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The Influence of Body Symmetry on the Run Up Velocity in the Final 5 Meters of the Long Jump

Influencia de la Simetría Corporal en la Velocidad de Carrera en los Últimos 5 Metros del Salto de Longitud

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SUMMARY: The aim of this research was to determine if there is any relation between run up velocity and athletes body characteristics in long jump. Subjects sample included 45 participants (19 national level jumpers and 26 faculty of sport students) of both genders (men = 25, women = 20). Body characteristics were measured using the Inbody720 and a 3D body scanner, while velocity at last 5 meters were measured using Optogate Witty. Stepwise regression extracted zero one (in the first and the fourth attempt) or one important predictor - difference in height between right and left shoulder (in attempts number 2, 3, 6, and for average velocity across all six attempts) or arms mass difference (attempt 5). Regression explained between 9.6 % (average velocity across all 6 attempts) to 13.5% of velocity (second attempt). Beta coefficients were negative in all cases, indicating that lower the shoulder height difference or arms mass was associated with higher velocity. Nevertheless, more than 85% of velocity variance depends on other factors, such as neuromuscular activity, perception, knowledge and experience. According to the results, coaches and athletes should place greater emphasis on symmetrical body loads.

KEY WORDS: Differences; Shoulder height; Arms mass; Low velocity.

INTRODUCTION

The long jump is an athletics discipline in which the jumper attempts to jump as far as possible from a run-up with a single-leg take-off. It is one of the oldest athletics disciplines, as it was already known to the ancient Greeks. The long jump belongs to the group of natural movements and is one of the jumping athletics disciplines, which also include the triple jump, high jump and pole vault. Successful execution requires a combination of velocity, strength, coordination and technique. According to the structure of the movement, it is divided into a cyclic part (run-up) and an acyclic part (take-off, flight and landing) (Hay *et al*., 1986). The connection between the individual phases, and especially their interdependence, gives the long jump its effectiveness and ultimately determines the length of the jump.

From a biomechanical point of view, the long jump has the characteristics of an oblique throw, and the laws that define an oblique throw are the same. The oblique throw is affected by the take-off velocity, the take-off angle and the take-off height. The result of the long jump is also affected by air resistance, but it is so small that it can be conditionally ignored. The take-off velocity is divided into horizontal and vertical components. The length of the jump is also negatively affected by the lateral velocity at take-off, but this is undesirable.

Technical execution of the take-off: jumper leans to the side of the take-off leg during the take-off, which is a consequence of lowering the hip in the ultimate step, when the jumper is looking for the take-off angle. Ideally, the jumper would be able to lower the hip in the penultimate step without a lateral movement, as this movement does not contribute to a longer jump and places more strain on the joints (Sidorenko, 1985). Neglecting air resistance, the jumper's position in flight has no effect on the result, but mainly serves to maintain balance in the air, ensuring an appropriate position during landing. The landing also affects the result in the long jump, during which more or less length can be lost, depending on body position during the landing) (Hay *et al*., 1986).

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The length of the long jump is also influenced by biological (physiological) factors and cognitive factors. Biological (physiological) factors are explosive propulsive power, coordination and neuromuscular control; elasticity of muscles and tendons according to Hay & Nohara (1990). Important cognitive factors include attention and concentration (Hildebrandt, & Cañal-Bruland, 2020), good spatial and temporal perception (Schmidt & Lee, 2019), decision-making and movement control, as well as visualization and mental preparation (Slimani *et al*., 2017). The run-up is the most important component for success in the long jump, as it provides the necessary velocity and energy to achieve a long distance (Hay & Nohara, 1990). According to the rules of the International Athletics Federation (World Athletics Competition and Technical Rules), the run-up for the long jump must be at least 40 m long, with 45 m recommended. The jumper's run-up is not otherwise limited. Long jump run-ups vary in length, depending on the athlete and the type of competition (Olympic Games, World Championships, European Championships, Diamond League, etc.). To achieve a fast take-off, most long jumpers use 16–24 steps, covering a distance of approximately 35–55 m, with some exceeding 55 m. At the end of the run-up, the athlete reaches approximately 95–98 percent of maximum sprint velocity (Hay & Nohara, 1990; Linthorne, 2008).

