Submitted: 06 May, 2025 Accepted: 15 August, 2025 Published: 30 October, 2025 DOI:10.22514/jomh.2025.127

JOMH Journal of Men's Health

ORIGINAL RESEARCH

Analysis of the phases of sprint in terms of isokinetic leg strength, anaerobic endurance, and balance

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Abstract

Background: The 100 m sprint in track and field is widely used to demonstrate human capacity for extreme speed. However, there is limited research on how isokinetic leg strength, balance, and anaerobic endurance affect specific phases of sprinting. This study aimed to examine their influence on different sprint phases. **Methods**: A total of 45 men participated in the study and a 100 m sprint test, a three-corner running test, Biodex balance device, and Cybex Humac Norm 2004 device were used to collect data. To ascertain the connection between isokinetic leg strength, anaerobic endurance, general balance, and the different phases of speed, a Pearson correlation test was used. The level of influence of the data acquired for the isokinetic leg strength, anaerobic endurance and general balance on the speed phases was determined using a Linear Regression test. **Results**: The results indicated that left leg extension peak torque (left LEPT) values affected all phases of sprint except reaction speed ($p < 0.05$), while left leg flexion peak torque (left LFPT) values affected all phases of sprint except reaction speed and mid-acceleration ($p < 0.05$). Right leg extension peak torque (right LEPT) values were found to affect all phases of sprint except reaction speed and early acceleration phase ($p < 0.05$). Moreover, right leg flexion peak torque (right LFPT) values were found to affect all phases of sprint ($p < 0.05$). General balance score (GB) was found to affect the phases of early acceleration, late acceleration, maximum sprint, and sprint continuity ($p < 0.05$). Anaerobic endurance (AE) values were found to affect all phases of sprint except reaction speed ($p < 0.05$). **Conclusions**: Consequently, all parameters were found to have a significant effect on overall sprint performance but have the most effect, especially in the maximum speed and sprint continuity phase.

Keywords

Sprint; Isokinetic; Balance; Anaerobic endurance

1. Introduction

Sprinting is defined as running a predetermined short distance in the shortest time possible [1]. Sprint performance refers to executing rapid, cyclic running movements at maximal velocity over a brief duration [2, 3]. It is unequivocally regarded as one of the most essential and sought-after abilities across a wide range of sports disciplines [4–8]. Within track and field, the 100 m sprint is widely recognized as a benchmark event, showcasing human capacity for extreme speed over short distances. It serves as a standard indicator of peak sprinting ability and is often used to identify "the fastest person in the world" during a given era [9].

Sprinting performance is determined by several interrelated factors: the ability to accelerate, the attainment of maximal velocity, and the capacity to maintain that velocity in the face of fatigue [10]. Notably, the 100 m sprint in track and field is one of the few events that permits purely linear acceleration to achieve maximal speed [11]. As one of the most powerful human locomotor activities, sprinting demands a comprehensive understanding of the biomechanical, kinematic, and kinetic factors that critically influence performance. Individualized biomechanical analysis can offer valuable feedback to coaches, supporting the development of targeted technical training interventions aimed at enhancing sprint outcomes [12].

Sprinting is a central component of major athletic competitions such as the Olympic Games, World Championships, and European Championships. In these elite-level events, outcomes are often determined by min time differentials—sometimes measured in hundredths of a second. For instance, at the 2018 European Championships, the time difference between second and fourth place in the men's 200 m final was only 0.01 seconds, representing the distinction between winning a medal and missing the podium. Similarly, at the 2020 Tokyo Olympics, the top three finishers in the men's 200 m event were separated by just 0.12 seconds, with only 0.04 seconds dividing the subsequent three places. In the 2004 Athens Olympics, the gold medal in the men's 100 m race was decided by a mere 0.01 seconds [13, 14]. These examples underscore the significance of even marginal improvements in sprint performance, which can ultimately determine medal outcomes.

Sprint performance largely depends on the athlete's ability to rapidly accelerate their body mass and sustain high running velocity in the forward direction. This is achieved through neuromuscular mechanisms—primarily involving the trunk and lower limbs—that generate and apply force to the ground during the support phase of the running stride, *i.e.*, during the brief foot-ground contact period within each stride cycle [15]. The capacity to produce force and speed constitutes the foundation for an athlete's acceleration potential [16–18]. Hence, it is essential to understand the technical demands of sprinting, acknowledging that it represents not only a physical ability but also a skill deeply rooted in motor coordination and precision [4].

The technical nature of sprinting encompasses various dimensions, including characteristics of force application, biomechanical principles, and motor learning processes [8]. Ultimately, sprint performance is shaped by a multitude of variables emerging from sport-specific movement patterns [14].

The effects of isokinetic leg strength, anaerobic endurance and balance on the phases of sprint performance have not been investigated sufficiently in the literature. This study aims to enhance the current understanding of sprint performance by investigating the distinct phases of sprinting in relation to isokinetic leg strength, anaerobic endurance, and balance. The findings are anticipated to offer meaningful insights for sports scientists, coaches, and athletes regarding training program development and performance assessment. In turn, this may facilitate the creation of sprint-specific performance enhancement strategies grounded in scientific evidence.

2. Materials and methods

2.1 Experimental approach to the problem

The Cybex Humac Norm 2004 device (Cybex International, Medway, MA, USA) was used in the study to determine the 100 m sprint test for the evaluation of the phases of speed, the three-corner running test for the determination of anaerobic endurance, the Biodex balance device (Biodex Medical Systems Inc., Shirley, NY, USA) for the determination of balance performance, and the Cybex Humac Norm 2004 device for the determination of isokinetic leg strength. The tests were conducted on the days that the athletes did not have training during the competition period (September–November 2023). Each test for all groups was performed on different days, at least 72 hours later, in the same environment and conditions. Required information about the test was given to the participants by the researcher before each test. A test-specific warm-up program was performed before each test. Moreover, each test was administered to the participants twice, and the best score was evaluated. Besides, all participants gave written informed consent to participate in this study following being informed about the procedures approved by the ethics committee and in accordance with the Declaration of Helsinki.

2.2 Subjects

A total of 45 men sports science faculty students (15 licensed sprinters, 15 licensed athletes from different branches, 15 unlicensed participants), participated in this study, which was conducted to examine the phases of sprint in terms of strength, anaerobic endurance, and balance. The mean age of the participants was 19.64 ± 2.02 years, mean height was 175.11 ± 14.54 cm, mean body weight was 68.44 ± 5.96 kg, and the mean sports experience was 5.40 ± 3.90 years.

2.3 100-m sprint test

The 100 m sprint was performed on the Tartan track of Selçuk University 15 July Stadium. During the 100 m sprint, times were measured with an 11-door wireless photocell system. The photocells were placed at the start (0 m), 5 m, 15 m, 25 m, 35 m, 45 m, 55 m, 65 m, 75 m, 85 m, and finish (100 m) [1, 17, 19]. Sprint performance was evaluated by dividing into 5 phases:

- ➢ Reaction speed (0–5 m);
- ➢ Acceleration: Early acceleration (5–15 m);
  Mid-acceleration (15–25 m);
  Late acceleration (25–35 m);
- ➢ Transition phase (35–45 m);
- ➢ Maximum Speed (45–75 m);
- ➢ Sprint Continuity (75–100 m) [1, 17, 19].

A 15 min active warm-up program was applied to the participants before the test. At the starting point (0 m), the subject adopted a linear static standing position with one knee in front and one behind and began running when ready. The time taken at each stage was recorded.

2.4 Three corner run test

The three-corner running test was performed on a soccer field. During the run, times were measured with a 2-door wireless photocell system. The photocells were placed at the start and end points. A 15 min active warm-up program was applied to the participants before the test. The athlete takes the starting position next to the first flagpole (start). If the athlete is ready, he/she runs to the first flagpole at a distance of 80 m, turns around the flagpole, runs to the second flagpole at a distance of 20 m, turns around the flagpole, runs to the third flagpole at the starting point (82.4 m), turns around the flagpole, and runs to the fourth flagpole (finish) to finish the test. Measurements are evaluated in seconds [20, 21].

2.5 Dynamic balance test

The balance test was performed with the Biodex Balance System (Biodex Medical Systems, Shirley, NY, USA). The general balance score (GB) was used to assess the dynamic balance values of the study participants. The athletes' ability to balance was assessed using the eyes-open dynamic balance test. The eyes-open balance test was performed on the dominant leg, and the difficulty level of the measurement tool was set to "level 6". The participants were allowed to move the platform freely while looking at the screen to determine the coordinates of the foot position for the test and to determine the ideal foot position. They were instructed to adjust the position of the support leg until they reached a stable position.

Once the appropriate position was found, the platform was locked according to the athletes' foot position, and the coordinates of this position were recorded by the device. The tests were performed with reference to the recorded foot position. Participants were instructed to place their hands diagonally on their right and left shoulders to eliminate the effect of the arms during the tests. The athletes participated in all the tests barefoot and wore comfortable sportswear and were allowed sufficient practice before the measurement to become familiar with the equipment. The duration of the balance test was 20 seconds. After the participant adjusted the center of gravity using visual information from the screen of the measuring tool during the tests, the test was started. The measurement tool's screen was turned off during the test. The participants were instructed to look at a point approximately 1 m away at the participant's eye level. A high balance score indicates poor balance performance [22–25].

2.6 Isokinetic leg strength test

An isokinetic leg strength test was performed with an isokinetic dynamometer (Cybex International, Medway, MA, USA). Prior to the test, the participants warmed up with a bicycle ergometer Monark Ergomedic 894E Peak Bike (Monark Exercise AB, Vansbro, Sweden) at 55–65 rpm for 7 min, followed by stretching for 3 min. Isokinetic muscle strength of the lower extremities of the athletes was measured at an angular velocity of 60 °/s. Isokinetic muscle strengths were measured in 2 different joint movements, right and left knee flexion/extension. After preliminary information about the test was given, anthropometric data were entered into the Cybex apparatus one by one, and the device was adjusted. The range of motion of the joint was determined by the computer by making a sample movement. After the trial measurements were taken, the test measurement values made in accordance with the determined protocol were transferred to the computer environment. The gravity effect, which may cause false results in the measurements made in these joint movements, is also reset by the device [26, 27].

In five repetitions of maximum contraction, knee extension and flexion torque values were obtained at a speed of 60 °/s. Rest was given for 5 min between knee changes [26–29].

