaration of Helsinki. The approval for this study was obtained from Ethics Committee for Clinical Research at Inonu University, (Decision no: 2023/2296, Date: 14/12/2023), ensuring that all participants' rights, safety, and well-being were upheld throughout the research process. Participation in this study was voluntary, and informed consent was obtained from all players and their respective legal guardians.

Participants

Participants in this study were 16 elite youth football players (age: 17.88 ± 0.61 years) competing at the national level. All participants were trained five times weekly and competed in an official match on the weekend. Their regular training program included technical-tactical sessions combined with strength and conditioning work. A priori power analysis was conducted using G*Power v3.1, indicating that a minimum sample size of 16 participants was required to achieve 85% power (two-tailed, $\alpha = 0.05$) for detecting a correlation effect size (r) of 0.632, based on a previously reported association [5]. Inclusion criteria required participants to be within the specified age range, healthy, actively engaged in competitive football training, and have at least five years of competitive football experience. Exclusion criteria included any existing injuries or medical conditions affecting test performance, fewer than five years of structured football training, or the self-reported use of performance-enhancing substances that could alter physiological outcomes.

Testing Procedures

All assessments were carried out in an indoor sports performance laboratory to ensure standardized testing conditions. The ambient temperature was maintained between 21°C and 23°C, and relative humidity between 45% and 55%. Participants were instructed to refrain from strenuous exercise, caffeine, and alcohol consumption for at least 24 hours before testing and to maintain their usual sleep routines. All tests were performed between 9:00 a.m. and 12:00 p.m. to minimize circadian variations in performance. Before data collection, each participant completed a standardized warm-up protocol consisting of 5 minutes of light jogging, dynamic stretching, and three progressive 20-meter acceleration runs. A brief familiarization period was provided to ensure that all players understood the testing procedures and could perform each test with proper technique.

To minimize fatigue effects, all performance tests were conducted on the same day in a standardized sequence: (1) 10-m sprint test, (2) T-test for agility, (3) leg-press 1RM strength test, and (4) 30-15_{IFT}. A passive recovery period of 5 minutes was provided between each test, and up to 10 minutes of rest before the 30-15 IFT to ensure full recovery. The testing sequence and rest intervals were identical for all participants and supervised by the same researcher to ensure procedural consistency and reproducibility.

Anthropometric Measurements

Prior to the performance tests, body height and body mass were measured using a calibrated stadiometer and digital scale (Seca, Germany). Measurements were taken with participants wearing light clothing and no shoes, and recorded to the nearest 0.1 cm and 0.1 kg, respectively. These anthropometric data were used in the calculation of running momentum and VO_2max according to the established equations described in the following subsection.

Aerobic Capacity Test

The 30-15 Intermittent Fitness Test (IFT) was administered to assess intermittent aerobic fitness in the athletes. The 30-15_{IFT} is a highly reliable and valid method for estimating maximal aerobic speed, with reported intraclass correlation coefficients exceeding 0.90 [5]. The test involves 30-second exercise intervals followed by 15 s of walking recovery, with the running speed progressively increasing until volitional exhaustion. Participants run back and forth on a 40-meter course, paced by audio signals. The test continued until the participant could no longer keep up at the required pace.

Cones were placed at every 5-meter interval along the 40-meter running area to define turning zones. An official 30-15 IFT audio file was played through portable loudspeakers to control running pace and recovery intervals. The audio signal automatically indicated each 30-second running phase and 15-second recovery period, with the speed increasing by 0.5 $km \cdot h^{-1}$ per stage. Timing and stage control were managed using a digital stopwatch and the pacing signal itself, ensuring identical conditions for all participants. The test was terminated when a participant failed twice consecutively to reach the designated line in synchrony with the audio signal. The final running velocity achieved during the test was considered the end-test velocity. Momentum was calculated by multiplying the athlete's body mass with their final running velocity, reflecting the combined effect of speed and mass on movement force (Formula 1). Additionally, VO_2max was estimated based on the performance of the 30-15_{IFT} (Formula 2). Normative values for male soccer players are reported to lie between approximately 48 and 62 $ml \cdot kg^{-1} \cdot min^{-1}$ in the literature, depending on age and competitive level [20].

Formula 1: Final running momentum ($kg \cdot m \cdot s^{-1}$) = V_{IFT} ($m \cdot s^{-1}$) × body weight (kg).

