

Relationship between lower body strength and swim start performance of swimmers

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Abstract:

Problem Statement. The effective execution of the swim start can be fundamental to the event performance. **Purpose.** The aim of the present study was to analyze which jump test: countermovement jump (CMJ), standing long jump (SLJ), or squat jump (SJ) was the most adequate for predicting swim start performance, and to study its mediating role on the relationship between flight distance and time needed to cover the first 15 meters. **Methods.** Forty-eight swimmers participated, with each performing 3 swim starts, which allowed us to obtain the kinematic variables and the time needed to cover 15 meters (T15). Also, the participants performed 3 jump tests. **Results.** The results showed significant differences as a function of gender for each of the jump tests, and the kinematic variables identified with flight time and distance ($p < 0.05$) in the start. The T15 showed a high and significant inverse correlation with flight distance and time. The regression study pointed to the SLJ as the best predictor of performance of the T15 ($\text{performance} = 8.51 - (0.79 \times \text{SLJ})$). Lastly, after the regression analysis, the resulting models had a good fit and relationship with flight time ($\beta = -0.95$; $p < 0.001$), thus establishing that this relationship is partially conditioned by the result obtained in the SLJ test ($\beta = -0.54$; $p < 0.001$). **Conclusions.** These results suggest that the strength of the lower body, through the results obtained in the SLJ test, could be decisive for the prediction and explanation of the relationship between the time obtained in T15 and the flight time in the swim start of the swimmers. Strength training of the lower body must be used as an improvement tool in the performance of the swim start.

Key Words: Swimming, jump test, kick start, force.

Introduction

A good swim start time is a key indicator in the performance of a speed swim trial (Da Silva et al., 2020; García-Ramos et al., 2016; Qiu et al., 2020) as shown by its significant correlation with the total time used by the swimmer during the trial (Arellano et al., 1996). The performance in a swim trial is understood as the time used at the start, when swimming, and the flip turns (Qiu et al., 2020). The swim start is at the same time a combination of explosive movements that try to provide the swimmer with a momentum towards the water from the jumping stand, following an adequate trajectory (Cuenca-Fernández et al., 2019; Keiner et al., 2019; Pérez-Olea et al., 2018). This combination of movements includes a fast reaction speed, a significant jumping power, a high take-off speed, and a low hydrodynamic load when entering the water (Beretić, et al., 2013; Cuenca-Fernández et al., 2019; Qiu et al., 2020).

In speed trials, a fast start is fundamental for the final result of the trial (Cuenca-Fernández et al., 2019; Da Silva et al., 2020) implying between 0.8% of the total trial time in the longest trial of the year, and 26.1% of the total time used in the shortest trial (Cossor & Masson, 2001). More specifically, in the world championships in Barcelona (2013), the time used for the start oscillated between 24% of the time used in the 50 meter trials, to 11% in the 100 meter trials (Carvalho et al., 2017). Given that the differences between winning and losing are often very small, the time used for the start and its correct technical execution is a decisive factor in the final result of the trial (Da Silva et al., 2020; Rojano & Betanzo-López, 2014). A correct execution of the start technique will significantly influence the first strokes of the swimmer due to the high speed of movement achieved with the jump from the stand and the posterior underwater phase (Vantorre et al., 2010).

The speed trials in swimming are highly influenced by a broad set of neuromuscular and biomechanical factors, such as muscle strength, the efficiency in the propulsion, and the mechanical work (Da Silva et al., 2020; Keiner et al., 2019; Loturco et al., 2016). However, despite these neuro-mechanical abilities playing an important role in the performance of the swimmers, the evaluation of the force-time curve in the aquatic medium is not easily measured (Loturco et al., 2016). To improve their strength and power, top level swimmers habitually perform training exercises in the water and on dry land as well, based on specific strength and power exercises (Gussakov et al., 2021; Loturco et al., 2016; Pradas-Valverde et al., 2022).