2.7 Statistical analyses

SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, USA) was used to organize and calculate the data. The data were summarized by giving the mean and standard deviations. The normal distribution of the data was tested by One-Sample Kolmogorov Smirnov test, and it was determined that the data showed a normal distribution. To ascertain the connection between the isokinetic leg strength, anaerobic endurance, general balance and speed phases, a Pearson correlation test was used. The level of influence of the data acquired for the isokinetic leg strength, anaerobic endurance and general balance on the speed phases was determined using a Linear Regression test. The data obtained in this study were tested at a 0.95 confidence interval.

3. Results

When Table 1 is examined, it is seen that the participants' reaction speed mean was 1.11 ± 0.15 s, early acceleration mean was 1.39 ± 0.13 s, mid-acceleration mean was 1.19 ± 0.11 s, late acceleration mean was 1.16 ± 0.12 s, transition phase mean was 1.14 ± 0.16 s, maximum speed mean was 2.43 ± 0.29 s, sprint continuity mean was 1.83 ± 0.22 s, left LEPT mean was 149.16 ± 33.04 Nm, left LFPT mean was 90.11 ± 33.64 Nm, right LEPT mean was 145.20 ± 29.85 Nm, right LFPT mean was 96.56 ± 27.74 Nm, general balance score mean was 2.63 ± 0.88 and anaerobic endurance mean was 32.33 ± 2.62 s.

TABLE 1. Transition times of sprint phases, leg peak torque, balance and anaerobic endurance values of the subjects participating in the study.

Variables	Mean	Standard Deviation
Reaction Speed (s)	1.11	0.15
Early Acceleration (s)	1.39	0.13
Mid-Acceleration (s)	1.19	0.11
Late Acceleration (s)	1.16	0.12
Transition Phase (s)	1.14	0.16
Maximum Speed (s)	2.43	0.29
Sprint Continuity (s)	1.83	0.22
Left LEPT (Nm)	149.16	33.04
Left LFPT (Nm)	90.11	33.64
Right LEPT (Nm)	145.20	29.85
Right LFPT (Nm)	96.56	27.74
General Balance (score)	2.63	0.88
Anaerobic Endurance (s)	32.33	2.62

LEPT: leg extension peak torque; LFPT: leg flexion peak torque.

An analysis of Fig. 1A reveals that there was no significant relationship between reaction speed and left LEPT of the subjects who participated in the study. It has been observed that the change in left LEPT values does not affect reaction speed ($p > 0.05$).

An analysis of Fig. 1B reveals that there is no significant relationship between reaction speed and left LFPT of the subjects who participated in the study. It has been observed that the change in left LFPT values does not affect reaction speed ($p > 0.05$).

An analysis of Fig. 1C reveals that there was no significant relationship between reaction speed and right LEPT of the subjects who participated in the study. It was observed that the change in right LEPT values did not affect reaction speed ($p > 0.05$).

An analysis of Fig. 1D reveals that there was a significant relationship between reaction speed and right LFPT in the same direction ($p < 0.05$). It has been seen that the right LFPT value explains 8.7% of the reaction speed. One-Nm change in the right LFPT value affects reaction speed by 0.002. One-Nm increase in the right LFPT value positively affects the reaction

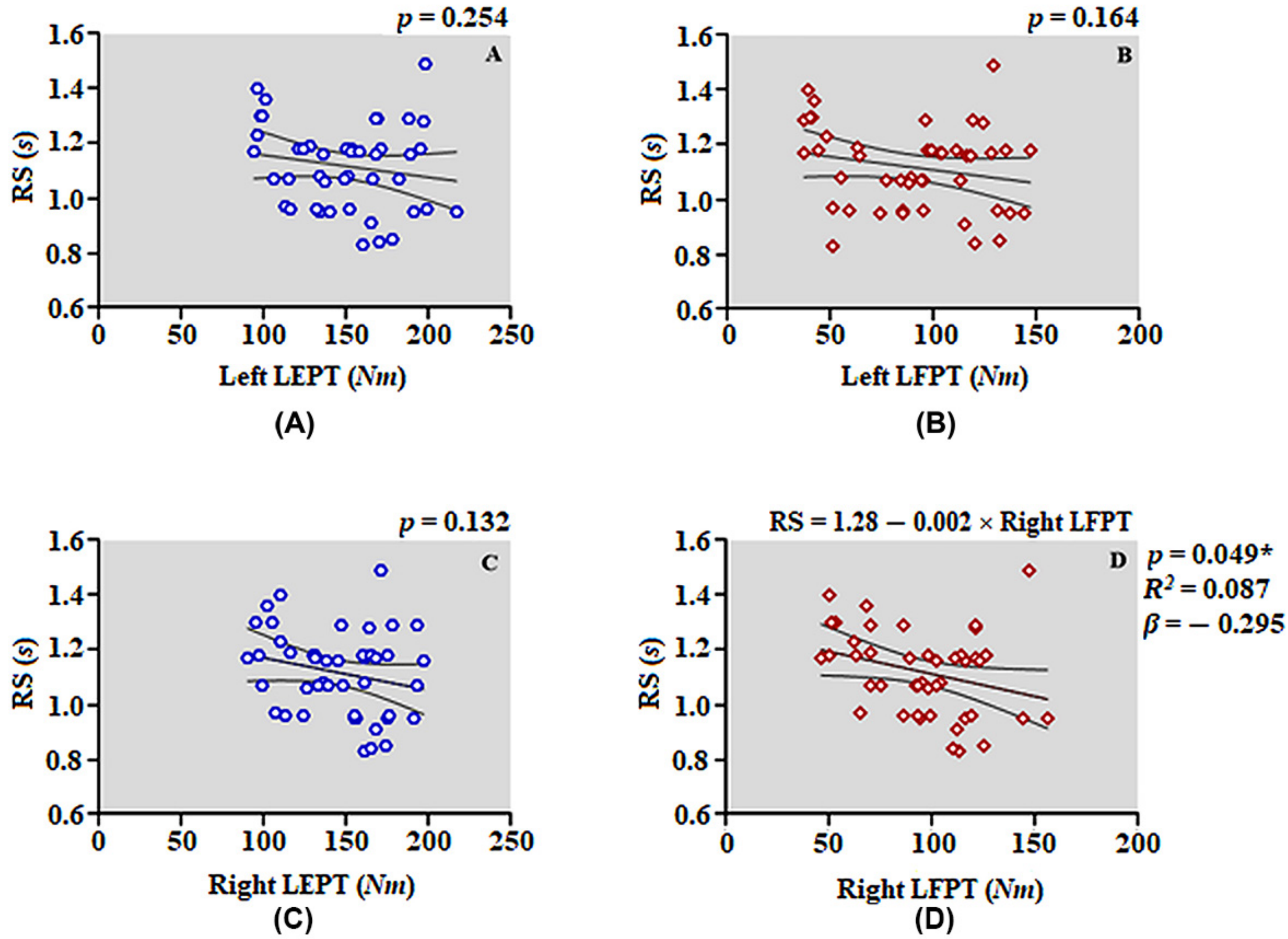


FIGURE 1. Relationship between reaction speed and isokinetic leg strength. (A) Relationship between reaction speed and the left LEPT. (B) Relationship between reaction speed and the left LFPT. (C) Relationship between reaction speed and right LEPT. (D) Relationship between reaction speed and the right LFPT. LEPT: leg extension peak torque; LFPT: leg flexion peak torque; RS: reaction speed. *: indicates statistically significant difference ($p < 0.05$).

speed by 0.002, whereas one-Nm decrease negatively affects the reaction speed by 0.002.

An analysis of Fig. 2A reveals that there is no significant relationship between GB and reaction speed of the subjects who participated in the study ($p > 0.05$).

An analysis of Fig. 2B reveals that there is no significant relationship between reaction speed and AE ($p > 0.05$).

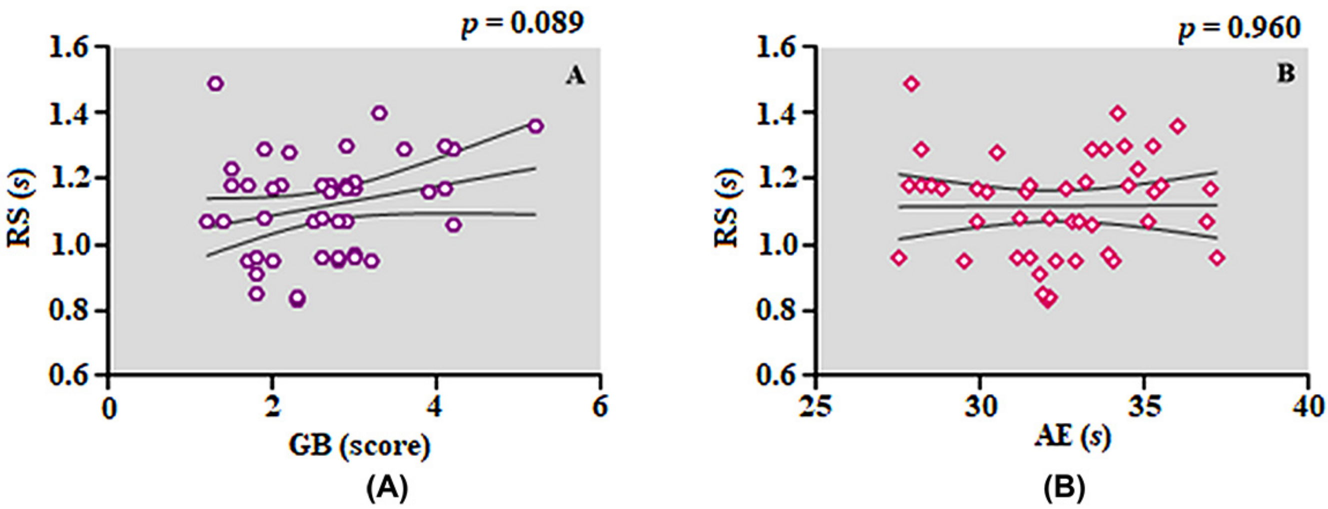
An analysis of Fig. 3A reveals that there is a significant relationship between early acceleration values and the left LEPT values in the same direction ($p < 0.05$). It was seen that the left LEPT value explained 9.8% of the early acceleration. One-Nm change in the left LEPT value affects early acceleration by 0.001. One-Nm increase in the left LEPT value affects the early acceleration positively by 0.001, while one-Nm decrease affects the early acceleration negatively by 0.001.

An analysis of Fig. 3B reveals that there is a significant relationship between early acceleration values and left LFPT values in the same direction ($p < 0.05$). It was observed that the left LFPT value explained 26.5% of the early acceleration. One-Nm change in the left LFPT value affects early acceleration by 0.002. One-Nm increase in left LFPT value affects early acceleration positively by 0.002, whereas one-Nm decrease affects early acceleration negatively by 0.002.