Formula 2: VO_2max ($ml.kg^{-1}.min^{-1}$) = 28.3 − (2.15 × 1) - (0.741 × age) - (0.0357 × body weight) + (0.0586 × age × V_{IFT} + (1.03 × V_{IFT}) [11].

Speed Test

The 10-meter sprint evaluated players' ability to rapidly increase their speed over a short distance. The testing procedure was conducted according to a previously established sprint assessment protocol [19]. Participants started from a stationary position behind the start line, and the timing began when they initiated movement. The subjects sprinted as quickly as possible over a distance of 10 m. Time was recorded using a Smart Speed electronic timing gate system (Fusion Sport, Brisbane, Australia). Each participant performed three trials, with a 90-second passive recovery period between each trial to minimize fatigue. The best performance (i.e., the fastest time) was selected for the analysis.

Agility Test

The T-test assessed players' ability to change direction rapidly while maintaining control over their movement. This test has been shown to have high reliability (ICC = 0.98) and validity in measuring agility in physically active young adults [21]. The test involves sprinting from a starting point 9.14 meters forward to a cone, then side shuffling 4.57 meters to the left, then 9.14 meters to the right, followed by another side shuffle back to the center cone, and finally backpedaling 9.14 meters to the starting point. The time was recorded from the start to the completion of the course. The time was recorded using the electronic timing gates system (Fusion Sport, Brisbane, Australia). Each participant performed three trials, with a 90-second passive recovery period between each trial to minimize fatigue. The best performance (i.e., the fastest time) was selected for the analysis.

Lower-Limb Strength Test

Maximal lower-limb strength was assessed using a one-repetition maximum (1RM) test on a 45-degree incline plate-loaded leg press machine (Technogym, Italy). The leg press has been widely used in research to assess lower maximal body strength [22]. Before the test, a warm-up consisting of dynamic stretches and submaximal leg press repetitions at progressively heavier loads (e.g., 40 %, 60 %, and 80% of the estimated one-repetition maximum) was completed.

After warming, participants performed successive single repetitions with progressively heavier loads until reaching their maximal weight that could be lifted once with proper technique. Each participant completed two to three maximal attempts, with 3-5 minutes of rest between trials to minimize fatigue. Standardized verbal encouragement was provided throughout each trial to ensure maximal effort.

During the test, the participants were seated on the leg press machine with their feet placed shoulder-width apart on the platform. Standardized verbal encouragement was provided throughout each trial to ensure maximal effort. The movement started with 90° knee flexion, and the participants were instructed to extend their legs fully without locking the knees. A certified strength and conditioning specialist closely supervised all sessions, ensuring correct form, movement tempo, and participant safety. Safety stoppers on the leg press machine were used to prevent overextension, and the highest successfully lifted load was recorded as the 1RM value.

Statistical Analysis

Statistical analyses were performed using SPSS (v24, IBM Corporation Armonk, NY, USA). Data are presented as mean ± standard deviation with 95% confidence intervals. The normality of the data distribution was assessed using the Shapiro-Wilk test and inspection of Q-Q plots. The relationships between performance variables were examined using Pearson's product-moment correlation coefficients. The magnitude of correlations was interpreted as trivial (<0.10), small (0.10-0.29), moderate (0.30-0.49), large (0.50-0.69), very large (0.70-0.89), and nearly perfect (≥0.90) [23]. Simple linear regression analyses were conducted to determine the extent to which running velocity and running momentum (independent variables) predicted selected performance outcomes, including acceleration, agility, VO_2max, and lower-limb strength (dependent variables). The assumptions of linearity, normality of residuals, and homoscedasticity were verified through scatterplots and standardized residual analyses. A significance level of $p < 0.05$ was set for all statistical tests.

RESULTS

Participant characteristics and training background are presented in Table 1, while performance test outcomes are summarized in Table 2.

Table 3 summarizes the correlation coefficients between the running velocity, running momentum, and performance outcomes. Final running velocity showed a moderate positive correlation with acceleration ($r = 0.553$, $p = 0.026$) and a moderate negative correlation with agility time ($r = -0.666$, $p = 0.048$). In contrast, no statistically ing velocity and maximum leg press strength (r = 0.431, p = 0.094). A large positive correlation was observed between the final running velocity and $VO_2max_{30\text{-}15IFT}$ (r = 0.777, p < 0.001). The final running momentum exhibited stronger associations with the performance measures. A large positive correlation was found with acceleration (r = 0.695, p = 0.002), whereas a large negative correlation was observed with agility time (r = −0.779, p < 0.001). Additionally, running momentum was positively correlated with the one-repetition maximum leg press strength (r = 0.775, p< 0.001). On the other hand, a significant and moderate correlation was found between running momentum and $VO_2max_{30\text{-}15IFT}$ (r = 0.530, p = 0.034).

