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Kinetics and kinematic analysis of different phases in 100m sprints

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Abstract
Purpose: This paper reports on the effect of the leg strength, pre-running pulse rate and other kinematic characteristics, such as velocity and acceleration, on sprinters' ability to complete a 100-meter sprint.
Methodology: The study subjects are eight Rajshahi University sprinters (5 males and 3 females) chosen through the inter-university athletics championship-2022. Their ages ranged from 21 to 24 years. In the present study, a 100-meter running distance was divided into ten equal distance zones, with two manual stopwatch timers stationed at the end of each 10-meter segment. Time data was calculated using the two timekeepers' averages for each zone. Two 100m trials were conducted after an hour's rest from the initial trial, and the fastest time was used as the final data. Leg strength and pre-run heart rate were measured using the Japanese leg strength machine ZARITZ BM-220 and an oximeter.
Results: The present study observed that the sprinter (both male and female) having normal pre-run pulse rate, superior leg strength, better reaction time ability, longer speed endurance, but lower deceleration rate takes least time to cover the 100m sprint. In contrast, the sprinter taking longer time has poor leg strength, weak reaction time ability, shorten speed maintenance, and higher deceleration rate. The present study concludes that sports performance anxiety can increase heart rate prior to a sprint, thereby reducing performance, whereas peak limb strength indicates peak performance.

Keywords: Leg strengths, kinematic, 100m sprint, sports performance, phase analyses

Introduction

Sprinting ability is the most important factor for performance excellence in most of the games and sports. Sprinting is a track event in which a small distance of track is covered in a short period of time [1, 2]. It has an extensive history. For an example, the "stadium", the earliest and most widely recognized event in the old Olympic Games, was one among the ancient Greek races comparable to a sprint. In the current Olympic competition there are three sprint events: 100m, 200m, and 400m run. These sprinting events are significant in athletics because they demonstrate an athlete's quickness, strength, and athleticism. Obviously, the 100m dash is presently the fastest race in outdoor field and track running competitions [3]. The nature and qualities of an athlete's sprinting ability can be better understood by running 100 meters. As a result, 100m sprinting is rightly recognized as the most stunning athletics event at major championships such as the Olympic Games.

The 100m dash for men debuted at the modern Olympic Games in Greece at 1896. However, for the female, it was included later at the Olympics of 1928 in Amsterdam. Since electronic timing became obligatory in 1977, the men's world record has been broken twelve times. The world record of 9.58 seconds set by Usain Bolt of Jamaica at the IAAF World Athletics Championships 2009 in Berlin, Germany remains history's fastest 100. He beat his own standing world record, which was set in 1998 during the Olympic Games in China, by 0.11 seconds [3]. Florence Griffith-Joyner of the United States established the current women's world mark of 10.49 seconds at the 1988 United States Olympic Trials in Indianapolis, Indiana. In a recent competition held in Queen Elizabeth Olympic Park in London, Bangladeshi athletes Imranur Rahman, an English sprinter of Bangladeshi descent, set a career best time of 10.11 seconds in the 100-meter sprint. Sprint running can thoroughly be studied in terms of kinematic, kinetic, and cardiac aspects [4].

There are certain variables that are significant in sprint running as well as distance running. Significant factors include force production technique, reaction time, muscle structure, electromyographic (EMG) activity, and neural factors [5]. Some researchers [6-8] divide the 100m dash into three stages: (i) acceleration, (ii) highest speed, and (iii) deceleration. Other study [9], however, demonstrated that throughout this short-distance race, the sprinter goes through five different speed phases: i) the reaction speed phase in the start, ii) the acceleration phase (pick-up), 3) the maximal speed phase, iv) the speed maintenance phase, and v) finishing style.

Total reaction time is referred to as the period from the shooting signal until the runner produces force onto the starting blocks [10]. Good reaction time implies an excellent beginning. Usually, the first 10m indicates reaction time capability. Acceleration ability denotes the ability to reach high speeds in the shortest amount of time. The first 30 meters are considered as the acceleration phase, in which competitors seek to attain their maximal velocity by driving strongly off the starting blocks and progressively moving from a crouching to an upright sprinting stance. Maximum velocity is the ability to reach the highest speed, and it is calculated by calculating regional velocity. 10-meter segments extending between 60 and 80 meters can be considered to be part of the maximum speed phase [11, 12]. Speed endurance is another term for speed maintenance. It is the capacity to sustain maximal speed for an extended period, and it is computed using regional velocity. Competition analysis indicates that athletes that have excellent starts are also good in velocity maintaining phase [13]. The final part of the 100-meter sprint involves deceleration measuring the percentage of velocity lost at the finish. At international championships, during the deceleration phase of a 100m race, the loss of velocity from maximum is usually varied from 0.9 to 7.0% [14, 15].

The explosive leg strength and speed both are dependent variables. Leg muscular strength is the driving force behind any activity including a 100-meter run, and it is thus an essential component of any efforts to improve total physical health [16]. The capacity to rapidly apply force with the lower extremities is a measure of leg muscle power (Power= force velocity), which is predictive of disability in older adults performance in sports [17, 18].