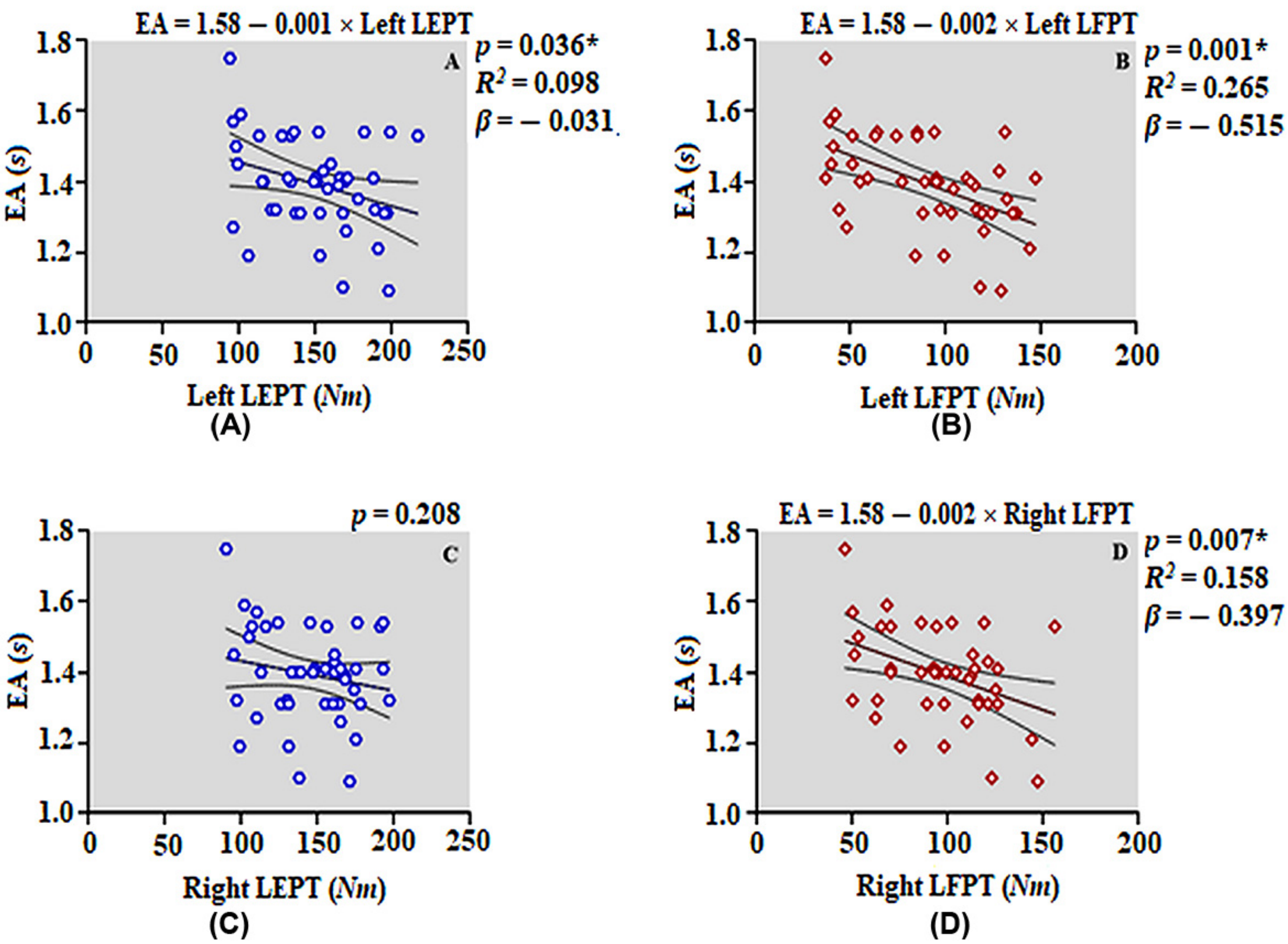
An analysis of Fig. 3C reveals that there was no significant relationship between early acceleration values and right LEPT of the subjects who participated in the study. It was observed that the change in right LEPT values did not affect early acceleration ($p > 0.05$).

An analysis of Fig. 3D reveals that there is a significant relationship between the early acceleration values of the subjects participating in the study and the right LFPT in the same direction ($p < 0.05$). It was seen that the right LFPT value explained 15.8% of the early acceleration. One-Nm change in the right LFPT value affects early acceleration by 0.002. One-Nm increase in the right LFPT value affects early acceleration positively by 0.002, whereas one-Nm decrease affects early acceleration negatively by 0.002.

An analysis of Fig. 4A reveals that there is a significant relationship between GB and early acceleration values of the subjects who participated in the study in the opposite direction ($p < 0.05$). It was observed that GB explained 18.1% of the early acceleration. One-score change in GB affects early acceleration by 0.06. One-score increase in GB affects early acceleration negatively by 0.06, whereas one-score decrease



F I G U R E 2. Relationship between reaction speed, balance, and anaerobic endurance. (A) The relationship between reaction speed and GB. (B) The relationship between reaction speed and AE. GB: general balance score; AE: anaerobic endurance; RS: reaction speed.



F I G U R E 3. Relationship between early acceleration and isokinetic leg strength. (A) The relationship between early acceleration and left LEPT. (B) Relationship between early acceleration and left LFPT. (C) Relationship between early acceleration and right LEPT. (D) Relationship between early acceleration and right LFPT. LEPT: leg extension peak torque; LFPT: leg flexion peak torque; EA: early acceleration. *: indicates statistically significant difference ($p < 0.05$).

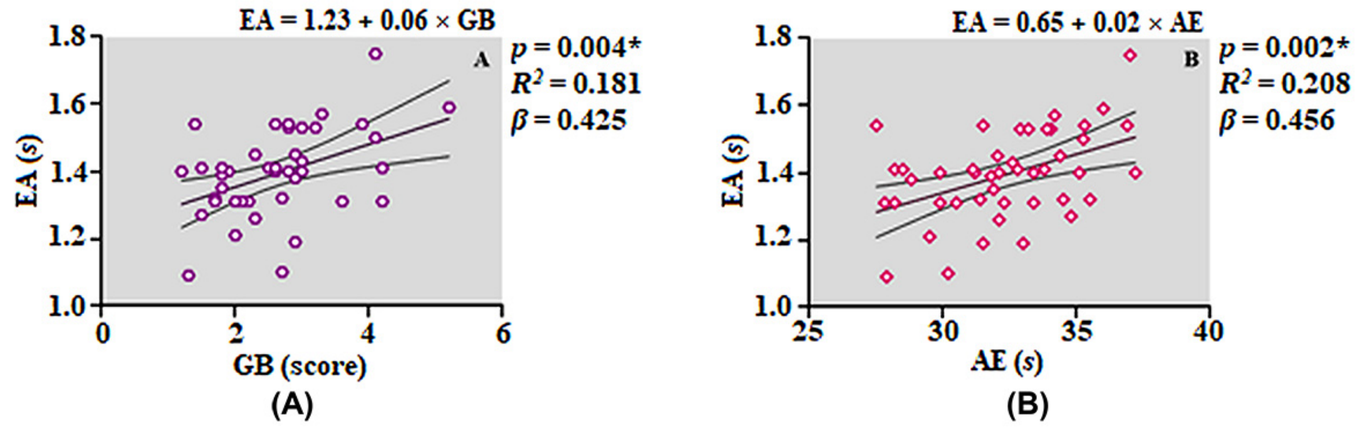


FIGURE 4. Relationship between early acceleration, balance, and anaerobic endurance. (A) The relationship between early acceleration and GB. (B) The relationship between early acceleration and AE. GB: general balance score; AE: anaerobic endurance; EA: early acceleration. *: indicates statistically significant difference ($p < 0.05$).

in GB affects early acceleration positively by 0.06.

An analysis of Fig. 4B reveals that there is a significant relationship between the early acceleration values and AE values of the subjects who participated in the research in the opposite direction ($p < 0.05$). The AE value was found to explain 20.8% of the early acceleration. One-s change in AE value affects the early acceleration by 0.02. One-s increase in AE value affects early acceleration negatively by 0.02, whereas one-s decrease affects early acceleration positively by 0.02.

An analysis of Fig. 5A reveals that there is a significant relationship between mid-acceleration and left LEPT in the same direction ($p < 0.05$). It was observed that the left LEPT value explained 18.8% of the mid-acceleration. One-Nm change in the left LEPT value affects the mid-acceleration by 0.002. One-Nm increase in the left LEPT value positively affects the mid-acceleration by 0.002, whereas one-Nm decrease in the left LEPT value negatively affects the mid-acceleration by 0.002.

An analysis of Fig. 5B reveals that there is no significant relationship between mid-acceleration and left LFPT values of the subjects who participated in the study ($p > 0.05$). It was observed that the change in left LFPT values did not affect mid-acceleration.

An analysis of Fig. 5C reveals that there is a significant relationship between the mid-acceleration values and right LEPT values in the same direction ($p < 0.05$). It was seen that the right LEPT value explained 13.7% of the mid-acceleration. One-Nm change in the right LEPT value affects the mid-acceleration by 0.001. One-Nm increase in the right LEPT value affects the mid-acceleration positively by 0.001, whereas one-Nm decrease affects the mid-acceleration negatively by 0.001.

An analysis of Fig. 5D reveals that there is a significant relationship between the mid-acceleration values and the right LEPT values of the subjects who participated in the study in the same direction ($p < 0.05$). It was observed that the right LFPT value explained 23.8% of the mid-acceleration. One-Nm change in the right LFPT value affects mid-acceleration by 0.001. One-Nm increase in the right LFPT value positively affects mid-acceleration by 0.001, whereas one-Nm decrease in the right LFPT value negatively affects mid-acceleration by 0.001.