Table 1. Descriptive characteristics and training status of the football players (n = 16).

Variables	Mean ± standard deviation	95% confidence interval
Age (years)	17.88 ± 0.61	17.55, 18.20
Height (cm)	178.8 ± 4.17	176.5, 181.0
Weight (kg)	81.19 ± 3.48	79.33, 83.05
Training experience (years)	7.81 ± 0.91	7.32, 8.29

Table 2. Descriptive statistics of performance variables in football players (n = 16).

Variables	Mean ± standard deviation	95% confidence interval
Acceleration ($m \cdot sec^{-2}$)	2.90 ± 0.25	2.76, 3.04
Agility time (sec)	9.97 ± 0.54	9.68, 10.26
One-repetition maximum strength (kg)	206.88 ± 24.41	193.86, 219.89
$VO_2max_{30\text{-}15IFT}$ ($ml^{-1} \cdot min^{-1} \cdot kg^{-1}$)	52.71 ± 1.80	51.75, 53.68
Final running velocity$_{30\text{-}15IFT}$ ($km \cdot h^{-1}$)	20.56 ± 0.87	20.09, 21.02
Final running momentum ($kg \cdot m \cdot sec^{-1}$)	463.61 ± 25.87	449.82, 477.39

$VO_2max_{30\text{-}15IFT}$ = estimated maximal oxygen uptake derived from the 30-15 Intermittent Fitness Test

Table 3. Pearson's correlation coefficients between running velocity, running momentum, and performance outcomes in football players (n = 16).

Correlation Matrix	*r* value	*p* value	95% confidence interval
Final running velocity			
Acceleration ($m \cdot sec^{-2}$)	0.553	0.026*	0.078 - 0.823
Agility time (sec)	-0.666	0.048*	0.873 - 0.255
1- maximum leg press (kg)	0.431	0.094	0.081 - 0.764
$VO_2max_{30\text{-}15IFT}$ ($ml^{-1} \cdot min^{-1} \cdot kg^{-1}$)	0.777	<0.001**	0.458 - 0.919
Final running momentum	*r* value	*p* value	95% CI
Acceleration ($m \cdot sec^{-2}$)	0.695	0.002**	0.304 - 0.885
Agility time (sec)	-0.779	<0.001**	-0.919 - 0.461
1- maximum leg press (kg)	0.775	<0.001**	0.453 - 0.918
$VO_2max_{30\text{-}15IFT}$ ($ml^{-1} \cdot min^{-1} \cdot kg^{-1}$)	0.530	0.034*	0.047 - 0.812

*= p < 0.05; **= p <0.01; r = correlation coefficient; $VO_2max_{30\text{-}15IFT}$ = estimated maximal oxygen uptake derived from the 30-15 Intermittent Fitness Test

Furthermore, a large positive correlation was found between final running velocity and final running momentum (r = 0.649, p = 0.007, CI%: 0.226 - 0.866) (Figure 1).

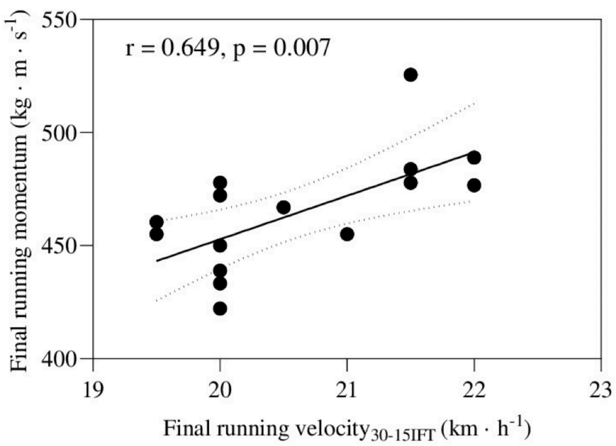

Figure 1. Correlation between the final running momentum and final running velocity with a 95% confidence interval.

