Original Research Article

Biomechanical Analysis of the Relationship Between Anthropometric Characteristics and Performance Results in Elite Track and Field Athletes

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Abstract

In athletics, sports performance may depend on the following biomechanical parameters of the athlete: muscle strength, body mass, moment of inertia, height, stride length, stride frequency and the length of an athlete's legs and arms. Each track and field discipline has its own requirements for these parameters, allowing for deviations from statistically calculated mean values. These deviations are due to the biomechanical characteristics of the specific discipline. In this article, we conduct a biomechanical analysis of deviations from mean values in the height, weight, and BMI indices of elite track and field athletes. We believe that when selecting and training athletes, coaches should consider their physical parameters as a whole, taking into account the biomechanical characteristics of the specific discipline.

Keywords: Sports biomechanics, biomechanical analysis, BMI index, athletics.

Introduction

It is well known that the Olympic champions, finalists and participants are well differentiated on age, height and weight (adjusted for height) in each of the eight running events [1]. Sprinters have a more massive body shape, shorter lower legs in relation to the length of the thigh, broader shoulders and narrower hips, greater musculature and cellular mass [2, 3]. Long-distance athletes are characterized by the highest ectomorphy and lowest muscle mass and body fat percentages to optimize oxygen utilization and reduce mass [4]. Some authors suggest that a mass distribution with smaller leg mass and greater trunk mass may be advantageous for achieving better running performance in endurance runners [5]. Middle-distance runners are the slimmest, and have a narrow trunk and little subcutaneous fat [2]. Throwers have predominantly mesomorphic somatotype and exhibit the largest body dimensions with significantly higher muscle mass and higher body fat percentages [4]. Jumpers tend to be more ectomorphic with leaner physiques, featuring substantially lower muscle mass [4].

The analysis of correlations between some body composition indicators and athletic performance is also recommended during the preparation of young athletes [6, 7]. Coaches and sports scientists can use the data obtained to better control training, as well as for talent identification and athlete selection.

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In recent works, we discussed the average values of height, weight, and BMI index of elite track and field athletes and explained their biomechanical essence [8, 9]. It became clear that in sports disciplines such as the men's 100, 200, and 400-meter sprints, 800-meter run, high jump, long jump, triple jump, javelin throw, and combined events, the aforementioned parameters for most athletes are very close to the statistically calculated mean values. However, exceptions also exist where an athlete's height, weight, or BMI differs significantly from the mean. In this paper, we investigate the biomechanical essence of such exceptions.

Research Objectives. The main objective of this study is to determine how the performance of an elite track and field athlete depends on the athlete's height and weight in a specific athletic discipline from the biomechanical point of view, and what causes the existing deviations in these parameters.

Materials and Methods. In this paper, we used data from the world's best male track and field athletes across 10 athletic disciplines, which are published on the internet [10]. We conducted a statistical analysis of this data, calculated the average values of the athletes' height, weight, and BMI index for all disciplines, and compiled a table of their deviations from the mean value, based on which a qualitative biomechanical analysis of these deviations was subsequently performed.

Results. The average values of the height, weight, and BMI index of elite athletes across 10 athletic disciplines are shown in Table 1. Table 2 presents the metrics of these same parameters for world champions. Table 3 includes the data of those athletes whose height differs from the average value by 5 or more centimetres.

Table 1. Statistically calculated average values of height, weight, and BMI index of world-ranked male track and field athletes.

Discipline	Number of Athletes	Average Height (m)	Average Weight (kg)	BMI (kg/m^2)
100 m Run	39	1.8	79.08	24.29
200 m Run	10	1.84	77.8	23.11
400 m Run	10	1.87	78	22.4
800 m Run	10	1.81	64.5	19.8
400 m Hurdles	20	1.82	65.76	19.88
High Jump	35	1.93	76.57	20.6
Long Jump	21	1.84	78.9	23.43
Triple Jump	10	1.86	79.6	22.98
Javelin Throw	11	1.9	97.18	26.84
Decathlon	61	1.9	88.34	24.56

Table 2. Values of height, weight, and BMI index of world record holders across 10 track and field disciplines.