Hay & Nohara (1990) studied the effect of take-off velocity in elite male long jumpers. They found that elite long jumpers maintain 95–97 % of their maximum velocity on the take-off board and lose 3–5 % of their horizontal velocity, which they convert into vertical velocity. This vertical velocity is approximately 3–3.5 m/s at the optimal take-off angle, which ranges between 18–22°. Take-off velocity and long jump length show a very strong correlation ($r \approx 0.9$). The authors reported excellent repeatability of movement in elite long jumpers, with small variations in velocity and take-off angle having a significant impact on jump performance. The study included 20 male and 26 female long jumpers who were cinematographically recorded and subsequently analyzed. It was found that the take-off distance of the fourth to last step, the landing distance of the last step and the height of the center of gravity (CG) at take-off were statistically significantly related to the length of the jump. Lees *et al*. (1993), analyzed the biomechanical characteristics of the last steps of the run, the touchdown with the take-off board and the take-off in female long jumpers. The aim was to determine how the run-up velocity affects the technique of the last steps and the take-off, as well as which biomechanical parameters have the greatest influence on long jump performance. They found a correlation of $r = 0.86$ between horizontal velocity at board touchdown and the jump length, indicating that velocity is the most important factor in success. An increase in the run-up velocity of 1 m/s increased the length of the jump by approximately 20 - 24 cm. The average loss of horizontal velocity was about 5 %, and the average vertical velocity was 3.1 m/s. Better results were associated with a combination of high horizontal and moderate vertical velocity at an optimal take-off angle of 19-21°, (Hay & Nohara, 1990). The study showed that jumpers who lost less horizontal velocity achieved longer jumps and that horizontal take-off velocity is a key predictor of jump length, but only if the jumper can effectively convert it into a vertical component during take-off. The authors emphasized that take-off success depends on the balance between maintaining velocity and generating vertical force. Bridgett *et al*. (2002), compared a theoretical mathematical model of the long jump with empirical measurements. The measurement results showed good agreement with the theoretical model and confirmed the generally accepted knowledge that a faster take-off results in a longer jump. However, the strength of the relationship between jump length and landing velocity (8 cm per 0.1 m/s) was smaller than that suggested by measurements (13 cm per 0.1 m/s). The trend line from the theoretical technique model reflects the improvements expected from better running technique, whereas the trend line from the cross-sectional study reflects improvements expected from increased muscle strength.

Bridgett & Linthorne (2006) reached similar conclusions in their study, finding that take-off velocity is statistically significantly higher at higher run-up velocity. The higher the run-up velocity, and the longer jumpers are able to maintain it during take-off, the better the result. As the run-up velocity increases, jump length and take-off velocity increase, while the angle of the feet at touchdown remains almost unchanged, and both take-off angle and take-off duration gradually decrease. The predictions of two previously published mathematical models of long jump take-off were in reasonable agreement with the experimental data. A study by Lees *et al*. (1993), investigated how run-up velocity affects long jump performance and key biomechanical parameters of take-off in men long jump, experienced jumpers. The study included 10 male competitors who performed 27 jumps with different, controlled run up velocity. Measurements included kinematic analysis of the movement and calculation of take-off parameters. The results showed that higher run-up velocity was statistically significantly associated with longer jump distance, mainly due to an increase in horizontal velocity at take-off. It was also found that jumpers at higher velocity maintained better take-off stability and lost less horizontal velocity, although the take-off angle decreased slightly, reflecting biomechanical adaptation to higher velocities. The authors conclude that run-up velocity is a key predictor of jump performance, while emphasizing the importance of training that develops the ability to maintain technical efficiency at high run-up velocities in the long jump.

Success in sports is also directly related to morphological characteristics, such as body size and composition, and body type (Carter, 1980). In some sports, morphological characteristics significantly influence success, while in others this influence is small or negligible (Milanovic & Salaj, 2014). Long jumpers are a relatively homogeneous group of athletes compared with the adult population in terms of morphological characteristics. Table I present the height and weight of the best male and female jumpers on the world's longest jump rankings. Table I includes only those for whom the data is publicly available.