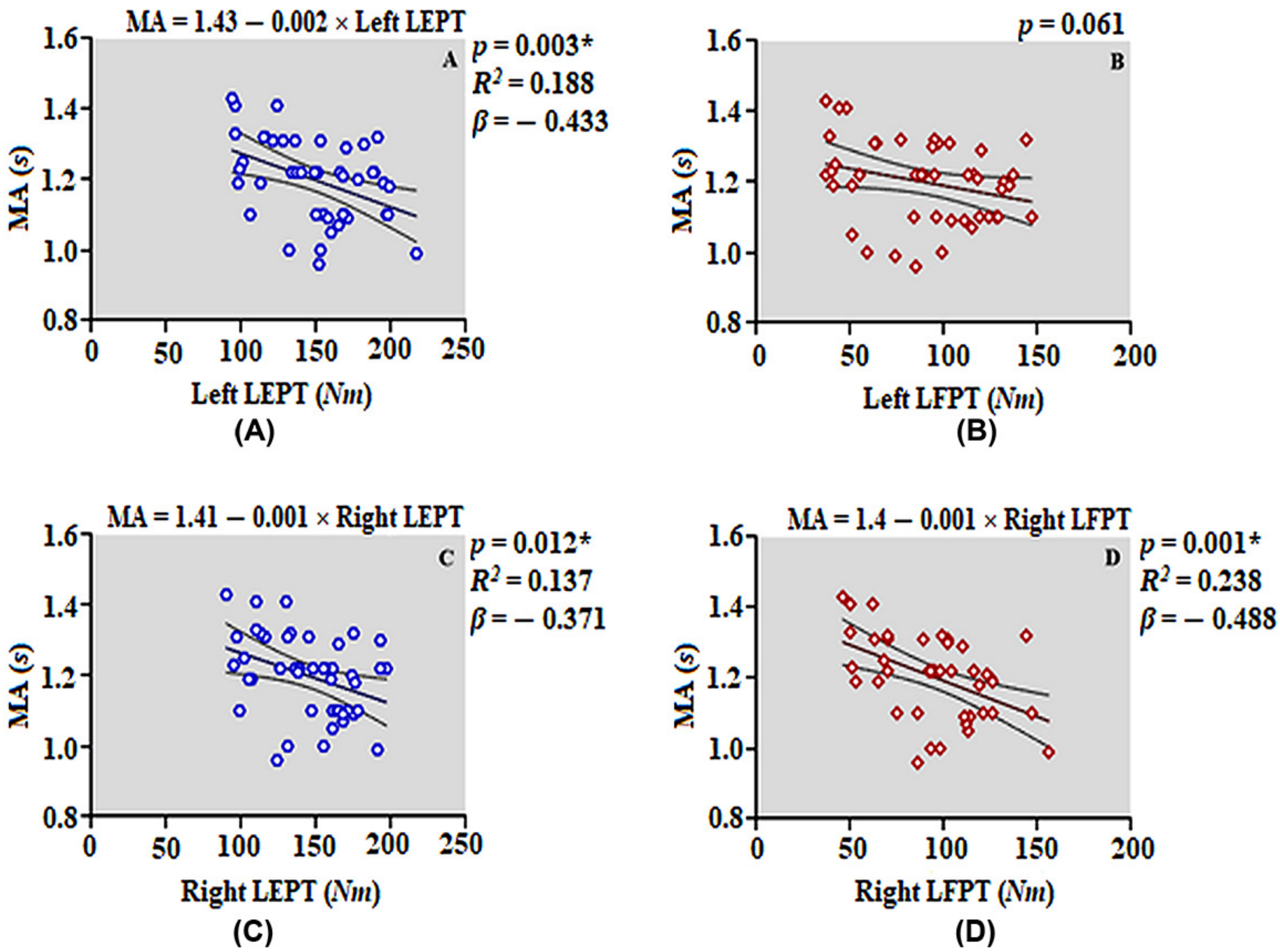
An analysis of Fig. 6A reveals that there is no significant relationship between GB and mid-acceleration values of the subjects who participated in the study ($p > 0.05$). It was observed that the change in GB did not affect mid-acceleration.

An analysis of Fig. 6B reveals that there is a significant relationship in the opposite direction between the AE values and the mid-acceleration values of the subjects who participated in the study ($p < 0.05$). It was observed that the AE value explained 24.5% of the mid-acceleration. One-s change in AE value affects mid-acceleration by 0.02. One-s increase in AE value negatively affects mid-acceleration by 0.02, whereas one-s decrease in AE value positively affects mid-acceleration by 0.02.

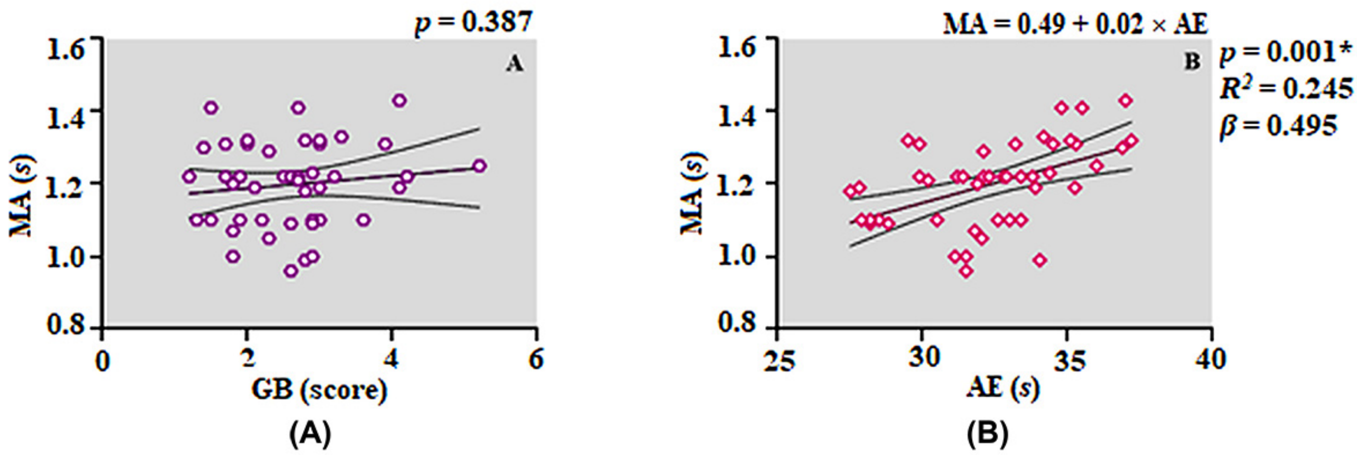
An analysis of Fig. 7A reveals that there is a significant relationship between late acceleration values and left LEPT values of the subjects who participated in the study in the same direction ($p < 0.05$). It was observed that the left LEPT value explained 14% of the late acceleration. One-Nm change in the left LEPT value affects late acceleration by 0.001. One-Nm increase in the left LEPT value has a positive effect on late acceleration by 0.001, whereas one-Nm decrease in LEPT value has a negative effect on late acceleration by 0.001.

An analysis of Fig. 7B reveals that there is a significant relationship between late acceleration values and the left LEPT values of the subjects who participated in the study in the same direction ($p < 0.05$). It was observed that the left LFPT value explained 25.8% of the late acceleration. One-Nm change in the left LFPT value affects late acceleration by 0.002. One-Nm increase in the left LFPT value affects late acceleration positively by 0.002, whereas one-Nm decrease affects late acceleration negatively by 0.002.

An analysis of Fig. 7C reveals that there is a significant relationship between late acceleration values and right LEPT values in the same direction ($p < 0.05$). It was observed that the right LEPT value explained 14.2% of the late acceleration. One-Nm change in the right LEPT value affects late acceleration by 0.002. One-Nm increase in the right LEPT value



F I G U R E 5. Relationship between mid-acceleration and isokinetic leg strength. (A) Relationship between mid-acceleration and left LEPT. (B) Relationship between mid-acceleration and left LFPT. (C) Relationship between mid-acceleration and right LEPT. (D) Relationship between mid-acceleration and right LFPT. LEPT: leg extension peak torque; LFPT: leg flexion peak torque; MA: mid-acceleration. *: indicates statistically significant difference ($p < 0.05$).



F I G U R E 6. Relationship between mid-acceleration, balance, and anaerobic endurance. (A) The relationship between mid-acceleration and GB. (B) The relationship between mid-acceleration and AE. GB: general balance score; AE: anaerobic endurance; MA: mid-acceleration. *: indicates statistically significant difference ($p < 0.05$).

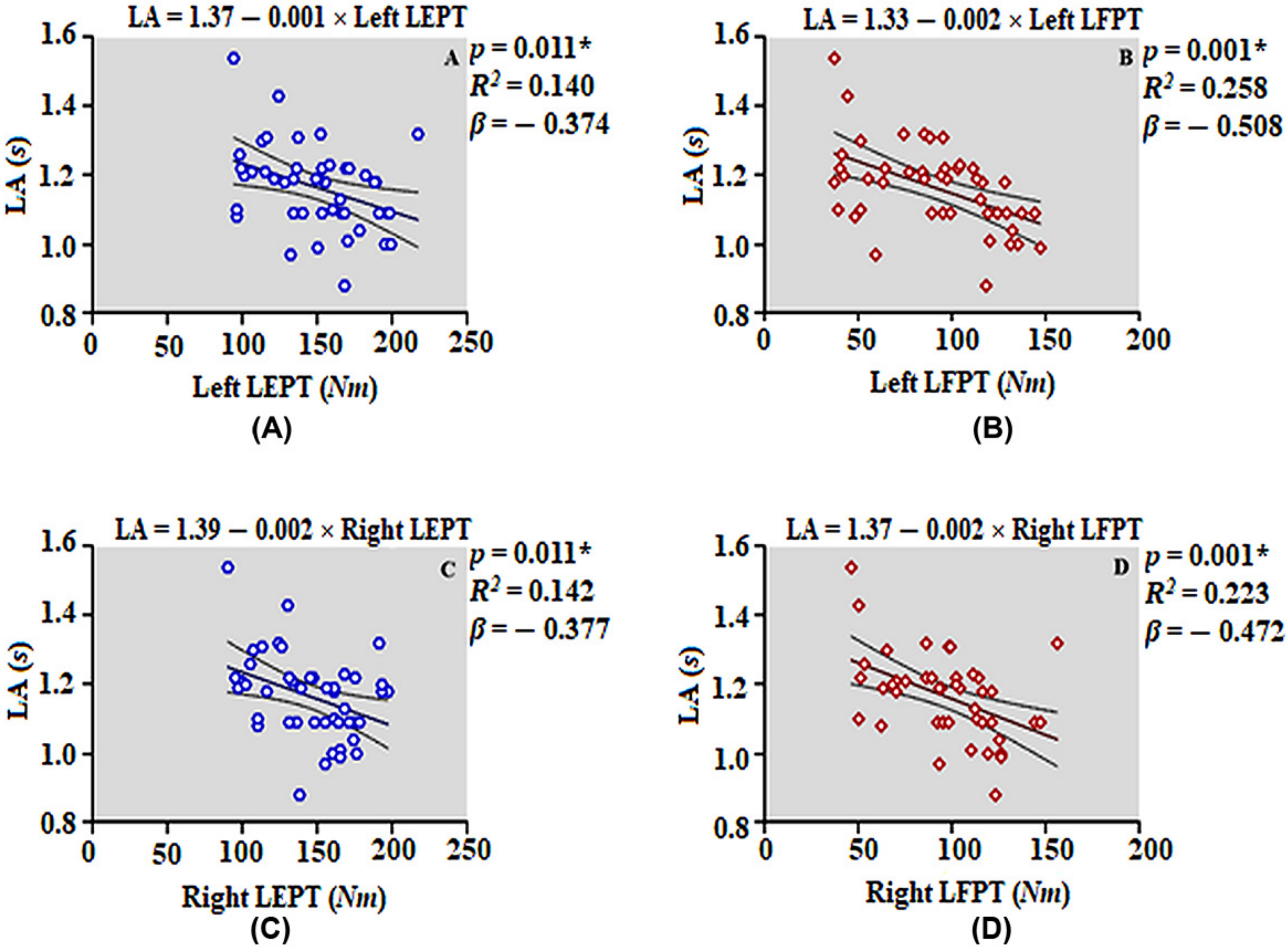


FIGURE 7. Relationship between late acceleration and isokinetic leg strength. (A) Relationship between late acceleration and left LEPT. (B) Relationship between late acceleration and left LFPT. (C) Relationship between late acceleration and right LEPT. (D) Relationship between late acceleration and right LFPT. LEPT: leg extension peak torque; LFPT: leg flexion peak torque; LA: late acceleration. *: indicates statistically significant difference ($p < 0.05$).

affects late acceleration positively by 0.002, whereas one-Nm decrease affects late acceleration negatively by 0.002.