Discipline	World Record	Athlete's Name	Height (m)	Weight (kg)	BMI (kg/m^2)
100 m Run	9.58 s	Usain Bolt	1.95	94	24.72
200 m Run	19.19 s	Usain Bolt	1.95	94	24.72

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400 m Run	43.29 s	Michael Johnson	1.85	79	23.08
800 m Run	1:40.9 min	David Rudisha	1.9	71	19.67
400 m Hurdles	46.78 s	Kevin Young	1.94	82	21.79
High Jump	2.45 m	Javier Sotomayor	1.93	80	21.48
Long Jump	8.95 m	Mike Powell	1.88	79	22.35
Triple Jump	18.29 m	Jonathan Edwards	1.82	72	21.74
Javelin Throw	98.48 m	Jan Železný	1.86	88	25.44
Decathlon	9039 pts.	Ashton Eaton	1.85	84	24.54

Table 3. Deviations of height, weight, and BMI index of world-ranked male track and field athletes from the statistically calculated average values.

#	Sport Discipline and Athlete's Full Name	Result	Height (m)	Weight (kg)	BMI (kg/m²)
	100 m Run				
1	Usain Bolt	9.58 s	1.95	94	24.72
2	Asafa Powell	9.72 s	1.9	88	24.38
3	Nesta Carter	9.78 s	1.73	78	26.06
4	Olusoji Fasuba	9.85 s	1.65	70	25.71
5	Mike Rodgers	9.85 s	1.7	76	26.3
6	Francis Obikwelu	9.86 s	1.95	74	19.46
7	Michael Frater	9.88 s	1.7	67	23.18
8	Travis Padgett	9.89 s	1.73	82	27.4
	200 m Run				
1	Usain Bolt	19.19 s	1.95	94	24.72
2	Walter Dix	19.53 s	1.75	86	28.08
3	Xavier Carter	19.63 s	1.91	77	21.11
4	Wallace Spearmon	19.65 s	1.91	79	21.66
	400 m Run				
1	Harry Reynolds	43.29 s	1.93	84	22.55
2	Lee Evans	43.86 s	1.8	78	24.07
	800 m Run				
1	David Rudisha	01:40.9 min	1.9	71	19.67
2	Joaquim Cruz	01:41.3 min	1.87	74	21.16
3	Mohammed Aman	01:42.4 min	1.73	55	18.38
	400 m Hurdles				
1	Kevin Young	46.78 s	1.94	82	21.79
2	Amadou Dia Ba	47.23 s	1.9	72	19.94
3	Bershawn Jackson	47.3 s	1.73	72	24.06
4	Hadi Soua'an Al-Somaily	47.53 s	1.72	72	24.34
5	Fabrizio Mori	47.54 s	1.68	68	24.09
6	Winthrop Graham	47.6 s	1.72	72	24.34
	High Jump				

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1	Carlo Thränhardt	2.42 m	1.99	85	21.46
2	Patrik Sjöberg	2.41 m	2	84	21
3	Hollis Conway	2.40 m	1.83	68	20.3
4	Stefan Holm	2.40 m	1.81	69	21.06
5	Linus Thörnblad	2.38 m	1.8	76	23.46
6	Dietmar Mögenburg	2.39 m	2.01	78	19.31
7	Gennadiy Avdeyenko	2.38 m	2	82	20.5
	Long Jump				
1	Bob Beamon	8.9 m	1.89	75	21.99
2	Robert Emmiyan	8.86 m	1.78	69	21.78
3	Irving Saladino	8.73 m	1.76	70	22.6
4	Iván Pedroso	8.71 m	1.76	66	21.31
5	James Beckford	8.62 m	1.78	78	24.62
6	Yago Lamela	8.56 m	1.77	79	25.22
7	Aleksandr Menkov	8.56 m	1.78	74	23.36
8	Savante Stringfellow	8.52 m	1.91	84	23.03
	Triple Jump				
1	Kenny Harrison	18.09 m	1.78	75	23.67
2	James Beckford	17.92 m	1.78	78	24.62
3	Jadel Gregório	17.9 m	2.02	104	25.49
	Combined Events (Decathlon)				
1	Ashton Eaton	9039 pts.	1.85	84	24.56
2	Jürgen Hingsen	8832 pts.	2	102	25.5
3	Bryan Clay	8832 pts.	1.8	84	25.93
4	Dmitriy Karpov	8725 pts.	1.98	98	25
5	Leonel Suárez	8654 pts.	1.8	78	24.07
6	Dean Macey	8603 pts.	1.97	92	23.71
7	Aleksandr Pogorelov	8528 pts.	2.01	94	23.27
8	Christian Schenk	8500 pts.	2.01	93	23.02

In athletics, sports performance may depend on the following biomechanical parameters of the athlete:

- Muscle strength;
- Body mass;
- Moment of inertia;
- Height;
- Stride length;
- Stride frequency;
- Length of legs and/or arms.