Vertical jump tests are frequently utilized in the evaluation of sport performance for measuring the mechanical capacity of the lower body muscles. The use of these jump tests is determined by their capacity to differentiate between athletes from different levels of competition, and their significant correlation with height and power found in a vertical jump (Ptronijevic et al., 2018). In spite of this, the relationship between the performance in swimming and the strength of the lower body measured through different jump tests (SLJ, CMJ or SJ) is not very clear, as shown by some authors (Espada et al., 2016; Keiner et al., 2015; Loturco et al., 2016); however, others indicate that a correlation exists (Garrido et al., 2010). A high power of propulsion created on the stand by the swimmer will imply a high speed of take-off and a greater flight distance, which means that the phase on the stand has a significant influence on the flight and the water entrance phases (García-Ramos et al., 2016; Pradas-Valverde et al., 2022). Different jump tests such as the CMJ and the SJ can be used to assess performance in swimming (Carvalho et al., 2017; Pérez-Olea et al., 2018; Sammoud et al., 2019), and the performance in the start due to their correlation with these actions (García-Ramos et al., 2016). The performance of the start in a swimming trial is understood as the time it takes for the swimmer to reach the 15 meter mark, and it is shaped by the following phases: the time spent on the stand, the take-off, the flight phase, the water entrance, the underwater phase, and the transition to swimming (García-Ramos et al., 2016).

Considering the importance of the start in these swimming speed trials, as well as its possible relationship and influence with the levels of strength of the swimmers, the objective of the present study was to analyze which of the different jump tests, countermovement jump (CMJ), standing long jump (SLJ), or squat jump (SJ) was the most adequate for predicting the performance in the swim start, as well as to study the mediating role of the test on the relationship between the flight time and the time needed to cover the first 15 meters.

Material & methods

Desing and Participants

In the study, a descriptive and cross-sectional design was utilized, with a non-probabilistic sampling method. The sample was selected using a convenience sampling method. A total of 48 swimmers aged between 11 and 20 years old from two swimming clubs in the Region of Murcia and province of Albacete (Spain) participated in the study. The gender distribution of sample, shown as percentages, was male (n=27 (56.3%)) and female (n=21 (43.7%)) swimmers. Demographic and anthropometric characteristics data, including BMI classification (Cole et al., 2020) are shown in Table 1.

Table 1. Demographic and anthropometric characteristics of the study sample

	Total (n=48) M±SD	Boys (n=27; %=56.3) M±SD	Girls (n=21; %=43.7) M±SD
Age (years)	14.72±2.05	15.58±2.16	13.67±1.32
Height (cm)	165±0.10	170±0.08	159±0.08
Weight (kg)	58.01±9.3	61.57±7.95	53.60±9.10
BMI (kg/m ²)	20.98±2.32	20.97±1.98	20.99±2.74
Thin (%(n))	2.10(1)	0(0)	4.80(1)
Normal weight (%(n))	76.60(36)	84.60(22)	66.70(14)
Over-weight (%(n))	17(8)	11.50(3)	23.80(5)
Obese (%(n))	4.30(2)	3.80(1)	4.80(1)
FINA points	432.02±135.67	446.52±146.53	413.38±121.24
Competitive level			
Regional championship (%(n))	78.80(34)	63(17)	81(17)
National championship (%(n))	29.20(14)	37(10)	19(4)
Swimming practice (years)	7.98±3.30	8.67±3.54	7.10±2.79
Weekly training (hours)	9.04±2.22	9.70±2.13	8.19±2.10
T15 (s)	8.51±1.37	7.86±1.15	9.37±1.17

Legend: kg, kilograms; cm, centimeters; m, meters; BMI, body mass index; s, seconds; n, number; % percentage; T15, time to cover 15 meters.

Sample Size

The calculations to establish the sample size were performed using the G*Power 3.1.9.4 software. The significance level was set at $\alpha=0.05$. Accordingly, the sample size (power analysis) revealed that 46 participants would obtain a 95% power to significantly detect a correlation of $r=0.30$ in the population. In order to prevent possible dropouts or elimination of recorded data by the detection of an abnormal response, we decided to recruit a larger number of participants.