Simple linear regression analysis revealed that final running velocity significantly predicted aerobic capacity (Y = 1.607 × X - 19.68, r^2 = 0.604, p < 0.001). In addition, velocity predicted 44% of the variance in agility time (Y = -0.4133 × X + 18.47, r^2 = 0.444, p = 0.005) and 31% in acceleration (Y = 0.1634 × X - 0.4552, r^2 = 0.305, p = 0.026), but showed no significant predictive value for leg press strength (Y = 12.08 × X - 41.45, r^2 = 0.186, p = 0.095) (Figure 2A-D).

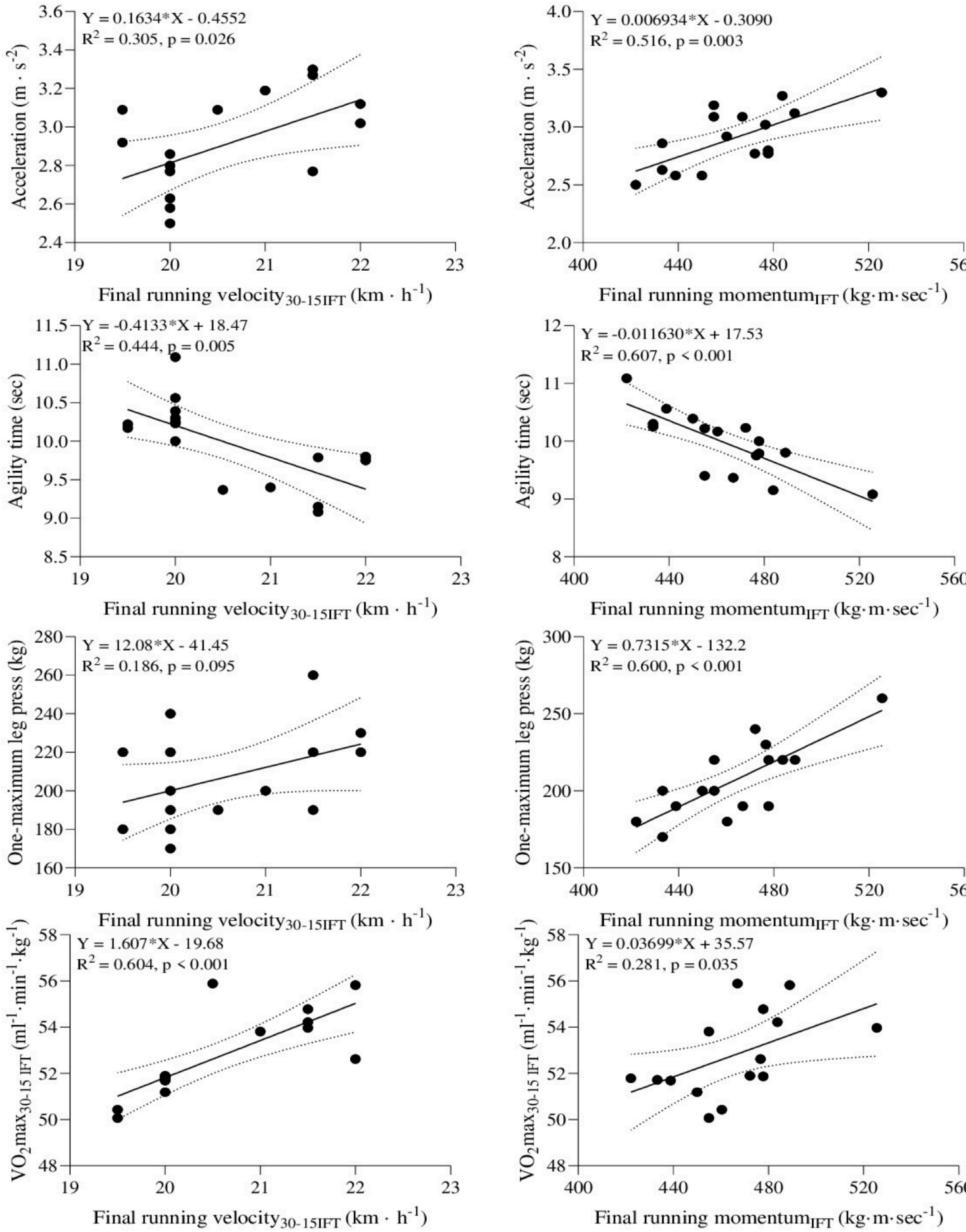

Figure 2. Simple linear regression analysis with a 95% confidence interval between the final running velocity, running momentum, and performance.