Anxiety, on the other hand, is an adverse mental state that includes worry and bodily activation that has been widely regarded as detrimental to athletic achievement [19]. Heavy playing timetables, competition for team positions, media attention and followers, and the desire to win medals all contribute to players developing high levels of stress and anxiety. A recent study found that the mental and emotional health of male and female athletes is negatively impacted by stress brought on by fear, dis-comfort, conflict, excessive anxiety, and pressure to win [20]. Competitive nervousness can cause physiological reactions such as sweating and a faster heart rate just before competitions. Runners who are anxious are more likely to perform poorly. Given that the ability to deal with pre-competition anxiety is a pre-requisite for high-level performance [21]. The present study, therefore, aims to assess the 100-meter sprint skills of both male and female sprinters of Rajshahi University, Bangladesh in terms of some kinetic and kinematic variables and their relationship to pulse rate and leg strength.

The rest of this paper is organized as follows. The next section provides materials and methods of the current study. In section three, the results of our study are described and thoroughly compared with existing data and previous reported investigations. This paper concludes with a conclusion based on our findings.

Materials and Methods

Study Subject: A total of eight (five male and three female) sprinters from Rajshahi University, Bangladesh were chosen as the subject. They were selected through the inter-university athletics championship-2022. These sprinters can be classified as national or average-level performers based on their performance level. Their ages were ranged from 21 to 24 years with mean of years.

Preparation of field and Participants: The sprinting event was held in the field of Rajshahi University stadium. A 100m linear path was divided into 10 equal distance regions as shown in Fig. 1. A pair time-keeper was stationed on both sides of the lane at the end of each 10m segment. The times were recorded using a manual stopwatch. The goal of the experiment was briefly communicated to all subjects at the start of the experiment for improved understanding and motivation. The participants were instructed to put forth his greatest effort. The participant was given enough warm-up time prior to the race.

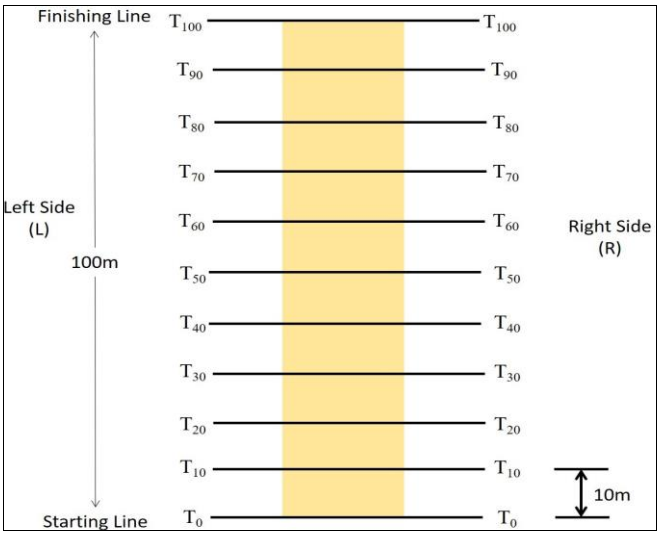

Fig 1: A 100m linear runway divided into ten equal distance intervals of 10m each.

Data Collection: Leg strength and pulse rate were measured using the Japanese leg strength machine ZARITZ BM-220 and pulse oximeter. The BM-220 is a portable and lightweight testing instrument used to assess a person's instant muscle strength, balance, and speed. In this study the measurement was taken by setting both feet on the platform while sitting in a chair and informing the subject when to get up and sit down three times in a row. The chair-sitting posture for the measurement of ground reaction is displayed in Fig. 2A. The upward ground reaction force created when standing from a chair was obtained by laying the right and left legs on the black area in the image with the chair-sitting posture. For the speed and acceleration analyses the only determining criterion was the time to cover distinct zones. The timers were taking time data (as shown in Fig. 2B) for various regions for distinct racers during data collection. Time data was taken as the mean of the two times recorded by each of the two timekeepers in each zone. The best timing from the two 100-meter trials was used to generate the final data. The first trial lasted for an hour before the second one started.

Fig 2: Experimental set-up for the measurements of A. ground reaction force and knee joint Extension/flexion muscle strength, and B. the time to cover different zones.

Data Analysis: The BM-220 is linked to a laptop, and the measurement data was analyzed with Zaritz software, which produced a report on a query sheet. A person's motor function is indicated by the test analysis results, which range from 1 to 150 points. Regional time and speed were computed using a suitable formula [9] based on the recorded data. The graph was constructed using MS Excel program.

Results

The estimated zonal times for all the subjects are presented in Table 1. First five rows (Registered as RUM1 to RUM5) are for the male sprinters and last three (registered as RUF1 to RUF3) are for the female sprinters. These times were obtained from the distance-time data measured in this study. Table 1 demonstrates that all the male sprinters spent the shortest time in the zone 50-60m. Whereas, for the female sprinters the shortest times were seen at 60-70m zone. A deceleration phase for all male sprinters has been observed after 80m, which is absent in the case of female sprinters. In overall, the female sprinters took much times as compared to the male sprinters to cover full length (100m).