Muscle strength is important in all sports, but at the same time, we must consider the fact that muscle mass increases total body mass. This, in turn, requires more energy from the athlete and can cause fatigue in athletic disciplines where the athlete has to perform prolonged, intense movements.

Body mass is necessary when the athlete must perform a short-term action related to moving other physical objects (javelin throw, shot put, etc.).

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The moment of inertia depends on the distribution of the athlete's mass in space. The further the centers of gravity of individual body parts are from the athlete's overall body center of gravity, the more energy it requires for the athlete to actuate and move these parts. Therefore, performing a movement by a tall athlete with long legs or arms requires more energy than performing a similar movement by a short athlete.

Height is important in many athletic events. Therefore, in all ten disciplines discussed, the average height of the athletes exceeds 1.80 m. Height is particularly important in disciplines such as the high jump, javelin throw, and combined events (decathlon).

Stride frequency indicates how often the athlete's foot touches the ground per minute. Stride length, on the other hand, determines the distance the athlete covers in a single stride. Speed is a function of frequency and stride length. These parameters are interdependent, and their optimal ratio yields maximum speed. An increase in speed is achieved by increasing either stride length or frequency.

Long arms can prove beneficial in athletic disciplines where athletes perform throws, strikes, and puts. Long legs, on the other hand, are useful in running and when performing jumps.

Based on a detailed analysis of the accumulated data, we can explain the biomechanics of the aforementioned athletic disciplines:

100 m: The height of athletes in this discipline ranges from 1.65 to 1.95 m. This is due to the fact that a short athlete can achieve a good result through quickness—meaning a higher stride frequency—while a tall athlete has longer strides but will have to expend more energy to overcome inertia. In this discipline, the athlete must find the optimal balance between stride length and frequency.

200 m: The height of athletes in this discipline ranges from 1.75 to 1.95 m. In this sport, more emphasis is placed on stride length and less emphasis on muscle strength; therefore, 200-meter sprinters are taller and leaner than 100-meter sprinters.

400 m: The height of athletes here ranges from 1.80 to 1.93 m. As the distance increases, energy expenditure increases. Therefore, 400-meter runners put more emphasis on stride length and less emphasis on muscle strength. On average, they are taller than 200-meter runners and have a lower BMI.

800 m: The height of athletes here ranges from 1.73 to 1.90 m. They are shorter and lighter than 400-meter runners because, due to the quite long distance, the focus is on the economical expenditure of resources. In this discipline, the athlete must find the optimal balance between stride length, stride frequency, and energy expenditure. Athletes in this discipline have the lowest BMI index (19.80 kg/m^2) among the 10 disciplines.

400 m Hurdles: In this sports discipline, athletes have low average values for mass and BMI - 65.76 kg and 19.88 kg/m^2. The height of the athletes ranges from 1.68 m to 1.94 m. These figures are very similar to the corresponding metrics of 800-meter runners, but 400-meter hurdlers have a wider range of heights. This means that both very short and very tall athletes have their own advantages in this discipline.

High Jump: It is well known that high jumpers are usually very tall (height ranges from 1.80 to 2.01 m, with an average height value of 1.93 m). However, there are exceptions (for example, Hollis Conway and Stefan Holm with personal bests of 2.40 m, and Linus Thörnblad—his result is 2.38 m). Despite their relatively short stature (1.83 m,

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1.81 m, and 1.80 m, respectively), these athletes achieved phenomenal results due to their sports technique and relatively small moment of inertia. Carlo Thränhardt, Patrik Sjöberg, Dietmar Mögenburg, and Gennadiy Avdeyenko are very tall (1.99 m, 2.00 m, 2.01 m, and 2.00 m, respectively) and have relatively large moments of inertia. In this discipline, an athlete's great height significantly improves jump performance and partially counteracts the negative effect of increased moment of inertia.

Long Jump: The world record in this sport belongs to Mike Powell, the second-best result to Bob Beamon, and the third to Robert Emmiyan, whose heights are 1.88 m, 1.89 m, and 1.78 m, respectively; Table 3 contains even more athletes whose heights are significantly below the average value (1.84 m). It is well known that a long jumper must also be a good sprinter and possess good jumping technique. A tall athlete can achieve a good result due to their height, which increases speed during the runway approach because of increased stride length, while a short athlete may turn out to be faster due to a relatively smaller moment of inertia.