In athletics, coordination is important in all disciplines in which running is natural component, such as the 100-meter dash, long jump and triple jump. Body coordination plays a key role in the accuracy of the long jump take-off. Proper body alignment allows for:

1. Even distribution power and force. When the body is aligned, the muscles on both sides of the body are equally developed, allowing for an even distribution of power and force during the run. This contributes to a more efficient and repeatable jump. Unbalanced power can cause inaccuracies during takeoff and flight (Chaitidou & Panoutsakoulos, 2023).

2. Better balance position and control. An aligned body maintains a more efficient balance position during running and jumping. The more balanced the body is, the less likely the athlete is to deviate from the running direction or lose control during the run-up and take-off, which is crucial to achieving maximum running velocity and an appropriate take-off angle (Hay *et al*., 1986; Theodorou *et al*., 2017).

3. Control of the body's center of gravity position. Proper body alignment allows the body's center of gravity to remain on the midline that divides the left and right sides of the body into two equal halves. When the center of gravity is centrally positioned, the athlete can more accurately direct his energy into the jump. Deviation from the center may cause the athlete to lean excessively outward or inward or forward or backward, which negatively affects both the length and quality of the jump (Zifchock *et al*., 2008).

Morphological characteristics can be the result of heredity (e.g. longitudinal dimension), or of training (e.g. volumetric dimension) (Hay *et al*.,1986). Above all, the impact of training on morphological characteristics that enable improved performance is important. Simenko (2018) states in his research that judo training causes the development of morphological assymetries in all age categories, however, these are not related to technical knowledge or technical execution of throws; although in certain age categories they are related to competitive performance in judo. Zeleznik (2024) examined how morphological asymmetries affect the efficiency of motor skills expression and football performance in samples of players of different ages. The results showed that morphological asymmetries have a different impact on performance efficiency in football across age groups. Unilateral loading can also lead to a greater risk of injury. Luk *et al*. (2014) identified muscle imbalances among weightlifters and jumping athletes using various measures of push-off strength and found that athletes who predominantly train and use their dominant side are more susceptible to injury than those who compensate for muscle imbalances.

Kozinc & Sarabon (2020), extensively addressed the issue of consistency, finding that movement asymmetries

Table I. Basic morphological characteristics of top 10 male and female long jumpers of all time.

Males	Body height (cm)	Body mass (kg)	Body mass index (kg/m^2)	Females	Body height (cm)	Body mass (kg)	Body mass index (kg/m^2)
Powell M.	188	77	21.78	Chistyakova G.	169	53	18.55
Beamon B.	191	70	19.18	Joyner-K. J.	178	70	22.09
Lewis C.	188	80	22.63	Drechsler H.	181	68	20.75
Emmiyan R.	178	69	21.77	Cusmir-S. A.	172	63	21.29
Phillips D.	180	82	25.30	Kotova T.	182	59	17.81
Saladino I.	183	70	20.90	Lebedeva T.	170	60	20.76
Pedroso I.	176	66	21.30	Reese B.	173	64	21.38
Bayer S.	189	79	22.11	Mihambo M.	171	58	19.83
Manyonga L.	189	82	22.95	Maggi M.	173	61	20.38
Tentoglou M	185	75	21.91	Spanovic I.	176	65	20.98
Average	184.7 ± 5.21	75 ± 5.87	21.98 ±1.60	Average	174.5 ± 4.55	62.1 ± 5.00	20.60 ±1.22

and symmetries in athletes from different sports affect muscle strength, stability, flexibility and the efficiency of performing sport-specific tasks. Structural and functional asymmetries often occur in athletes, but their significance varies depending on the sport, training process and specific loads. Sudden and explosive unilateral tasks often result in greater asymmetries than static measurements, while athletes with smaller differences between the left and right sides had better stability, velocity, push-off efficiency and a lower incidence of overuse injuries.

Given the characteristics of the long jump, it is assumed that the run-up will is as consistent as possible, while the take-off is a distinctly unilateral load. Theodorou *et al*. (2017) examined the consistency of the left and right legs during the long jump run by analyzing the run-up, kinematic characteristics of the steps, step frequency, and ground contact time. The results showed that characteristic and repeatable changes occur in the final steps of the run-up, allowing the jumper to prepare for an optimal take-off. These changes were associated with small but systematic asymmetries between the left and right legs, particularly in step length and ground contact time.