It is also evident from Table 1 that the sprinters RUM5 and RUF1 took the shortest time among the male and female sprinters respectively. The displacement versus time curves of these two fastest sprinters are depicted in Fig. 3. These two curves exhibit similar pattern but with different in times to cover the same displacement. The male sprinter (RUM5) is faster than the female one (RUF1). Similar picture has been observed for the case of other male and female sprinters, but not included in this paper because of space constraints. To finish full length of 100m the sprinter RUM5 took 12.11 seconds whereas it was 15.37 seconds for RUF1.

Table 1: Regional time in second while passing the respective area in the subscripts.

Subject	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T10	Total
RUM1	1.97	1.37	0.91	1.46	0.91	0.75	1.24	1.38	1.23	1.36	12.39
RUM2	1.95	1.32	0.99	1.33	0.96	0.88	0.94	1.52	1.24	1.29	12.26
RUM3	2.05	1.31	1.05	1.31	1.02	0.90	0.95	1.54	1.06	1.38	12.41
RUM4	1.97	1.23	1.06	1.31	1.02	0.91	0.92	1.55	1.04	1.28	12.35
RUM5	1.92	1.31	1.05	1.30	1.02	0.94	0.95	1.50	1.04	1.08	12.11
RUF1	2.28	1.52	1.41	1.61	1.33	1.37	1.03	2.14	1.56	1.12	15.37
RUF2	2.36	1.60	1.56	1.59	1.43	1.60	1.14	2.22	1.75	1.30	16.52
RUF3	2.26	1.58	1.49	1.55	1.42	1.53	1.15	2.21	1.69	1.24	16.02

We have estimated regional velocity of all the runners using their spending regional times, and are listed in Table 2. These data reveals a cyclic nature of velocity for the studied sprinters. For the male sprinters, the velocity increases over the first three 10m sections, and then decreases at the next 10m section. After that the sprinters regain their velocity and achieved their highest velocity at the 6th 10m section. The deceleration phase is then started and continued up to the finishing line. However, an elevated decrease rate of velocity is observed at the 8th 10m region. The fluctuating nature of velocity is rather more pronounced in the case of female sprinters. As in Table 2 an additional decrease in velocity of female sprinters is seen at the 6^{th} 10m section before attaining their highest velocity at the 7^{th} 10m section. However, unlike male sprinters, female sprinters did not loss velocity in the final 10m section.

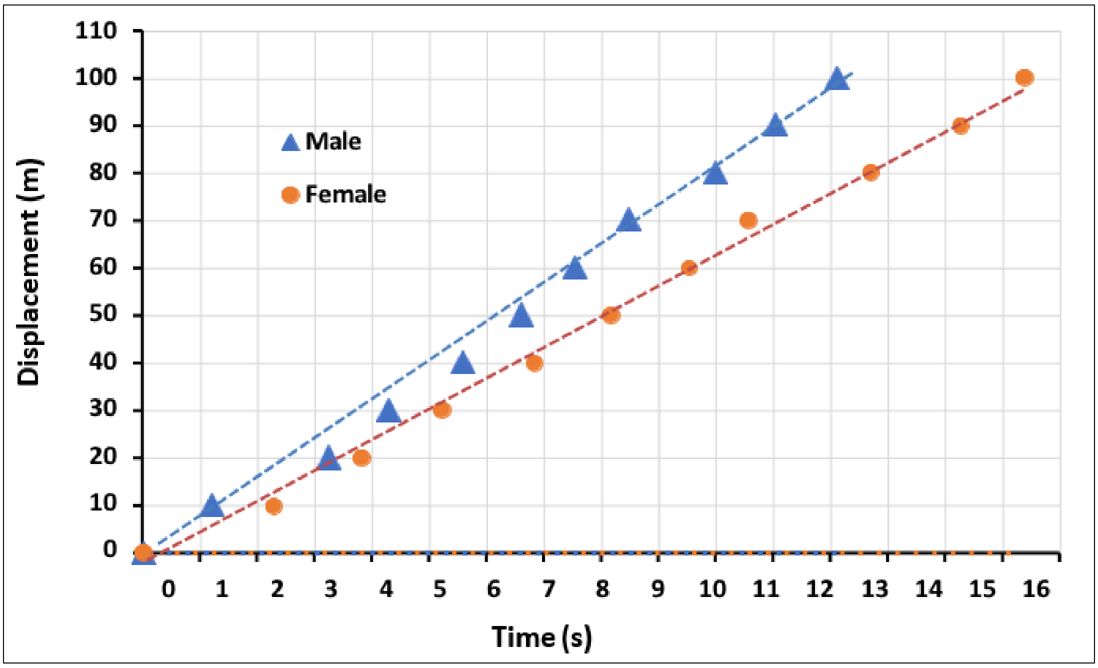

Fig 3: Displacement covered with time by the quickest male (RUM5) and female (RUF1) sprinters.

Fig 4 displays the variation of velocity with times of the fastest male (RUM5) and female (RUF1) athletes for comparison. These curves were obtained from the displacement time graphs of Fig 3. As seen in Fig 4, all through the racing time, the quickest female athlete has lower velocity as compared to that of the quest male athlete, and their velocity difference increases with time. As a result, the female athlete spent more time to cover the 100m length.