Momentum predicted 61% of the variance in agility time ($Y = -0.011630 \times X + 17.53$, $r^2 = 0.607$, $p < 0.001$), 60% in leg press strength ($Y = 0.7315 \times X + 132.2$, $r^2 = 0.600$, $p < 0.001$), and 52% in acceleration ($Y = 0.006934 \times X - 0.3090$, $r^2 = 0.516$, $p = 0.003$). For aerobic capacity, momentum explained only 28.1% of the variance in VO_2max ($Y = 0.03699 \times X + 35.57$, $r^2 = 0.281$, $p = 0.035$), indicating that momentum is more strongly related to strength- and agility-based performance than to aerobic fitness (Figure 2E-H).

DISCUSSION

This study examined the relationships between final running velocity, running momentum, and athletic performance metrics in elite youth football players. The findings demonstrated that, while the final running velocity was predominantly associated with aerobic capacity, running momentum showed stronger associations with lower-body strength, acceleration, and agility. These results highlight the differential contributions of physiological and mechanical factors to speed-related performance and suggest that running momentum may serve as a more comprehensive indicator of athletic capability in high-intensity sports.

The mean VO_2max value obtained in this study (52.71 $ml \cdot kg^{-1} \cdot min^{-1}$) aligns with previously reported values for trained male football players, generally ranging between 48 and 62 $ml \cdot kg^{-1} \cdot min^{-1}$ across competitive levels [20]. More specifically, recent findings have shown that VO_2max in male athletes aged 8-17 years typically varies between 47 and 54 $ml \cdot kg^{-1} \cdot min^{-1}$ [24], which is consistent with earlier reports for adolescent football players [25]. The present results therefore indicate that the participants demonstrated an aerobic fitness level consistent with their age and training background, reinforcing the validity of the $30\text{-}15_{IFT}$ as a suitable tool for evaluating aerobic performance in youth football players.

Although final running velocity and momentum were significantly correlated, their distinct physiological foundations indicate that they represent different dimensions of athletic performance. Velocity is primarily determined by aerobic power and running economy [26], whereas momentum is more closely associated with neuromuscular strength, acceleration capacity, and body mass [27,28]. These differences underscore the value of incorporating both variables into performance profiling and talent identification frameworks to provide a more comprehensive assessment of an athlete's physical capabilities. The current regression analyses further support this interpretation by demonstrating that running velocity explained approximately 60% of the variance in VO_2max, whereas momentum accounted for only 28%. In contrast, momentum explained a greater proportion of the variance (52-61%) in agility, acceleration, and lower-limb strength. These patterns indicate that while velocity serves as a strong predictor of aerobic capacity, momentum captures the neuromuscular and mechanical components of performance that are critical for rapid force generation and direction changes. From a developmental perspective, this distinction may reflect age-specific adaptations, as younger athletes are still optimizing their strength-to-mass ratio and movement coordination. Consequently, evaluating both velocity and momentum provides a more comprehensive understanding of performance determinants in youth football players, supporting individualized conditioning and talent identification strategies.

In the context of contact sports, sprint momentum has been shown to differentiate between elite and sub-elite athletes, suggesting that integrating momentum-based assessments could offer a more sensible measure of athletic proficiency than sprint speed alone [29]. In the literature, running momentum has been increasingly advocated as a performance indicator, particularly for collision-based sports where body mass significantly contributes to match success [30]. Supporting this notion, it was demonstrated that sprint momentum effectively distinguished elite from sub-elite rugby players, whereas sprint velocity alone did not [30]. It was found that higher-level athletes consistently exhibited greater momentum values, which were strongly related to lower-body strength [31]. Similarly, the relevance of momentum in rugby was underscored, demonstrating its utility in differentiating player roles and predicting match-relevant physical impact [14].

Its ability to distinguish between performance levels within a single sport and between athletes based on distinct sporting codes underscores its discriminative power. Recent research has shown that sprint momentum differs significantly among elite female athletes, with handball and rugby players displaying considerably higher momentum than football players [32]. This finding highlights the extent to which sport-specific demands and anthropometric characteristics influence the momentum. These insights affirm that sprint momentum is not merely a supplementary metric but also a fundamental component in athlete profiling, capable of capturing subtle yet significant performance differences across sports and within populations characterized by heterogeneous physical demands. Additionally, in football, most hamstring injuries, which account for 12 to 16% of all injuries [33], occur during high-speed and power actions such as sprinting [34], advocating the importance of monitoring sprinting performance.