Body composition characteristics measurement

The anthropometric measurements taken for the determination of weight and height followed the standards established by the International Society for the Advancement of Kinanthropometry (ISAK) (Esparza-Ros et al., 2019). Body weight (kg), body mass index (BMI) and % body-fat were measured without shoes using a Bioelectrical impedance analysis device (BIA) (Tanita BC-545N–Body composition monitor to measure per segment) to the nearest 0.1 kg. The Height (cm) was measured using a stadiometer (Tanita HR001 Leicester portable height rod) to the nearest 0.1 cm. The requirements and clothing for these measurements were

established beforehand through the information provided in the dossier given to the coaches, as well as in the information letter provided to parents or legal tutors and the swimmers themselves. It was established that swimmers should come with comfortable sportswear (short-sleeved shirt and swimwear), and both measurements were taken with swimmers in the upright position and barefoot.

Dry land power of lower body

To measure the strength of the lower body of the swimmers, 3 different jump tests were utilized. These were: i) Countermovement jump (CMJ) Test, ii) Squat Jump (SJ) Test, and iii) Standing Long Jump (SLJ) Test. In the case of the first two jump tests, many studies have accredited their validity within the area of sports for determining the maximum jump power (Jones et al., 2018; Markovic et al., 2004). Also, for the sport of swimming, these types of tests, used for the determination of the maximum jump power, have been strongly accredited by various studies (Espada et al., 2016; García-Ramos et al., 2016; Jones et al., 2018; Keiner et al., 2015; Potdevin et al., 2011). Lastly, for the measurement of this maximum jump power, a third validated test was included, named SLJ (Almuzaini & Fleck, 2008; Sammoud et al., 2019).

1. Countermovement Jump (CMJ) Test

The CMJ was performed starting with a standing position with hands on the hips. From this position, the participant must flex-extend the knees until a 90° angle has been reached, to then perform a high vertical jump, all of this without pausing (Markovic et al., 2004; Van Hooren & Zolotarjova; 2017). The complete sequence of the CMJ can be observed in Figure 1A. Once the maximum height (cm) and maximum force (N) are obtained in the jump, these are divided by the weight of the swimmer to obtain the relative power and height of the jump, to be able to better perform an inter-subject comparison (García-Ramos et al., 2016).

2. Squat Jump (SJ) Test

The SJ is a vertical jump that is performed starting in a semi-squatting position, with the legs bent at 90° and the hand on the hips. From this starting position, the knees are extended to perform a maximum vertical jump, without any type of previous countermovement or bounce (Markovic et al., 2004; Van Hooren & Zolotarjova; 2017). The complete sequence can be observed in Figure 1B. Just as with the CMJ test, the maximum height (cm) and power (N) obtained will be divided by the weight of the swimmer for a posterior inter-subject comparison (García-Ramos et al., 2016).

3. Standing Long Jump (SLJ) Test

Lastly, the SLJ is a longitudinal jump that begins from a standing position with the knees slightly bent and the arms at the sides of the body. From this position, balancing of the arms is not allowed, and one must be behind a line marked on the floor, which serves as the starting point for the placement of the feet before propulsion. Starting from here, a horizontal jump is made to reach the maximum distance possible (Almuzaini & Fleck, 2008; Fernández-Santos et al., 2015; Markovic et al., 2004; Moresi et al., 2011). Just as in the previous occasions, the complete sequence of the SLJ is found in Figure 1C.