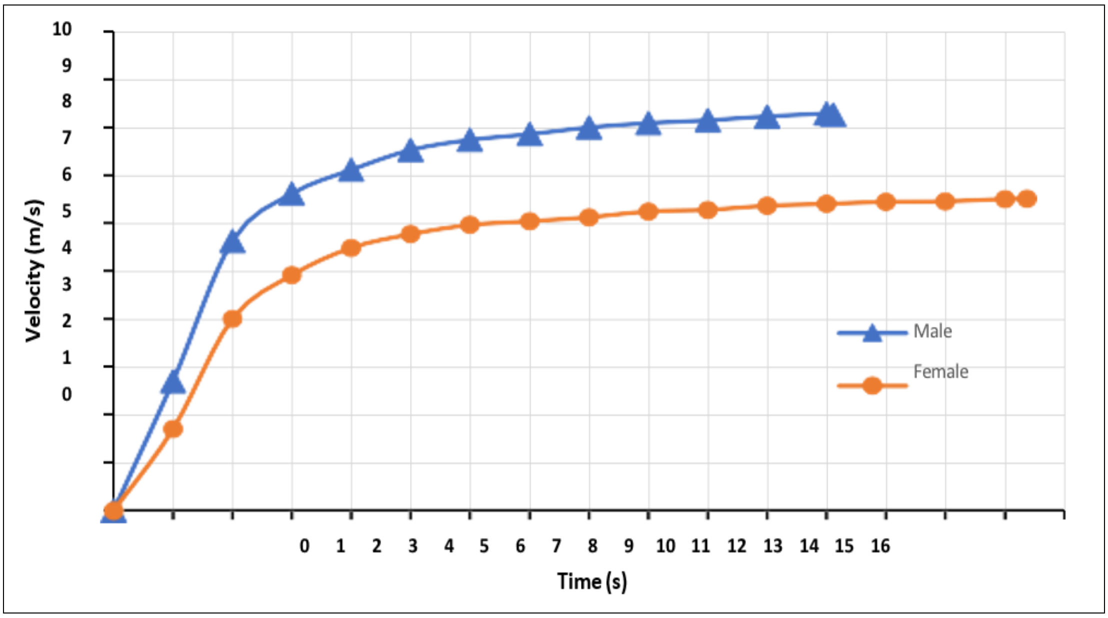

Fig 4: Variation of velocity with time for the fastest male (RUM5) and female (RUF1) athletes.

Table 2: Zonal velocity in meter per second while passing the respective area in the subscripts.

Subject	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V10
RUM1	5.07	7.28	10.99	6.85	10.99	13.33	8.06	7.25	8.13	7.35
RUM2	5.12	7.58	10.10	7.52	10.42	11.36	10.64	6.58	8.06	7.75
RUM3	4.88	7.63	9.52	7.63	9.80	11.11	10.53	6.49	9.43	7.25
RUM4	5.09	7.63	9.43	7.63	9.80	10.99	10.87	6.45	9.63	7.81
RUM5	5.22	7.63	9.52	7.69	9.80	10.64	10.53	6.67	9.60	9.26
RUF1	4.39	6.58	7.09	6.21	7.52	7.30	9.71	4.67	6.41	8.93
RUF2	4.23	6.25	6.41	6.29	6.99	6.25	8.77	4.50	5.71	7.69
RUF3	4.43	6.33	6.71	6.45	7.04	6.54	8.70	4.52	5.92	8.06

The measurement of sprinter's leg strength power included the stability, muscle strength, speed and leg strength score. All these quantities measured for the study subjects are displayed in Table 3. This Table also includes the pulse rates (normal, pre-run and post-run) of the athletes. As shown in 3, male sprinter RUM5 and female sprinter RUF1 had the greatest values of all four leg strength power parameters, but normal levels of pre-run pulse rate. All of these are impressive characteristics that could help them become the fastest athletes in their respective groups.

Discussion

In the present works, the achievement of the 100m dash has been analyzed by five phases: Reaction time, acceleration, maximum speed, speed maintenance, and deceleration. Good reaction time implies an excellent beginning. Here, first 10m indicates the reaction time capability. Acceleration ability denotes the ability to reach at higher speeds in the shortest amount of time; in this case, speed gained up to 30m shows acceleration capacity. Maximum speed is the ability to reach the highest speed, and maximum velocity is calculated by calculating regional velocity. Speed endurance is another term for speed maintenance. It is the capacity to sustain maximal speed for an extended period, and it has been computed using regional velocity. The final part of the 100m sprint involves deceleration measuring the percentage of velocity lost at the finish.

Table 3: Leg strength and pulse rate level of the study subjects.