A biomechanical analysis of the women's and men's long jump at the 2017 London World Championships showed among 12 females (8 of them performed take off with left leg and 4 with right leg) nine deviated from the linear running line. Similarly, among 12 male finalists (9 of them performed take off with left leg and 3 with right leg) eight deviated from the ideal running direction in the final three steps of the run-up. This deviation also led to departure from the ideal take-off line affecting the final long jump result by several cm (approximately 5-12 cm) (Theodorou *et al*., 2017).

According to the previously cited authors it can be concluded run-up is not always symmetrical. The reasons for such characteristics are predominantly neuromuscular (e.g. production of force) or physical (skeletal) in nature. As neuromuscular reasons have already been identified, the aim of the present study is to determine whether physical characteristics have an impact on the run-up velocity in the long jump.

MATERIAL AND METHOD

Ethics

All procedures were approved by the Ethics Committee of the Faculty of Sport, University of Ljubljana (2024) was obtained, and the research was conducted in accordance with the Helsinki-Tokyo Declaration (2024, Eighth revision, 75th Meeting, Helsinki) (World Medical Association, 2024). All participants were volunteers and signed a written informed consent, which described the objectives, procedures, and potential risks of the study. They were guaranteed the right to withdraw at any time, anonymity throughout the process. Upon completing the assessment, participants were informed of any relevant findings. All procedures were non-invasive and carried no foreseeable risks.

Sample

A power analysis for multiple regression with nine independent variables, a statistical power of 0.80, and a significance level of 0.05 indicated that a sample size of 41 subjects was required. The measured sample consisted of 45 participants, including both males and females (Table II). Of these, 19 were long jumpers who had been practicing the discipline for more than five years at national level and were older than 18 years, and 26 were students of the Faculty of Sport, University of Ljubljana, who had completed the Athletics 1 course and were familiar with the long jump. Among the jumpers, 8 were male and 11 were female, while among the students, 15 were male and 11 were female. Individual measurements were performed in a single day. All participants completed the OSTRC questionnaire, which collected information about their dominant leg and arm as well as their health status over the past six months.

Measurement protocols

The measurements were conducted on four separate days, namely (5.12.2024; 12.12.2024; 19.12.2024 and 8.1.2025). The schedule was arranged so that each participant could complete all measurement protocols in a single day. A group size of 12 subjects per day was chosen to ensure that each participant had adequate rest between jumps, consistent

Table II. Sample characteristics.

Subjects	N	Age	Body height (cm)	Body mass (kg)	Body mass index (kg/m^2)
Male jumpers	8	18.6±2.38	177.9±6.18	74.0±9.28	23.38±2.45
Female jumpers	11	20.8±2.52	173.8±5.66	61.7±5.71	20.42±1.75
Male students	15	22.7±6.32	180.3±7.52	77.5±10.36	23.84±1.83
Female students	11	22.0±1.41	169,0±4.58	59.9±4.58	20.97±2.18
N/Average	45	21.2±3.58	175.7±7.15	69.2±10.50	22.43±2.05

with typical athletics competitions (where finals include 12 athletes). The measurements were carried out in two parts. The first part took place at the athletics hall under standard conditions on all measurement's days (temperature 20 - 21o C and humidity between 50-60 %) at the Siska Sports Park (ZAK) in Ljubljana. The second part was conducted in the physiological laboratory and the sports diagnostics laboratory at the Faculty of Sports of the University of Ljubljana. In the first part, participants performed a thorough warm-up. Each participant started run-up according to his abilities and experience, all were requested to have such run-up to have highest controlled velocity at take-off. After warming up, they completed two practice long jumps to become familiar with run-up and measurement protocol. This was followed by six competitive long jumps conducted according to athletics rules with 10-12 min of rest between jumps. Jump lengths were measured in accordance with official rules and only correctly performed jumps were included in further analysis.

For the last 5 m of the run-up, Opto gate Witty photocells (Microgate Witty, Italy) were used to measure time with an accuracy of 1/1000)). The first photocell was positioned at the line of take of board and the second photocell was placed 5 m in front of the first. The cells were mounted at a height of 1.24 m, corresponding to the standard height used in official competitions. The velocity (m/s) over the last 5m of the run was calculated in Excel.