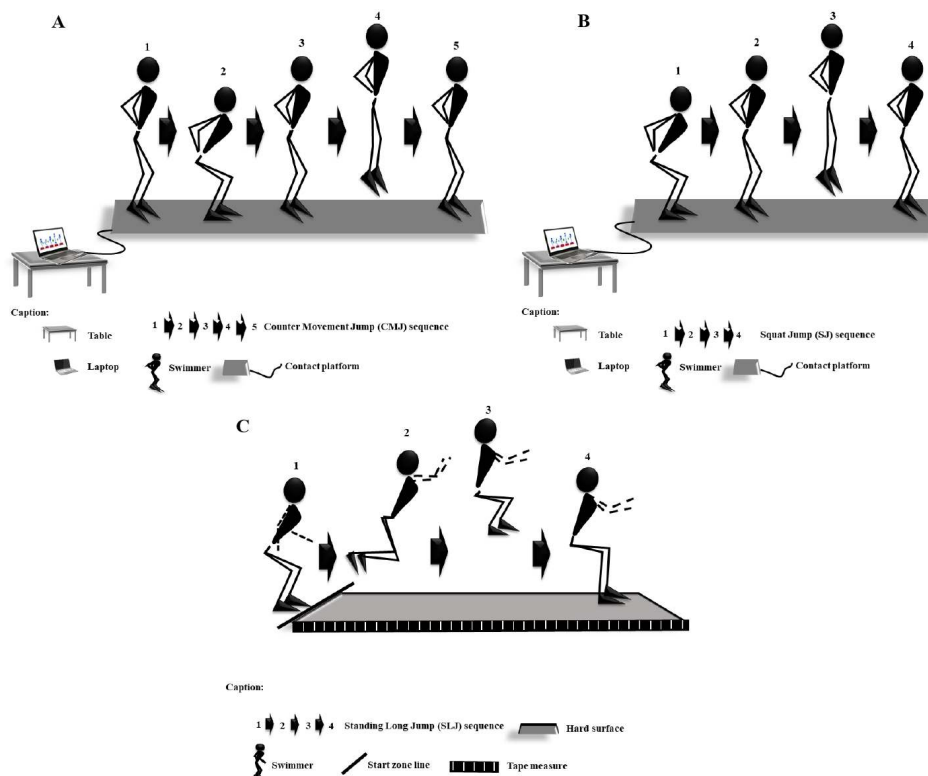


Fig 1. Dryland power of lower limb

Kinematic analysis and track start in swimming

During the experiments, video recordings were taken at a sampling rate of 480 frames per second (FPS) (Sony HDR-PJ410B) while the subject passed in front of a water window (Figure 2). Yellow tape markers were applied on select anatomical landmarks in order to facilitate the posterior video analysis. After the agreed upon start signal, the swimmer had to cover a total distance of 15 meters (T15) at top speed. The swim start technique utilized by the swimmers was Track Start, as it is the technique with which they train on and use in competitions (Thanopoulos et al., 2012). The stand utilized was a traditional one without a support platform for the back leg.

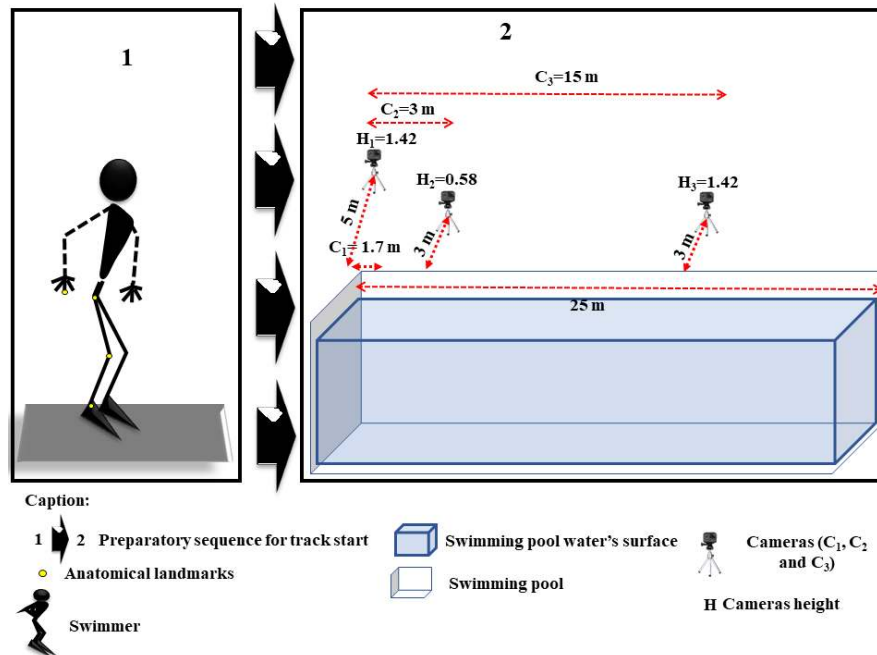


Fig 2. Measurement protocol

Lastly, within the kinematic analysis of the swim start, the following variables were considered:

Table 2. Kinematic variables analyzed during the swim start

Variable	Abbreviation	Description
Time to cover 15 meters	T15	Time needed by the swimmer from the sound exit signal until the head reaches the 15-meter mark (s) (Vantorre et al., 2010; García-Ramos et al, 2016).
Exit angle	EX_A	Angle formed by the front leg of the swimmer between the hip trochanter, the patella, and the malleolus of the ankle in the initial position over the stand before the start (°) (Beretic et al., 2012).
Entry angle	EN_A	Angle formed by the water horizon, the middle finger, and the center of mass (CM) of the swimmer at the first contact of the finger with the water (°) (Vantorre et al., 2014).
Flight distance	F_DST	Distance between the edge of the pool under the stand and the point in which the finger of the swimmer comes into contact with the water (m) (Beretic et al., 2012; Vantorre et al., 2010).
Flight time	F_TM	Time from the last contact of the swimmer's foot with the stand until that the finger of the swimmer comes into contact with the water (s) (Beretic et al., 2012).

Procedures

Informed consent and previous information

To guarantee that the data collection at the swimming sports clubs was the same during the process, the following protocol was established. First, the swimming clubs were contacted and a meeting was requested with the coaches to inform them about the purpose of the study and ask for their collaboration. After accepting to participate, a second meeting was set up in which all the necessary documents were provided, and their questions and doubts related to the measurement protocol to be followed, well as the instruments to be used and the tests to be performed, were answered.

Also in this second meeting, the different sports installations were visited to determine the spaces, means, and installations to be used for the distribution of tests to be conducted. At the same time, the schedule was set that was similar for all the centers with respect to the time and days for the administration of the tests. Before the start of the study, all students and their parents or legal tutors were informed about the study

characteristics as well as the possible benefits and potential risks. Subsequently, a consent form to voluntarily participate in the study was completed and signed. The study was conducted in accordance with the ethical principles of the Helsinki declaration for human research and was approved by the institutional review board of the Catholic University San Antonio of Murcia (Code: CE061922).

The researchers visited the swimming clubs in two different days (first and second phase), always at the same time of the day (19:30 – 21:30), separated by at least 48 hours and not more than 72 hours and controlling the environmental conditions (space, temperature, and humidity) (Petronijevic et al., 2018).

Measurements

The measurement sessions were divided into three phases. On the first phase, the different information and characterization questionnaires about the sample of swimmers were completed. In this same session, the body composition of the swimmers was measured.

In the second phase, the jump tests were performed to assess the strength of the lower body. Before this, the swimmers performed a standardized warm-up that lasted 10 minutes, and which including jogging for 5 minutes, followed by 10 squats and 3 squat jumps (SJ) (Markovic et al., 2004). For the effective performance of the different jump tests, the swimmers were divided into 3 equal groups, rotating according to stations and group (station1: CMJ, station 2: SJ, and station 3: SLJ) to ease the process of recording and performing of the tests. Each group was guided by the researcher in charge, who explained and monitored the performance of each test. On the other hand, the swimmers were instructed by the researcher in charge of the test to be performed before performing each of the jump tests.

The CMJ and SJ tests were conducted on a Chronojump contact platform model DIN-A1 (Chronojump BoscossystemR, Spain), which allowed us to obtain maximum force levels (Jones et al., 2018; Potdevin et al., 2011). For the SLJ test, a protocol was followed that consisted on tracing a horizontal line on a hard surface floor, which served as the starting line for the jump. The swimmer was placed behind it, without touching it, and jumped horizontally as far as he or she could, with the jump distance determined with a metric measuring tape placed as shown in Figure 1C (Almuzaini & Fleck, 2008; Markovic et al., 2004). Each of the swimmers performed a total of 3 tries for each of the jump tests, with the best result recorded (Almuzaini & Fleck, 2008; García-Ramos et al., 2016; Markovic et al., 2004; Potdevin et al., 2011).