Leg strength power					Pulse rate(beat/min)		
Subject	**Stability**	**Muscle strength**	**Speed**	**Score**	**Normal**	**Pre-run**	**Post-run**
RUM1	58	1.508	12.4	70	76	115	152
RUM2	60	1.698	18.4	83	73	97	155
RUM3	56	1.463	12.8	69	77	127	157
RUM4	63	1.671	15.9	77	71	109	145
RUM5	62	1.902	17.8	93	69	77	149
RUF1	61	1.789	19.3	92	72	96	145
RUF2	57	1.518	12.3	73	74	130	153
RUF3	54	1.263	11.8	62	69	113	148

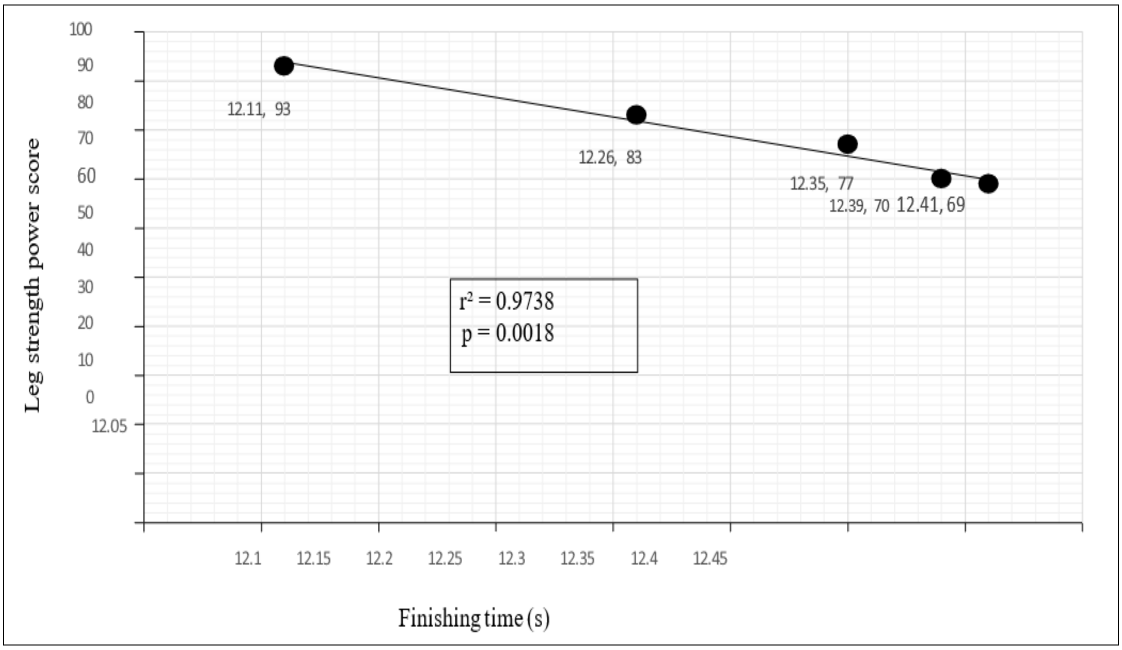

Fig 5: Correlation of leg strength power with the finishing time of the five male sprinters.

Table 4: Different phases of eight study subjects in comparison with those of Usain Bolt [22].

Subject	T_{10} (sec)	T_{10}-T_{30} (sec)	²Vmax (m/s)	³Sm (m)	⁴dT (s)	⁵Vloss (%)
RUM1	1.97	4.26	13.33	40-60	0.87	44.86
RUM2	1.95	4.26	11.36	40-70	1.23	31.77
RUM3	2.05	4.33	11.11	50-70	1.30	34.74
RUM4	1.97	4.32	10.99	40-70	1.31	28.94
RUM5	1.92	4.28	10.64	40-70	1.23	12.97
RUF1	2.28	5.21	9.71	40-60	0.93	8.03
RUF2	2.36	5.49	8.77	40-60	0.50	12.31
RUF3	2.26	5.33	8.70	40-60	0.58	7.36
Husain Bolt	1.90	3.80	12.34	40-100	1.34	2.35

T_{10}-T_{30}-Time taken for first 30 m.
[2]Vmax-Maximum zonal velocity.
[3]Sm-Maintenance level of highest velocity.
[4]dT-Time difference between first and second 50m distances.
5V_{loss}-Velocity loss at finish.