An analysis of Fig. 7D reveals that there is a significant relationship between late acceleration values and the right LEPT values of the subjects who participated in the study in the same direction ($p < 0.05$). It was observed that the right LFPT value explained 22.3% of the late acceleration. One-Nm change in the right LFPT value affects late acceleration by 0.002. One-Nm increase in the right LFPT value affects late acceleration positively by 0.002, whereas one-Nm decrease affects late acceleration negatively by 0.002.

An analysis of Fig. 8A reveals that there is a significant relationship between late acceleration and GB in the opposite direction ($p < 0.05$). It was observed that GB explained 17.9% of the late acceleration. One-score change in GB affects late acceleration by 0.06. One-score increase in GB affects late acceleration negatively by 0.06, whereas one-score decrease in GB affects late acceleration positively by 0.06.

An analysis of Fig. 8B reveals that there is a significant relationship between the late acceleration values and AE values of the respondents in the opposite direction ($p < 0.05$). It was observed that the AE value explained 33.9% of the late acceleration. One-s change in AE value affects late acceleration by 0.03. One-s increase in AE value affects late acceleration negatively by 0.03, whereas one-s decrease in AE value affects late acceleration positively by 0.03.

An analysis of Fig. 9A reveals that there is a significant relationship between the transition phase values of the subjects who participated in the study and the left LEPT values in the same direction ($p < 0.05$). It was observed that the left LEPT value explained 15.1% of the transition phase. One-Nm change in the left LEPT value affects the transition phase by 0.002. One-Nm increase in left LEPT value affects the transition phase positively by 0.002, whereas one-Nm decrease affects the transition phase negatively by 0.002.

An analysis of Fig. 9B reveals that there is a significant relationship between the transition phase values and the left LEPT values of the subjects who participated in the study in the same direction ($p < 0.05$). It was observed that the left LFPT value explained 15.9% of the transition phase. One-Nm change in the left LFPT value affects the transition phase by 0.002. One-Nm increase in the left LFPT value affects the transition phase positively by 0.002, whereas one-Nm decrease affects the transition phase negatively by 0.002.

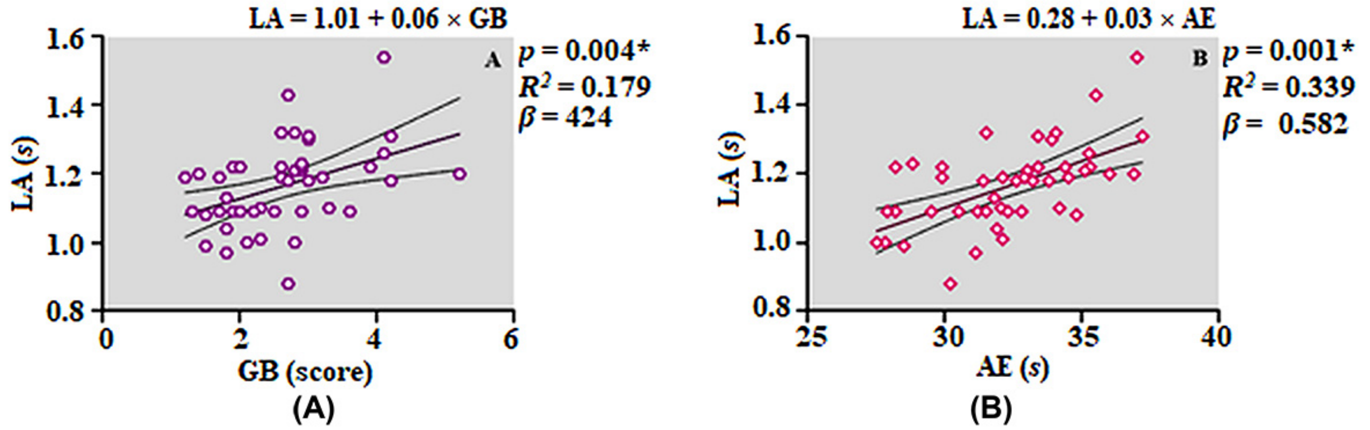


FIGURE 8. Relationship between late acceleration, balance, and anaerobic endurance. (A) The relationship between late acceleration and GB. (B) The relationship between late acceleration and AE. GB: general balance score; AE: anaerobic endurance; LA: late acceleration. *: indicates statistically significant difference ($p < 0.05$).

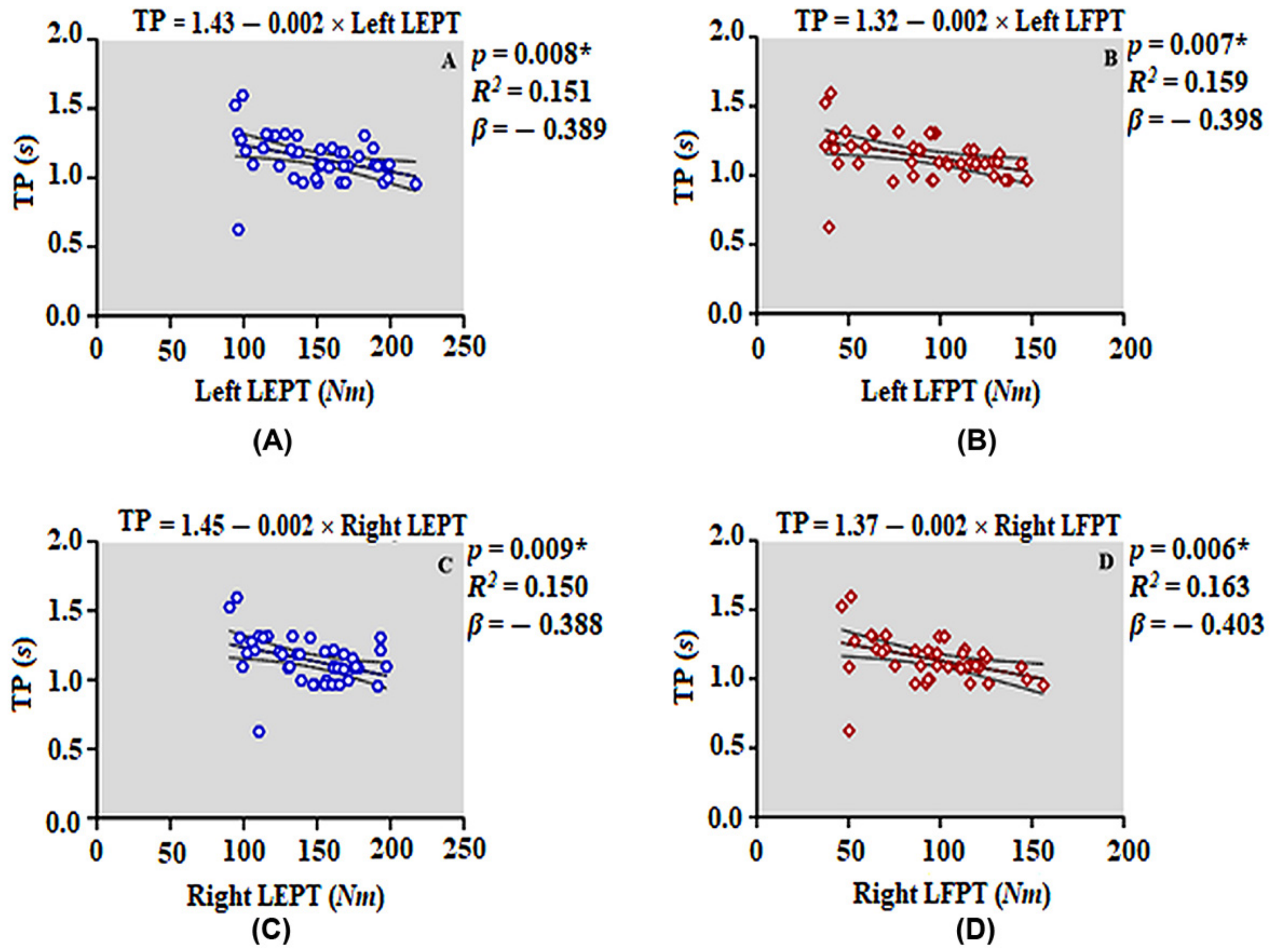


FIGURE 9. Relationship between transition phase and isokinetic leg strength. (A) Relationship between transition phase and left LEPT. (B) Relationship between transition phase and left LFPT. (C) Relationship between transition phase and right LEPT. (D) Relationship between transition phase and right LFPT. LEPT: leg extension peak torque; LFPT: leg flexion peak torque; TP: transition phase. *: indicates statistically significant difference ($p < 0.05$).

An analysis of Fig. 9C reveals that there is a significant relationship between the transition phase values and the right LEPT values in the same direction ($p < 0.05$). It was observed that the right LEPT value explained the transition phase by 15%. One-Nm change in the right LEPT value affects the transition phase by 0.002. One-Nm increase in the right LEPT value positively affects the transition phase by 0.002, whereas one-Nm decrease in the right LEPT value negatively affects the transition phase by 0.002.