Triple Jump: Due to its specific nature, the triple jump has a lot in common with the long jump. Therefore, the biomechanical parameters of the representatives of these two disciplines are close to each other. Triple jumpers are slightly taller, but their BMIs are slightly lower. This is because they expend more energy while performing three jumps than long jumpers do, and they must place a greater emphasis on height and weight reduction. Exceptions are Kenny Harrison and James Beckford, who are relatively short (1.78 m), and Jadel Gregório, who is very tall (2.02 m) and has a heavy weight (104 kg). The first two must focus on muscle strength and speed, while the third must utilize his height and body power.

Javelin Throw: In Table 3, this discipline has no exceptions because a javelin thrower must be physically strong, and possess sufficient mass and height. It is also desirable to have long arms and legs.

Combined Events (Decathlon): Combined events include the 100 meters, 400 meters, 1500 meters, 110 meters hurdles, long jump, high jump, pole vault, discus throw, javelin throw, and shot put. Only tall and strong athletes can achieve success in all of these sports. However, they are lighter on average than javelin throwers, which is due to the specific nature of their sport, which includes disciplines where a lighter weight provides more benefit. Height ranges from 1.80 to 2.01 m. This means that relatively short athletes focus on muscle strength and a reduced moment of inertia, while tall athletes focus on height and muscle power.

Conclusion

In this paper, using the data of world-ranked athletes across 10 track and field events, we studied the deviations of their height, weight, and BMI from the mean value. It was established that in all ten events, the aforementioned indicators for the majority of athletes do not differ significantly from the mean value: for example, the deviation of height from the average value is less than 5 cm. However, it was also established that in almost all disciplines except the javelin throw, there are significant deviations: for example, in the 100-meter sprint, the height of athletes ranges from 1.65 to 1.95 m, and weights range from 68 to 94 kg.

This means that in these disciplines, tall and relatively short athletes have their respective advantages and disadvantages. For instance, tall athletes have a greater stride length, which is very important in sprinting, but at the same time, they have a larger moment of inertia, which reduces the quickness of movements and requires more

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muscular energy. In contrast, short athletes have a shorter stride length but are faster. Regarding weight, it should be noted that in the case of athletes of the same height, a heavier athlete may have more energy and power, but will also have an increased moment of inertia. Therefore, it is crucial for an athlete to effectively utilize their physical parameters, such as height and weight, and find the optimal balance between power and speed.

ელიტური მძლეოსნობის სპორტსმენების ანთროპომეტრიულ მახასიათებლებსა და შესრულების შედეგებს შორის ურთიერთკავშირის ბიომექანიკური ანალიზი

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აბსტრაქტი. მძლეოსნობაში სპორტული მაჩვენებლები შეიძლება დამოკიდებული იყოს შემდეგ ბიომექანიკურ პარამეტრებზე: კუნთების ძალა, სხეულის მასა, ინერციის მომენტი, სიმაღლე, ნაბიჯის სიგრძე, ნაბიჯების სიხშირე და სპორტსმენის ფეხებისა და ხელების სიგრძე. თითოეულ მძლეოსნობის დისციპლინას აქვს საკუთარი მოთხოვნები ამ პარამეტრებისთვის, რაც გულისხმობს გადახრებს სტატისტიკურად გამოთვლილი საშუალო მნიშვნელობებიდან. ეს გადახრები განპირობებულია კონკრეტული დისციპლინის ბიომექანიკური მახასიათებლებით. ამ სტატიაში ჩვენ ვატარებთ ელიტური მძლეოსნების სიმაღლის, წონისა და სხეულის მასის ინდექსის საშუალო მნიშვნელობებიდან გადახრების ბიომექანიკურ ანალიზს. ჩვენ ვთვლით, რომ სპორტსმენების შერჩევისა და ვარჯიშის დროს მწვრთნელებმა უნდა განიხილონ მათი ფიზიკური პარამეტრები მთლიანობაში, კონკრეტული დისციპლინის ბიომექანიკური მახასიათებლების გათვალისწინებით.

საკვანძო სიტყვები: სპორტის ბიომექანიკა, ბიომექანიკური ანალიზი, BMI ინდექსი, მძლეოსნობა.

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