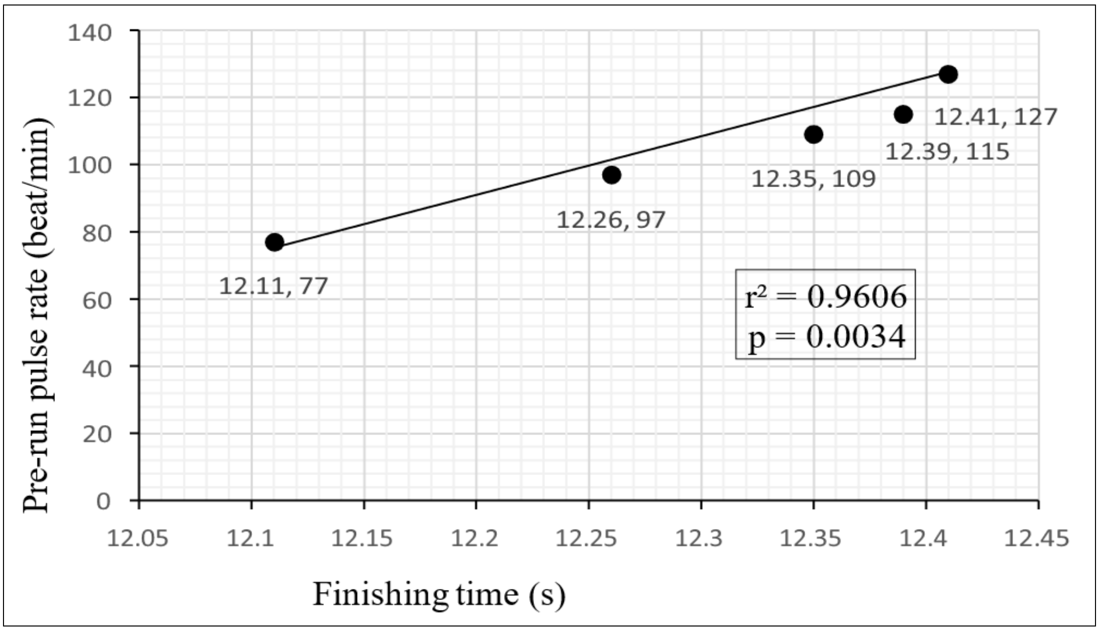

Fig 6: Correlation of pre-run pulse rate with the finishing time of the five male sprinters.

Table 4 shows the different phases of 100m sprint for five males and three female's athletes considered in the present research. As evident in this Table, among the five male sprinters subject no. RUM5 showed the best reaction time ability and got off to a good start. His speed endurance was greater than that of other athletes, and he experienced little deceleration, allowing him to complete the 100m sprint in the shortest time. Subject RUM1, on the other hand, achieved the fastest speed, but his percentage of deceleration (loss of velocity) and the time difference between the first and second 50 meters were higher. Subject RUM3 demonstrated poor reaction time, acceleration ability and speed maintenance, but a higher percentage of deceleration.

The performances of RUM1, RUM3 and RUM5 might be explained by their leg strength power and pulse-rate data displayed in Table 3. As seen in this Table, the participant RUM5 had more effective leg strength and his pre-run pulse rate was also normal. In contrast, individuals RUM1 and RUM3 had lower leg strength power and a higher pre-run pulse rate, resulting in a longer time to complete the 100-meter path. It is well known that leg strength is a key component for improving sprint velocity for both competitive runners and athletes. According to the National Strength and Conditioning Association (NSCA), the stronger the muscles in our legs, the more force we can exert, allowing us to accelerate and maintain a faster sprint speed. Bret *et al.* [8] discovered that the highest leg strength is linked to mean speed sustained in each sprinting phase and that considerable force is required to complete initial acceleration in order to attain and maintain an elevated maximum velocity. Fig. 5 depicts the correlation of leg strength power with the finishing time of our studied five male sprinters. The P=0.0018 value of this correlation indicates highly significance.

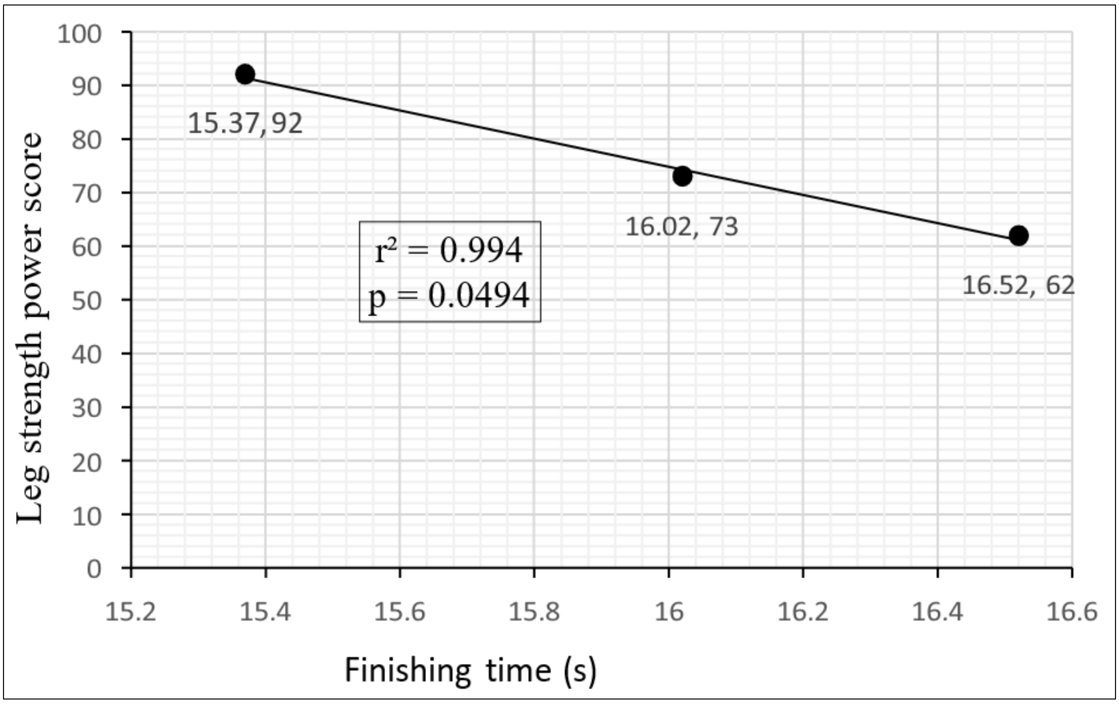

Fig 7: Correlation of leg strength power with the finishing time of the three female sprinters.