An analysis of Fig. 9D reveals that there is a significant relationship between the transition phase values of the subjects who participated in the study and the right LEPT values in the same direction ($p < 0.05$). It was observed that the right LFPT value explained the transition phase by 16.3%. One-Nm change in the right LFPT value affects the transition phase by 0.002. One-Nm increase in the right LFPT value affects the transition phase positively by 0.002, whereas one-Nm decrease affects the transition phase negatively by 0.002.

An analysis of Fig. 10A reveals that there is no significant relationship between GB and transition stage values of the respondents ($p > 0.05$). It was observed that the change in GB did not affect the transition phase.

An analysis of Fig. 10B reveals that there is a significant relationship in the opposite direction between the transition phase values and AE values of the subjects who participated in the study ($p < 0.05$). It was observed that the AE value explained 21.7% of the transition phase. One-s change in AE value affects the transition phase by 0.03. One-s increase in AE value affects the transition phase negatively by 0.03, whereas one-s decrease in AE value affects the transition phase positively by 0.03.

An analysis of Fig. 11A reveals that there is a significant relationship between the maximum speed values and left LEPT values of the subjects who participated in the study in the same direction ($p < 0.05$). It was observed that the left LEPT value explained 37% of the maximum speed. One-Nm change in the left LEPT value affects the maximum speed by 0.005. One-Nm increase in the left LEPT value affects the maximum speed positively by 0.005, whereas one-Nm decrease affects the maximum speed negatively by 0.005.

An analysis of Fig. 11B reveals that there is a significant relationship between the maximum speed values of the subjects who participated in the study and the left LFPT values in the same direction ($p < 0.05$). It was observed that the left LFPT value explained 47.7% of the maximum speed. One-Nm change in the left LFPT value affects the maximum speed by 0.006. One-Nm increase in the left LFPT value affects the maximum speed positively by 0.006, whereas one-Nm decrease affects the maximum speed negatively by 0.006.

An analysis of Fig. 11C reveals that there is a significant relationship between the maximum speed values and the right LEPT values of the subjects who participated in the study ($p < 0.05$). It was observed that the right LEPT value explained 35.9% of the maximum speed. One-Nm change in the right LEPT value affects the maximum speed by 0.006. One-Nm increase in the right LEPT value affects the maximum speed positively by 0.006, and one-Nm decrease affects the maximum speed negatively by 0.006.

An analysis of Fig. 11D reveals that there is a significant relationship between the maximum speed values of the subjects who participated in the study and the right LFPT values in the same direction ($p < 0.05$). It was observed that the right LFPT value explained 51.3% of the maximum speed. One-Nm change in the right LFPT value affects the maximum speed by 0.008. One-Nm increase in the right LFPT value affects the maximum speed positively by 0.008, whereas one-Nm decrease affects the maximum speed negatively by 0.008.

An analysis of Fig. 12A reveals that there is a significant relationship in the opposite direction between the maximum speed values of the subjects participating in the study and GB ($p < 0.05$). It was observed that GB explained 9.9% of the maximum speed. A one-score change in GB affects maximum speed by 0.11. One-score increase in GB has a negative effect on maximum speed by 0.11, whereas one-score decrease in GB has a positive effect on maximum speed by 0.11.

An analysis of Fig. 12B reveals that there is a significant relationship in the opposite direction between the maximum speed values and AE values of the subjects who participated in the research ($p < 0.05$). It was observed that the AE value explained 70.6% of the maximum speed. One-s change in AE value affects the maximum speed by 0.09. One-s increase in AE value affects maximum speed negatively by 0.09, whereas one-s decrease in AE value affects maximum speed positively by 0.09.

An analysis of Fig. 13A reveals that there is a significant relationship between the sprint continuity values of the subjects who participated in the study and the left LEPT values in the same direction ($p < 0.05$). It was seen that the left LEPT value explained 32.3% of the speed continuity. A one-Nm change in the left LEPT value affects the speed continuity by 0.004. One-Nm increase in the left LEPT value positively affects sprint persistence by 0.004, whereas one-Nm decrease in the left LEPT value negatively affects sprint persistence by 0.004.

An analysis of Fig. 13B reveals that there is a significant relationship between the sprint continuity values and the left LFPT values in the same direction ($p < 0.05$). It was seen that the left LFPT value explained 42.8% of the speed continuity. A one-Nm change in the left LFPT value affects sprint persistence by 0.004. One-Nm increase in the left LFPT value positively affects sprint persistence by 0.004, whereas one-Nm decrease in the left LFPT value negatively affects sprint persistence by 0.004.

An analysis of Fig. 13C reveals that there is a significant relationship between the sprint continuity values and right LEPT values of the subjects who participated in the study in the same direction ($p < 0.05$). It was seen that the right LEPT value explained 26.2% of the speed continuity. One-Nm change in the right LEPT value affects the speed persistence by 0.004. One-Nm increase in the right LEPT value positively affects speed persistence by 0.004, whereas one-Nm decrease in right LEPT value negatively affects speed persistence by 0.004.

An analysis of Fig. 13D reveals that there is a significant relationship between the sprint continuity values and right LEPT values of the subjects who participated in the study in the same direction ($p < 0.05$). It was seen that the right LFPT value explained 41.5% of the speed continuity. One-Nm change in the right LFPT value affects the speed continuity by 0.005.

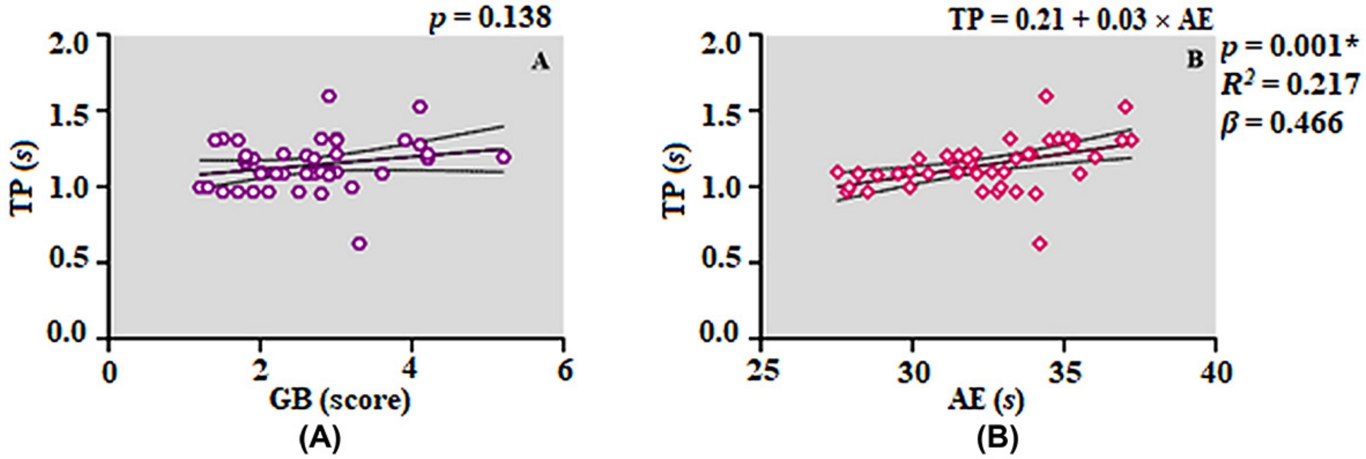


FIGURE 10. Relationship between transition phase, balance, and anaerobic endurance. (A) The relationship between the transition phase and GB. (B) The relationship between the transition phase and AE. GB: general balance score; AE: anaerobic endurance; TP: transition phase.*: indicates statistically significant difference ($p < 0.05$).

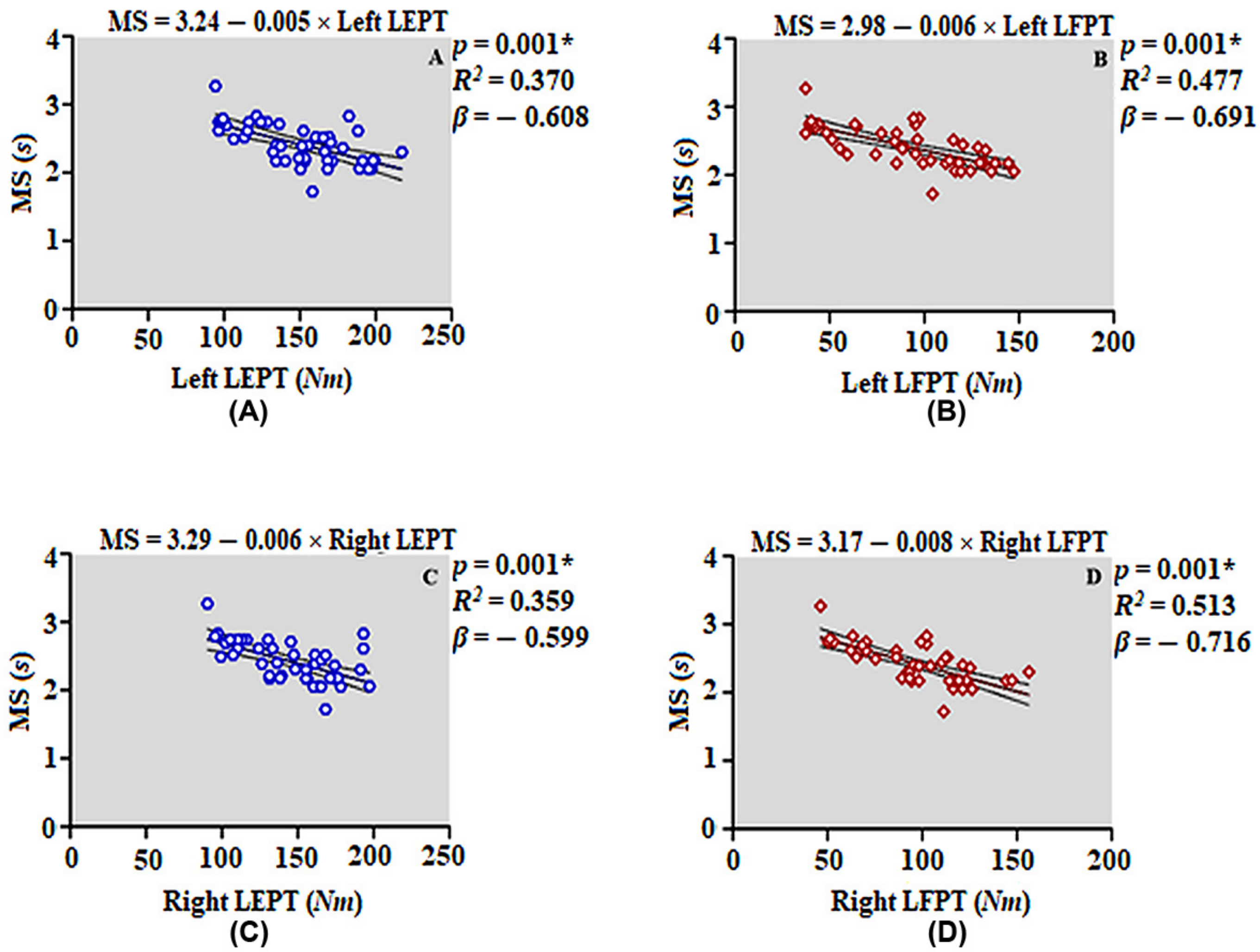


FIGURE 11. Relationship between maximum speed and isokinetic leg strength. (A) Relationship between maximum speed and left LEPT. (B) Relationship between maximum speed and left LFPT. (C) Relationship between maximum speed and right LEPT. (D) Relationship between maximum speed and right LFPT. LEPT: leg extension peak torque; LFPT: leg flexion peak torque; MS: maximum speed. *: indicates statistically significant difference ($p < 0.05$).