Sprint momentum is a more comprehensive indicator of functional performance, particularly in contexts where mass and force transmission are critical. Notably, body mass has been identified as a near-perfect predictor of sprint momentum, exerting a greater influence than sprint velocity across various simulated conditions [35]. These findings highlight the importance of incorporating mass-dependent parameters into performance assessments, especially in sports requiring high-impact collisions, acceleration, and resistance to external forces. This study identified a large and significant correlation between the final running momentum and the 1RM leg press strength. In contrast, no significant relationship was observed between 1RM strength and final running velocity. This finding suggests that maximal lower body strength contributes more directly to an athlete's ability to generate greater momentum than to achieve higher sprint velocities. It was highlighted that momentum requires movement speed and sufficient force production capacity to effectively propel a given mass [36]. Maximal strength and power capacity are fundamental for overcoming inertial resistance, especially in heavier athletes, thereby enhancing momentum generation without necessarily increasing peak sprint speeds. This rationale supports the current study's observed dissociation between maximal strength and final running velocity. This emphasizes the importance of evaluating momentum - a composite variable integrating both mass and velocity - rather than velocity alone when profiling athletes. While sprint velocity is predominantly influenced by neuromuscular characteristics such as stride frequency, technical sprint ability, and rapid force application [37,38] sprint momentum inherently captures both athlete speed and mass, providing a more comprehensive indicator of functional performance in high-intensity, collision-prone sports.

The current study has several limitations that should be acknowledged to guide interpretation and future research directions. While this investigation focused on the relationships between final running momentum, maximal strength, and aerobic capacity, it did not account for other critical performance determinants commonly associated with elite football performance. Variables such as anaerobic power, repeated sprint ability, change of direction speed, and neuromuscular efficiency are likely to influence running momentum and overall match performance but were not included in the present analysis. Incorporating these additional metrics in future studies could offer a more holistic perspective on the multifactorial underpinnings of sprint momentum and its broader implications for physical performance and talent identification. Moreover, biomechanical factors such as sprint kinematics, stride frequency, and ground reaction force profiles may also provide deeper insight into how athletes generate and sustain momentum during high-speed locomotion. It should also be acknowledged that the use of regression analysis with a relatively small sample size may limit the statistical power and generalizability of the findings. Nevertheless, the observed effect sizes and low standard errors indicate stable and meaningful relationships, consistent with previous reports on youth athlete cohorts of similar size. Future studies with larger samples are warranted to confirm these associations and further refine predictive modeling.

Despite these limitations, the current study is, to our knowledge, the first to explore the specific associations between final running momentum, lower-limb strength, and aerobic capacity within the context of the 30-15 Intermittent Fitness Test in elite male youth football players. This provides a novel and valuable foundation for future applied research and evidence-based performance profiling in team sports settings.

From a practical standpoint, running momentum may be a valuable tool for coaches aiming to tailor strength and conditioning interventions. Given its strong association with lower-body strength and agility, it can guide position-specific training plans and injury prevention programs, especially in youth development contexts where body mass and mechanical power evolve rapidly.

CONCLUSION

These findings underscore the potential of running momentum as a more comprehensive indicator of an athlete's physical capabilities. Specifically, running momentum demonstrated stronger relationships with lower-limb strength, acceleration, and agility, whereas running velocity was more closely associated with aerobic capacity. Given its multidimensional nature, momentum should be integrated as a complementary metric alongside traditional speed- and endurance-based assessments in athlete profiling, training evaluation, and talent identification. Future research should explore the utility of momentum across various playing positions, competitive levels, and match contexts. Incorporating momentum into longitudinal monitoring systems may yield more ecologically valid insights into performance readiness and match impact.

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Ethics Committee Approval / Etik Komite Onayı
The approval for this study was obtained from Ethics Committee for Clinical Research at Inonu University (Decision no: 2023/2296, Date: 14/12/2023) and was conducted in accordance with the principles of the Declaration of Helsinki. Informed consent was obtained from all the participants.

Conflict of Interest / Çıkar Çatışması
The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

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Author Contributions / Yazar Katkıları
Concept – FSC, CA, AHG; Design – FSC, CA; Supervision – FSC, CF, ERG, MA; Materials – CA, AHG; Data Collection and/or Processing – FSC, CA, AHG; Analysis and/or Interpretation – FSC; Literature Review – FSC, CF; Writing – FSC, CF, ERG, MA; Critical Review – FSC, CA, AHG, CF, ERG, MA. All authors approved the final version of the manuscript.

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