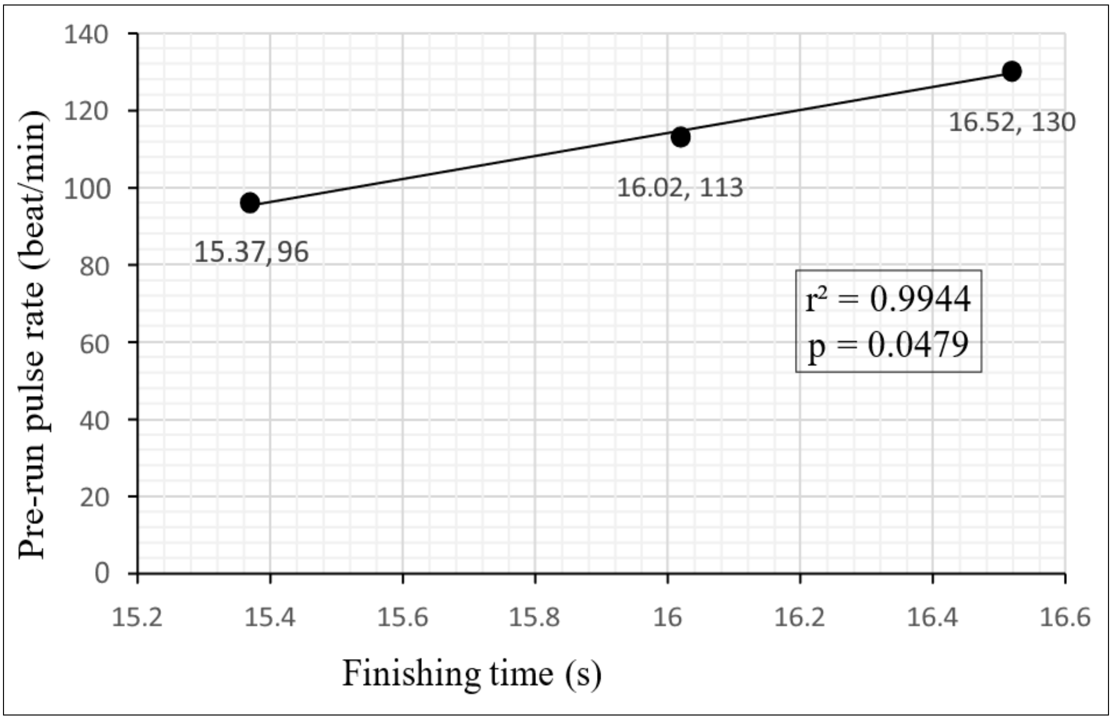

Fig 8: Correlation of pre-run pulse rate with the finishing time of the three female sprinters.

The pre-run pulse rate is another important parameter that has a great impact on athlete's performance. Sports anxiety is distinct from fear, which is a natural cognitive and psychological reaction to a perceived threat. It is regarded as an adverse psychological condition that influences perceptions in sporting events. Fear can manifest itself in physiological responses such as sweating and a faster heart rate immediately prior to sporting events [23]. Furthermore, most athletes believe that anxiety is detrimental to performance, which can lead to decreased performance [24]. Fig. 6 displays the correlation of pre-run pulse rate with the finishing time of our studied five male sprinters. This Figure also shows a strong correlation with P=0.0034.

Female sprinters' performances have been found to be influenced similarly by leg strength power (See Fig. 7) and pre-run pulse rate (See Fig. 8). The p-values for these correlation curves were 0.0495 and 0.0479, respectively, which are less than 0.05 and therefore significant. Female sprinter RUF1 displayed improved acceleration capability, maximum speed, and speed endurance (Table 4) due to increased leg strength power and normal pre-run pulse rate (Table 3). Furthermore, her deceleration% was consistent, resulting in the lowest time to complete the 100m. Subject No. RUF2, on the other hand, took longer time to finish the same distance due to her lack of leg strength, reaction time, acceleration capacity, and a larger proportion of deceleration and pre-run pulse rate.

Table 4 also displays Usain Bolt's 100-meter dash [22] from the 2009 World Athletics Championship in Berlin to compare the performance of our best sprinter (RUM5) to him. We discovered that Usain Bolt ran the 100-meter distance in just 9.58 seconds. The highest zonal velocity achieved at (70-80) m was 12.34 m/s, and the reaction time ability (time taken for the first 10 m) was 1.90 seconds. His acceleration time (time taken for the first 30 meters) was 3.80 seconds. In addition, we observed that Usain Bolt's speed maintenance range was 40-100 meters, the time difference between the first and second 50 meters was 1.34 seconds, and the velocity loss was only 2.35%. In the case of participant No. RUM5, the reaction time, acceleration time, maximum velocity, maintenance zone, timing difference between first and second 50m, and loss of velocity were, respectively, 1.92s, 4.28s, 10.64m/s, 40-70m, 1.23s, and 12.97%, which differ significantly from those of Usain Bolt.