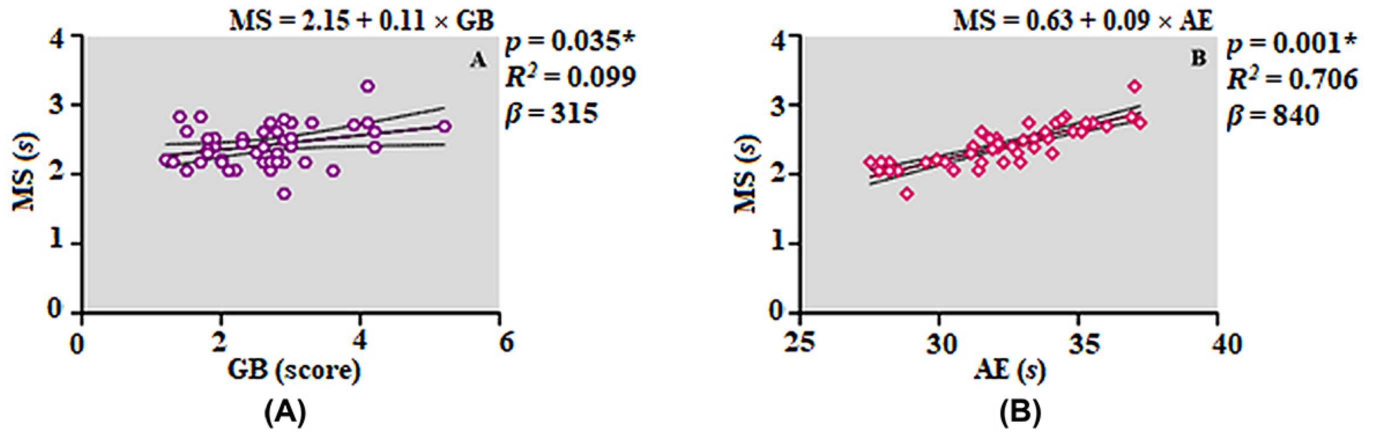


FIGURE 12. Relationship between maximum speed, balance, and anaerobic endurance. (A) The relationship between maximum speed and GB. (B) The relationship between maximum speed and AE. GB: general balance score; AE: anaerobic endurance; MS: maximum speed. *: indicates statistically significant difference ($p < 0.05$).

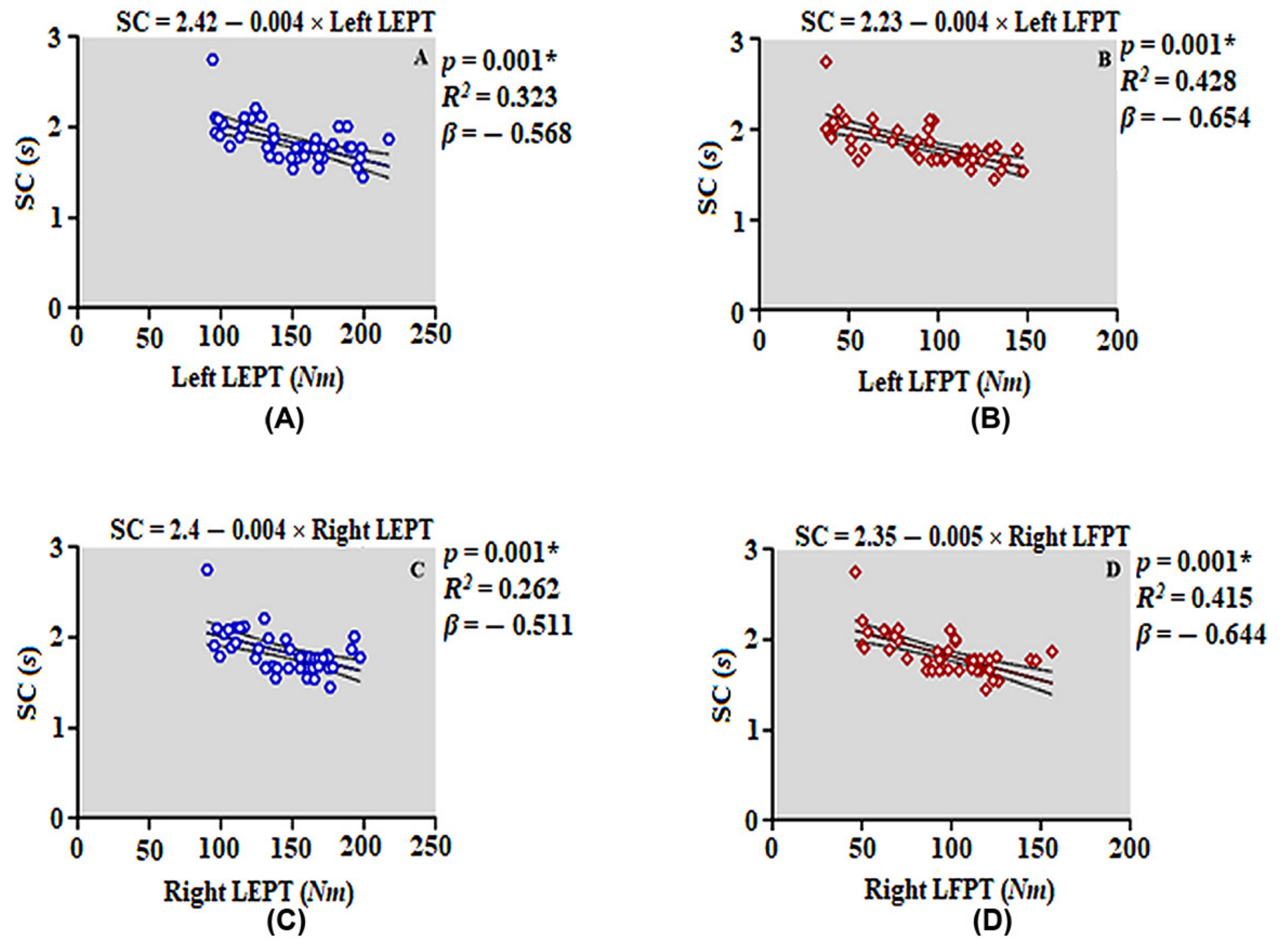


FIGURE 13. Relationship between sprint continuity and isokinetic leg strength. (A) The relationship between sprint continuity and left LEPT. (B) Relationship between sprint continuity and left LFPT. (C) Relationship between sprint continuity and right LEPT. (D) Relationship between sprint continuity and right LFPT. LEPT: leg extension peak torque; LFPT: leg flexion peak torque; SC: sprint continuity. *: indicates statistically significant difference ($p < 0.05$).

One-Nm increase in the right LFPT value positively affects speed persistence by 0.005, whereas one-Nm decrease in the right LFPT value negatively affects speed persistence by 0.005.

An analysis of Fig. 14A reveals that there is a significant relationship in the opposite direction between GB and sprint continuity values of the subjects who participated in the study ($p < 0.05$). It was seen that GB explained 16.6% of the speed persistence. One-score change in GB affects speed persistence by 0.1. One-score increase in GB has a negative effect on speed persistence by 0.1, whereas one-score decrease in GB has a positive effect on speed persistence by 0.1.

An analysis of Fig. 14B reveals that there is a significant relationship in the opposite direction between the sprint continuity values and AE values of the subjects who participated in the study ($p < 0.05$). It was observed that AE value explained 64.6% of the sprint continuity. One-s change in AE value affects the speed endurance by 0.07. One-s increase in AE value affects speed endurance negatively by 0.07, whereas one-s decrease in AE value affects speed endurance positively by 0.07.

4. Discussion

The present study offers a comprehensive assessment of the influence of isokinetic leg strength, anaerobic endurance, and balance on sprint performance by analyzing their specific contributions across different phases of sprinting. The findings provide valuable insights into the multifactorial nature of sprinting and underscore the importance of adopting an integrative approach to performance development. This study clarifies how specific physical capacities affect different sprint phases. These findings can help refine training methodologies aimed at improving phase-specific sprint performance. In doing so, it supports the implementation of more effective and evidence-based practices within sprint-focused athletic disciplines. Accordingly, the primary aim of this study was to investigate the effects of isokinetic leg strength, balance, and anaerobic endurance on the various phases of sprint performance.

It was observed that left leg extension peak torque (LEPT) values influenced all phases of sprinting except reaction speed, while left leg flexion peak torque (LFPT) values affected all phases except for reaction speed and the mid-acceleration phase. Right LEPT values were found to impact all sprint phases except for reaction time and early acceleration, whereas right LFPT values significantly influenced all sprint phases. Overall, isokinetic leg strength was found to play a role in all phases of sprinting, with the most pronounced effects observed in the maximum velocity and sprint continuity phases.

Previous research has shown that the early acceleration phase is more reliant on the proximal musculature of the hip and thigh [12], while the mid-acceleration phase receives substantial contributions from both hip and leg muscles [5]. The results of our study align with these findings, particularly the observed influence of leg strength during the mid-acceleration phase. In the late acceleration and maximum velocity phases, lower leg musculature has been shown to play a dominant role, as the foot strikes the ground with a forceful backward motion, generating high ground reaction force near the sprinter's center of mass [17, 30].

In a study of 14 male sprinters, Alexander *et al.* [31] reported a negative correlation between high-speed isokinetic knee extensor strength and 100 m sprint times. Sadi and Diker [32] found no relationship between isokinetic strength values measured at 60 °/s angular velocity and 10 m sprint performance. However, they observed a negative correlation between right and left leg extension peak torque and 30 m sprint times, suggesting that athletes with greater extensor muscle strength in both legs demonstrated better sprint performance. No relationship was found with 10 m performance; however, a weak correlation was observed for 30 m sprint times. This supports our finding that isokinetic force values at 60 °/s gain importance as sprint distance increases.