Body composition was measured using the Inbody 720 body impedance analyzer (Biospace Co., Ltd.). Height was also measured using a GPM height meter (Swiss) to input participant's data into the bioelectrical impedance analysis (BIA) program. The reliability and validity of the InBody 720 measurements have been well established. The following variables were recorded: right arm lean mass, left arm lean mass and calculated difference in arm lean mass, right leg lean mass, left leg lean mass and calculated difference in leg lean mass (InBody, 1996).

A 3D body scanner NX-16 ([TC]2, Cary, North Carolina) was used to obtain morphological data from the participants. A complete calibration procedure of the 3D scanner was performed prior to the measurements. The reliability and validity of measurements with this 3D body scanner have been recognized (Simenko & Cuk, 2016). The following variables were measured right and left long shoulder height, right and left upper arm girth, right and left elbow girth, right and left wrist girth, right and left thigh girth, right and left calf girth. For each pair of measurements, the differences were calculated using the formula: difference = right side - left side (a negative result indicates that left side has a higher value).

Data analysis

The collected data were processed using the IBM SPSS 25.0 for Windows statistical program (SPSS Inc., Chicago, IL, USA). Descriptive statistics were calculated and the normality of the data distribution was assessed using the Kolmogorov Smirnov and Shapiro Wilk tests. A paired t-test was performed to determine differences between the physical characteristics of the right and left sides of the body. Person and Spearman correlations were calculated and differences between them were tested using a Fisher z-test. The influence of morphological characteristics on velocity over the last 5 meters was analyzed using stepwise regression analysis. Statistical significance was set at a two-sided alpha level of 0.05 ($p \leq 0.05$).

RESULTS

Kolmogorov- Smirnov and Shapiro-Wilk test indicated a normal distribution for the measured morphologic variables and velocity of run-up over the last 5 meters. The calculated variables – differences between the left and right sides of the body were not normally distributed. The Fisher z-test showed no significant differences between Pearson and Spearman correlations for the calculated morphological variables and run-up velocity over the last 5 meters. Therefore, stepwise linear regression analysis was performed (Tables III to V).

Table III. Morphological characteristic of jumpers and students.

Students (26)	XA	SD	SE	Jumpers (19)	XA	SD	SE	t-	p
D_arm_mass (kg)	0.01	0.0	0.0	D_arm_mass	0.0	0.0	0.0	0.76	0.4
D_leg_mass (kg)	0.04	0.1	0.0	D_leg_mass (kg)	0.0	0.1	0.0	-	0.7
D_shoulder_height (cm)	0.01	2.4	0.2	D_shoulder_heig	0.3	1.1	0.2	0.64	0.5
D_u_arm_girth (cm)	0.30	1.5	0.2	D_u_arm_girth	0.7	1.4	0.3	0.92	0.3
D_elbow_girth (cm)	0.48	1.3	0.2	D_elbow_girth	0.3	1.0	0.2	-	0.7
D_f_arm_girth (cm)	0.31	0.7	0.1	D_f_arm_girth	0.1	0.7	0.1	-	0.3
D_wrist_girth (cm)	-	1.2	0.2	D_wrist_girth	-	0.8	0.1	-	0.5
D_thigh_girth (cm)	-	1.4	0.2	D_thigh_girth	-	0.9	0.2	0.63	0.5
D_calf_girth (cm)	-	0.9	0.1	D_calf_girth	0.0	0.5	0.1	0.72	0.4

Legend: XA – average, SD – standard deviation, SE – standard error, t-test – value of t-test, p – significance of t-test, D – difference.

Table IV. Morphological characteristic of left and right side.

Left side	XA	SD	SE	Right side	XA	SD	SE	t- test	p
Arm mass (kg)	3.27	0.93	0.13	Arm mass	3.29	0.91	0.13	2.04	0.04
Leg mass (kg)	9.29	1.69	0.25	Leg mass	9.34	1.71	0.25	2.66	0.01
Long Shoulder Height (cm)	141.99	7.20	1.07	Long Shoulder Height	142.15	6.76	1.00	0.54	0.58
Upper Arm Girth (cm)	31.06	3.63	0.54	Upper Arm Girth	31.54	3.43	0.51	2.15	0.03
Elbow Girth (cm)	25.27	2.39	0.35	Elbow Girth	25.71	2.80	0.41	2.43	0.01
Forearm Girth (cm)	25.85	2.68	0.40	Forearm Girth	26.08	2.67	0.39	2.12	0.03
Wrist Girth (cm)	16.05	1.77	0.26	Wrist Girth	15.89	1.36	0.20	-0.99	0.32
Thigh Girth (cm)	60.35	5.39	0.80	Thigh Girth	60.18	5.60	0.83	-0.88	0.38
Calf Girth (cm)	36.98	2.43	0.36	Calf Girth	36.89	2.53	0.37	-0.71	0.47