Conclusion

The results of eight sprinters (5 males and 3 females) in the 100m dash are shown. The study participants were recruited from the Rajshahi University inter-departmental athletes championship 2022. The current study found that leg-strength power and pulse rate had a substantial effect on performance. However, a comparison of our best athlete's (RUM5) performance to Usain Bolt's performance revealed that subject RUM5 had a worse reaction time, acceleration ability, and, most critically, speed maintenance. According to the findings of this study, in order to win a gold medal in the Olympic 100m sprint, athlete RUM5 should improve his starting, acceleration, and speed maintenance capacity through leg muscle strengthening training, nutrition, and psychological preparation prior to competition. Our future plan is to study some gait parameters of the athletes, such as number of strides, stride length, stride frequency, and so on, in order to reach a more accurate conclusion.

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Data Availability

Data will be made available on reasonable request.

Declarations

Conflict of interest: The authors have no relevant financial or non-financial interests to disclose.

References

1. Efiong JE, Olajubu EA, Felix OA. Formulation of sprint time predictive model for Olympic Athletic Games. Int J Inf Technol Com Sci. 2019;11(4):33-43.
2. Mishra M, Ghosh N. Development of performance in sprinting events in last 10 summer Olympics. Int J Phys Educ Sports Health. 2017;4(3):440-445.
3. Majumdar AS, Robergs RA. The science of speed: Determinants of performance in the 100 m sprint. Int. J. Sports Sci. 2011;6(3):479-93.
4. Bissas A, Havenetidis K. The use of various strength-power tests as predictors of sprint running performance. J Sports Med Phys Fitness. 2008;48(1):49-54.
5. Mero A, Komi PV, Gregor RJ. Biomechanics of sprint running: A review. Sports Med. 1992;13:376-92.
6. Volkov NI, Lapin VI. Analysis of the velocity curve in sprint running. Med Sci Sports Exerc. 1979;11(4):332-7.
7. Delecluse C, Coppenolle VHE, Willems EU, Leemputte VM, Diels R, Goris MA. Influence of high-resistance and high-velocity training on sprint performance. Med Sci Sports Exerc. 1995;27(8):1203-9.
8. Bret C, Rahmani A, Dufour AB, Messonnier L, Lacour JR. Leg strength and stiffness as ability factors in 100 m sprint running. J Sports Med Phys Fitness. 2002;42(3):274.
9. Ghosh SS, Bhowmick S. An analytical study on timing of Kalyani university sprinters in 100m Race. Int J Phys Educ Sports Health. 2018;5(2):143-149.
10. Tønnessen E, Haugen T, Shalfawi SA. Reaction time aspects of elite sprinters in athletic world championships. J Strength Cond Res. 2013;27(4):885-92.
11. Mackala K. Optimisation of performance through kinematic analysis of the different phases of the 100 metres. New Stud. Athlet. 2007;22(2):7.
12. Paradisis GP, Cooke CB. The effects of sprint running training on sloping surfaces. J Strength Cond Res. 2006;20(4):767-77.
13. Keränen T, Jouste P, Salo AI. A new method for evaluating the balance between the different phases in 100 m sprinting. In ISBS Conference Proceedings Archive; c2000.
14. Mero A, Komi PV. Effects of supramaximal velocity on biomechanical variables in sprinting. J Appl Biomech. 1985;1(3):240-52.
15. Moravec PE, Ruzicka J, Susanka P, Dostal E, Kodejs M, Nosek M. Time analysis of the 100 meters events at the II World Championships in Athletics. New Stud. Athlet. 1988;3(3):61-96.
16. Kurniawan D, Hidayatullah F, Handayani HY, Himawan A. Measurement of physical fitness aspects of lower limb muscle strength in students using wall squat test instruments. Halaman Olahraga Nusantara: J. Ilmu Keolahragaan. 2023;6(1):308-16.
17. Evans WJ. Exercise strategies should be designed to increase muscle power. J Gerontol A Biol Sci Med Sci. 2000;55(6):M309-10.
18. Skelton DA, Kennedy J, Rutherford OM. Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. Age and ageing. 2002;31(2):119-25.
19. Jones G, Swain A, Hardy L. Intensity and direction dimensions of competitive state anxiety and relationships with performance. J Sports Sci. 1993;11(6):525-32.
20. Stevens RE, Loudon DL, Yow DA, Bowden WW, Humphrey JH. Stress in college athletics: Causes, consequences, coping. Routledge; c2013.
21. Lazarus RS. How emotions influence performance in competitive sports. J Sport Psychol. 2000;14(3):229-52.
22. Krzysztof M, Mero A. A kinematics analysis of three best 100 m performances ever. J Hum Kinet. 2013;36(1):149-60.
23. Dammalli BV. An empirical study of social phobia among young athletes. Int J Phys Educ Sports Health. 202;8(3): 448-454.
24. Hanin YL. Emotions in Sport: Current issues and perspectives [w:] G. Tenenbaum I RC Eklund (Red.). Handbook of Sport Psychology; c2007.