Schache [33] highlighted that knee extensor joint torque is a key contributor to powerful knee extension during the swing phase of sprinting. Dowson *et al.* [34], in a study involving rugby players, sprinters, and team athletes, examined the relationship between isokinetic strength and sprint performance using a Cybex isokinetic dynamometer. They assessed strength in the hip extensors/flexors, knee extensors/flexors,

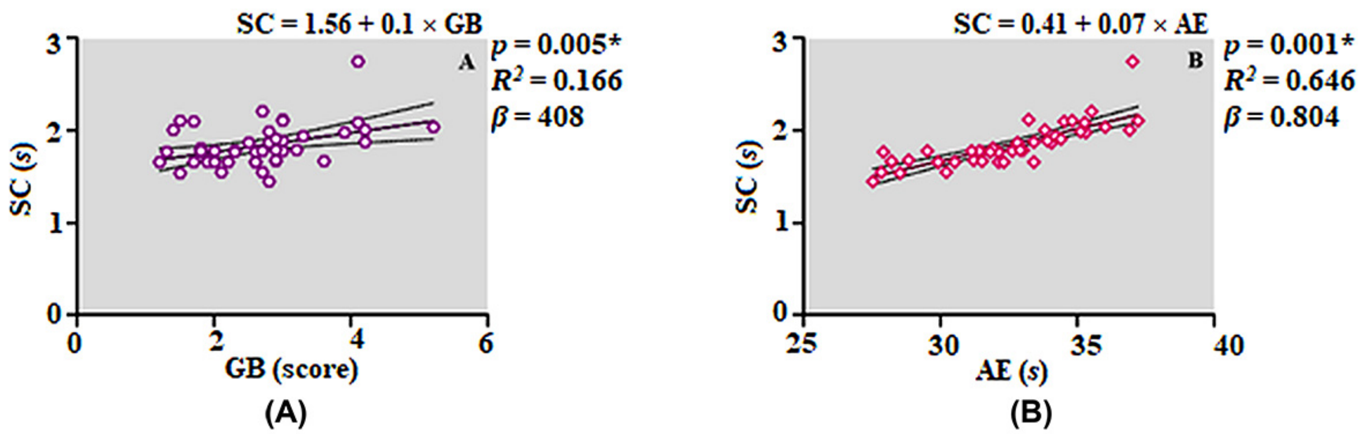


FIGURE 14. Relationship between sprint continuity, balance, and anaerobic endurance. (A) The relationship between sprint continuity and GB. (B) The relationship between sprint continuity and AE. GB: General balance score; AE: Anaerobic endurance; SC: sprint continuity. *: indicates statistically significant difference ($p < 0.05$).

and ankle plantar/dorsiflexors of the dominant leg and found significant relationships between isokinetic strength and both acceleration and speed phases, supporting our findings.

Similarly, Hori [35] investigated the relationship between speed performance and isokinetic strength in sprinters and non-sprinters and found stronger correlations at higher angular velocities. He attributed this to the specificity of training at higher speeds and concluded that isokinetic knee extensor strength is an important determinant of sprint performance. Although some studies have reported no significant relationships between knee extensor/flexor strength at 60 °/s and sprint performance [36, 37], others have found statistically significant correlations at the same velocity [38, 39]. The reason for this situation is thought to be due to differences in sprint distance.

İbret [40] found a negative relationship between isokinetic strength and 10, 20, and 30 m sprint performance. Another study reported a weak negative correlation between quadriceps relative strength (dominant and non-dominant legs) and 30 m sprint performance at 60 °/s. These findings underscore that both maximal strength and the ability to sustain force are critical during the acceleration phase [41]. Harris *et al.* [42] emphasized a positive relationship between leg strength and sprint performance, while Ozçakar *et al.* [43] reported a significant relationship between leg muscle strength and sprint performance at 60 °/s in elite athletes aged 18 to 31. Another study found a significant correlation between isokinetic leg strength and 30 m sprint performance but no relationship with 10 m acceleration performance [44]. The results of these studies in the literature support our research findings.

Majumbar and Robergs [45] noted that muscular strength plays a greater role in the acceleration phase of sprinting. Increasing lower extremity muscle strength and power has been shown to improve athletic performance across various disciplines [46]. Overall, most studies in the literature have evaluated maximum 30 m sprint performance, and many support the findings of our current research.

With regard to balance, general balance scores were found to influence the early acceleration, late acceleration, maximum speed, and sprint continuity phases, with the strongest effects observed during the maximum speed and sprint continuity phases.

Hunt [47] identified a positive trend between balance and sprint performance, noting that while balance is associated with overall sprint ability, it has a lesser effect on peak sprint speed. He emphasized that the acceleration phase, which demands more coordination, is more influenced by balance ability. Hunt's [47] research findings support our results regarding the relationship between balance and sprint performance. However, they contradict our results regarding the effect of balance on the sprint phases. While our study found that balance performance increased as sprint distance increased, Hunt's study indicated that the acceleration phase was more strongly affected by balance performance.

Myer *et al.* [48] found that participants' acceleration performance improved significantly after a 6-week balance training program. They argued that the direction of force application is critical during acceleration, and poor balance can result in non-linear force application, negatively affecting subsequent sprint phases. They also noted that each step's velocity must contribute to forward propulsion, and inefficiencies in one step may accumulate over subsequent steps. They further emphasized that since the acceleration and total sprint durations are longer than the maximum speed phase, poor balance has a greater impact on total sprint time due to the accumulation of errors over multiple steps.

One study identified a significant correlation between balance performance and 30 m sprint performance in male sprinters, where improvements in balance were associated with improved sprint performance [49]. However, other studies did not find a significant relationship between balance and 30 m sprint performance [50]. Eğribel [51] found that 8 weeks of balance training did not improve 20 m sprint performance, and Engin [52] reached similar conclusions in young athletes aged 12–15. Since most studies focus only on 30 m sprints, the effects of balance on the maximum speed and sprint continuity phases remain underexplored. These findings support our results, as balance was not found to affect reaction speed, mid-acceleration, or the transition phase in our study.

Anaerobic endurance values were found to influence all sprint phases except for reaction speed, with the greatest effects observed during the maximum speed and sprint continuity phases. Dural [53] found that anaerobic endurance did not affect 5- or 30 m sprint performance, but had an impact on 15 m acceleration. The findings of Dural [53] partially support the results of the present study, as anaerobic endurance was found to influence the acceleration phase rather than the reaction phase. However, unlike our results, Dural reported no significant effect of anaerobic endurance on 30 m sprint performance. This inconsistency may stem from the methodological difference, particularly Dural's evaluation of 30 m sprint performance as a whole, without distinguishing between its phases. Solak [54] studied 14-year-old football players and found no significant relationship between anaerobic endurance and sprint or agility parameters. Mohr and Krustrup [55] reported that sprint endurance training improved repeated sprint performance in football players over four weeks. Another study examining the effects of a 6-week sprint endurance program on 10- and 35 m sprint performance in elite soccer players found significant improvements in 10 m sprints but not in 35 m sprints [56].

Gunnarsson *et al.* [57] found that a five-week pre-season sprint endurance program did not affect 10- or 30 m sprint performance. Similarly, Ferrari Bravo *et al.* [58] reported no correlation between 6 × 40 m runs and 10 m sprint performance in young soccer players. Overall, the literature includes limited research on the effect of anaerobic endurance on sprint performance, supporting the novelty and relevance of our study.

5. Conclusions

An analysis of the research findings revealed that only the right LFPT variable had a statistically significant effect on reaction speed. This outcome is likely attributable to the athletes' dominant use of the right leg. In contrast, balance was found to have no significant impact on reaction speed, mid-acceleration, or transition phases. This may be explained by the relatively fixed body position observed during mid-acceleration and the upright posture maintained during the transition phase, which may limit the influence of balance-related factors. Notably, all measured variables—namely isokinetic leg strength, balance, and anaerobic endurance—were found to influence the early acceleration, late acceleration, maximum speed, and sprint continuity phases. These results highlight the considerable contribution of these physical capacities to overall sprint performance. Among all phases, the maximum speed and sprint continuity phases were most strongly influenced by the variables under investigation. This may be due to the longer distances covered during these particular sprint segments compared to other phases, thus providing a greater window for performance variables to exert their effects.

Based on these findings, it is recommended that athletes' leg strength, balance, and anaerobic endurance capacities be prioritized in the design of training programs across all sports disciplines that involve short- or long-distance sprinting. These parameters appear especially critical in sports that require sprinting distances of 40 m or more, where maximal velocity and sprint endurance are key determinants of performance.

6. Limitations

This study has several limitations that should be taken into account.

First, the participant sample consisted of individuals with unspecified training backgrounds, which may limit the generalizability of the findings to more homogeneous or athletic populations.

Second, isokinetic testing was conducted solely at a low angular velocity (60 °/s), which may not fully capture strength characteristics observable at higher velocities.

Third, the cross-sectional nature of the study design prevents the establishment of causal relationships between the variables examined.

Fourth, the inclusion of only male participants in the study limits the relevance of the results to female athletes.

Fifth, the participants' training history and sprint training experience are unknown, limiting the external validity and interpretability of the findings.

Sixthly, the lack of a control/intervention group limits the interpretability of the study.

AVAILABILITY OF DATA AND MATERIALS

Data are available for research purposes upon reasonable request to the corresponding author.

AUTHOR CONTRIBUTIONS

İHŞ and AOK—designed the research study; wrote the manuscript; performed the research; analyzed the data. Both authors contributed to editorial changes in the manuscript. Both authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the ethics committee of Selcuk University, Faculty of Sport Sciences, Non-Interventional Clinical Research (Reference number: 2022/163). Besides, all participants gave written informed consent to participate in this study following being informed about the procedures approved by the ethics committee and in accordance with the Declaration of Helsinki.

ACKNOWLEDGMENT

The author would like to thank all the dedicated athletes and their coaches for their participation. This work was funded by Selçuk University Scientific Research Projects Coordination. The authors have no conflicts of interest to disclose.

FUNDING

This research was supported by Selçuk University Scientific Research Projects Coordination with the Project numbered 22212045.

CONFLICT OF INTEREST

There is no personal or financial conflict of interest among the authors of the article within the scope of the study.

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How to cite this article: İbrahim Halil Şahin, Ali Osman Kıvrak. Analysis of the phases of sprint in terms of isokinetic leg strength, anaerobic endurance, and balance. Journal of Men's Health. 2025; 21(10): 62-78. doi: 10.22514/jomh.2025.127.