Legend: XA – average, SD – standard deviation, SE – standard error, t-test – value of t-test, p – significance of t-test, D – difference.

Velocity of run-up over last 5 meters (in m/s) were for the 1st attempt (XA=7.57, SD=0.95, CV%(coeeficient of variantion)=12.5), for the 2nd attempt (XA=7.60, SD=0.96, CV%=12.6), for the 3rd attempt (XA=7.70, SD=0.96, CV%=12.5), for the 4th attempt (XA=7.47, SD=1.44, CV%=19.2), for the 5th attempt (XA=7.52, SD=1.46, CV%=19.4), for the 6th attempt (XA=7.68, SD=0.91, CV%=11.8), for the average 1-6th attempt (XA=7.59, SD=0.96, CV%=12.6).

Table V. Regression analysis – dependent variable velocity in last 5 meters.

Attempt.	R	R2	Sig. F	Predictor	%	β
1 (m/s)	-	-	-	-	-	-
2 (m/s)	0.368	0.135	0.013	D_shoulder_height	13.5	-0.368
3 (m/s)	0.323	0.105	0.030	D_shoulder_height	10.5	-0.323
4 (m/s)	-	-	-	-	-	-
5 (m/s)	0.362	0.131	0.015	D_arms_mass	13.1	-0.362
6 (m/s)	0.346	0.120	0.020	D_shoulder_height	12.0	-0.346
Average 1 – 6	0.310	0.096	0.038	D_shoulder_height	9.6	-0.310

Legend: R – multiple correlation coefficient, Sig. F – significance of regression, b – value of beta coefficient, D – difference.

DISCUSSION

The comparison between long jumpers and students shows no statistically significant differences in body asymmetries between the two groups (Table III). It is worth noting that among students, 19 used left leg for take-off and 7 used right leg, while among the jumpers, the proportion was 12:7 in favor of the left leg. In Table IV, all t-test values for the asymmetry variables of individual body parts were not significant ($p > 0.05$), indicating that the level of body symmetry does not differ between the groups. From this point forward, we will use the term "jumpers" for both groups, treating them as a single sample and emphasizing their homogeneity in body symmetry.

The measured sample includes 45 jumpers with an average age of 21.25 ± 3.58 years, body height of 175.72 ± 7.15 cm, and body weight of 69.26 ± 10.50 kg. Their BMI was 22.43 ± 2.05 kg/m^2. Compared to the top ten male and female long jumpers of all time, minor differences were observed. Top male and female jumpers are slightly taller (men 184.7 ± 5.21 cm, women 174.5 ± 4.55 cm). Our male and female jumpers were approximately the same in body mass (our male jumpers about 75 kg, top male jumpers 75 kg; our female jumpers about 60.8 kg, top female jumpers 62.1 kg). The BMI of top jumpers is slightly lower: 21.98 ± 1.60 kg/m^2 for men and 20.60 ± 1.22 kg/m^2 for women. We conclude that our sample is anthropometrically closer to the general sports population than to the narrowly selected profile of top long jumpers. Top male and female jumpers exhibit a very homogeneous combination of tall stature, relatively low body mass, and optimal muscle-to-fat ratio, which the literature identifies as a foundation for achieving world-class results. Our sample represents young long jumpers, whose potential for improvement is also related to further optimization of body composition and specific strength, consistent with the training perspective highlighted by Guth & Roth (2013).

Analyses of differences between the right and left sides of the body (Table IV) showed that body asymmetries were small but statistically significant ($p < 0.05$) in 7 out of 11 cases, primarily in the upper limbs (upper arm circumference, elbow circumference, forearm circumference) and lean body mass of the arms and legs. In most cases, the right side was more developed, which is expected given the general population's right-handed dominance. In shoulder height, wrist, thigh, and shin circumference, the differences were not statistically significant ($p > 0.05$), indicating no major asymmetries or pronounced physical inconsistencies in the lower limbs. These results suggest that the observed asymmetries are functional, occurring as a natural consequence of movement. Sidorenko (1985) and Kozinc & Sarabon (2020) also reported that physical asymmetries arise in athletes due to more frequent use of one side of the body in daily life and sports tasks. Our measurements show that these asymmetries are moderate in jumpers, which is important, as excessive differences can negatively affect stability, technical performance, and injury risk, as found by Luk *et al*. (2014), in studies of unilateral loading. Controlling asymmetries is therefore important for injury prevention, since pronounced inconsistencies can increase the risk of overuse injuries in the lower limbs.

The average velocity over the last five meters of the run-up in our sample was 7.59 ± 0.96 m/s, consistent with results for young and promising jumpers but significantly lower than the velocity achieved by top jumpers (top female jumpers between 8.5–9.5 m/s, top male jumpers between 9.5–10.5 m/s) according to Hay *et al*. (1986). The coefficient variation is between 10 % and 20%, indicating small variability. Hay & Nohara (1990) state that elite jumpers maintain 95–97 % of their maximum velocity on the take-off board, enabling the development of a vertical velocity of 3.0–3.5 m/s, which leads to an optimal take-off angle and high performance. Our sample did not reach these values, consistent with the physical and training characteristics of participants. Other studies (Leed *et al*., 1993; Bridgett *et al*., 2002; Theodorou *et al*., 2017) have shown that horizontal take-off velocity is a key predictor of jump length, with an increase in velocity by 1 m/s results in approximately 20–24 cm of additional jump distance. Long jumpers complete the last 5 m of the run-up in 2–3 steps (depending on individual stride length in the final phase), making 4–6-foot contacts with the ground over this distance. Based on the measured velocity (7.59 ± 0.96 m/s), we conclude that our jumpers have mastered the technique of the final steps, but their velocity performance does not yet reach the level required for distances typical of elite long jumpers. Fig. 1.

Regression analyses in our study showed statistically significant results, indicating that body asymmetries explain a proportion of the variance in the velocity of the last five meters of the run-up. Individual variables were statistically significant ($p < 0.05$) in several attempts (2, 3, 5, 6, and the average 1 to 6), confirming that the asymmetries are not random but have a measurable biomechanical impact on running performance (Table V). Only in the first and fourth attempt were not statistically significant, which was expected as no independent variables showed a significant correlation with dependent variable (r should be >=0.30, p<0.05). In the first attempt, difference in shoulder height was close to significance (r=0.28), while in the fourth attempt, the difference in legs mass was closest to significance (r=0.22). Predictor of velocity included differences in shoulder height (attempt 2, 3, 6 and average 1 to 6) and arm mass (attempt 5), which appeared individually and were statistically significant. It is important to note that a large proportion of variance remained unexplained - more than 86,5 % in the case of the highest multiple correlation (second attempt), and even higher in other attempts - emphasizing that other factors such as muscle power and sprint technique, are likely more influential. The most frequent and strongest predictor was the difference in shoulder height, which was significant in several regression models. The b-coefficient was negative, indicating that postural asymmetries between the right and left shoulders negatively affect horizontal velocity by causing lateral oscillation and reducing the efficiency of force transmission. In other words, greater asymmetry corresponds to lower velocity (on Figure 1 is athlete during take-off, where shoulders height is evident). Importantly there were no significant differences between right and left shoulder height in the overall sample (Table V), but individual differences caused lower velocity in last 5 meters of run-up. This finding aligns with Kozinc & Sarabon (2020), who report that postural asymmetries reduce stability and explosiveness and increase energy expenditure during movement. The difference in arm mass, which was statistically significant in the fifth attempt, also had a negative b-coefficient. Although the arms are not directly involved in take-off, they play a key role in balancing, directing the torso, generating rotational forces, and stabilizing the final steps. Jumpers with asymmetric arm mass expend additional energy stabilizing the torso, which directly reduces horizontal velocity. This finding is consistent with Luk *et al*. (2014), who demonstrated that unilateral loads create functional asymmetries that affect explosive power and running efficiency. Overall, our results confirm that body asymmetries in this sample are a significant factor, with low amount of explained variance in determining takeoff velocity. Previous studies presented in the introduction (Hay & Nohara, 1990; Lees *et al*., 1993; Brigett & Linthorne, 2006) primarily emphasize the importance of velocity, last-step technique, and the ability to convert the horizontal to vertical velocity, but they do not highlight body asymmetries as a key predictor of velocity. Theodorou *et al*. (2017) and Panoutsakopoulos *et al*. (2021), note systematic asymmetries in the last steps, but mainly in terms of preparing for take-off and ensuring precise of contact with the take-off board, rather than as a

Fig. 1. Body posture example at moment of take-off. Red lines are parallel to take off board and show relative position of jumper's hips and shoulders(a)symmetry.

factor influencing velocity. These asymmetries are not errors but adaptations that allow optimal preparation for take-off. Research from other sports (Simenko, 2018; Zeleznik, 2024) confirms that asymmetries can affect movement efficiency and performance, although these effects are often sport specific. Our study demonstrates that, in this sample, body symmetries are related to velocity over last 5 meters of run-up. Individual asymmetries can significantly affect the ability to maintain velocity in this final phase. Proper body alignment theoretically and practically influences run-up velocity by helping maintain linear movement, controlling the center of gravity, and optimally generating force in the take-off. The practical implication for coaches is clear, they should occasionally assess the physical characteristics of their athletes on both sides, plan and implement exercises to promote symmetry, provide physiotherapy or target training to correct detected asymmetries.

Research limitations include the cross-sectional design and a relatively narrow scope of variables. Future studies should include a broader range of factors, such as biomechanical parameters of run-up steps, dynamic measurements on force plates, and similar analyses.

CONCLUSIONS

The results confirm that differences in body alignment among long jumpers are generally small, functional, and favor the right side. Body asymmetries—particularly differences in shoulder height (which may result from acquired or congenital scoliosis) and arm muscle mass (arising from uneven loading)—significantly, though modestly, influence the biomechanics of the final steps of the run-up. It is important to note that a large proportion of variance remained unexplained - more than 86,5 % in the case of the highest multiple correlation and even higher in other attempts - emphasizing that other factors such as muscle power and sprint technique, are likely more influential. These asymmetries are associated with reduced run-up velocity, which can negatively affect jump length. Future research should focus on longitudinal studies to validate and extend these findings.

KREFT, R. & CUK, I. Influencia de la simetría corporal en la velocidad de carrera en los últimos 5 metros del salto de longitud. *Int. J. Morphol., 44(3)*:842-850, 2026.

RESUMEN: El objetivo de la investigación fue determinar si existe alguna relación entre la velocidad de carrera y las características corporales de los atletas en el salto de longitud. La muestra incluyó 45 participantes (19 saltadores de nivel nacional y 26 estudiantes de la facultad de deportes) de ambos sexos (25 hombres y 20 mujeres). Las características corporales se midieron con el Inbody720 y un escáner corporal 3D, mientras que la velocidad en los últimos 5 metros se midió con el Optogate Witty. Mediante regresión escalonada se extrajo un predictor significativo (cero o uno en el primer y cuarto intento) o uno: la diferencia de altura entre el hombro derecho e izquierdo (en los intentos 2, 3 y 6, y para la velocidad promedio en los seis intentos) o la diferencia de masa entre los miembros superiores (intento 5). La regresión explicó entre el 9,6 % (velocidad promedio en los 6 intentos) y el 13,5 % de la velocidad (segundo intento). Los coeficientes beta fueron negativos en todos los casos, lo que indica que una menor diferencia en la altura de los hombros o una menor masa de los miembros superiores se asociaron con una mayor velocidad. Sin embargo, más del 85 % de la varianza de la velocidad depende de otros factores, como la actividad neuromuscular, la percepción, el conocimiento y la experiencia. Según los resultados, los entrenadores y atletas deberían hacer mayor hincapié en las cargas corporales simétricas.

PALABRAS CLAVE: Diferencias; Altura de los hombros; Masa de los miembros superiores; Baja velocidad.

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