Lastly, the third phase consisted on performing and recording of the swim start. Before the swim start, the standard warm-up utilized by each coach during competitions was performed. Once the warm-up period ended, the recording of the swim start began, along with the measuring of the time needed to cover 15 meters (T15). Just as with the jump tests, all the swimmers performed a total of 3 starts. The instructions given to the swimmers were to execute and swim with a similar speed and effort as that used during a 50m crawl competition, having to prolong the swim for 25 meters. In this test, the researchers took the time relative to T15 (Carvalho et al., 2017). The swimmers rested for 5 minutes between each of the swim starts and swim trials (García-Ramos et al., 2016; Thng et al., 2020).

Statistical Analysis

Means (M), standard deviations (SD), percentages (%), and frequencies were calculated using descriptive statistics. Data normality and homogeneity (Shapiro-Wilk and Levene tests) were performed prior further analysis. Data variables with different units and arithmetic scales were transformed on standardized scores (Z score). Subsequently, when differences between groups were observed, an independent sample t-test or Pearson's chi-squared test (χ^2) were used, depending on the assumption of normality. Effect size was calculated with Cohen's d [0.2 (small); 0.5 (medium) and >0.8 (large) effect]. In addition, a multiple regression analysis was performed to determinate the relationship between variables. In all cases, data independence, absence of collinearity, normality, and homoscedasticity were verified. The existence of a relationship between these variables was measured by Pearson's correlation coefficients.

In order to assess whether an association between the main variables was present, a multiple moderated mediation analysis was performed. The mediation analysis was performed using the PROCESS macro from SPSS (SPSS Inc., Chicago, Illinois). The resampling procedure of 10,000 bootstrap samples was used for the non-parametric sample (Preacher & Hayes, 2008), while the classical method of stepwise regression by Baron and Kenny (1986) was used for the parametric sample.

The statistical significance of the mediation effect was examined with Sobel's test (Sobel, 1982). When the Z value was larger than 1.96 and the p-value was lower than 0.05, a mediating effect was admitted (Preacher & Hayes, 2008; Sobel, 1982). The data analysis was performed using the SPSS software (IBM Corp., Armonk, NY, USA) for Windows, Version 24.0. The statistical significance level was set at 0.05 for all statistical comparisons.

Results

Next, Table 3 shows the data obtained for the study variables as a function of the gender of the participants.

Table 3. Sample descriptive data according to gender for the jump tests, the kinematic variables, and the specific ones for the practice of swimming

	Total (n=48) M±SD	Boys (n=27; %=56.3) M±SD	Girls (n=21; %=43.7) M±SD	p	d
Dry land vertical tests					
CMJ (cm)	666.10±154.16	751.90±138.12	555.78±91.29	0.000**	1.63
Relative CMJ (cm/kg)	11.42±1.68	12.17±1.56	10.44±1.29	0.000**	1.19
SJ (cm)	658.96±149.06	747.02±124.34	545.74±90.53	0.000**	1.82
Relative SJ (cm/kg)	11.29±1.55	12.12±1.35	10.44±1.08	0.000**	1.53
SLJ (cm)	171.76±36.80	191.83±30.98	145.95±26.29	0.000**	1.58
Kinematic analysis variables					
Exit Knee angle (°)	141.96±4.32	141.89±4.21	142.05±4.55	0.901	-0.04
Entry angle into the water (°)	34.60±4.55	34.37±3.54	34.90±5.67	0.691	-0.12
Flight distance (m)	3.21±0.28	3.31±0.26	3.08±0.26	0.003**	0.90
Flight time (s)	0.34±0.07	0.36±0.07	0.32±0.05	0.014*	0.74
Swimming test specific variables					
T15 (s)	8.51±1.37	7.86±1.15	9.37±1.17	0.000**	-1.28
FINA points	432.02±135.67	446.52±146.53	413.38±121.24	0.407	0.24
Swimming practice (years)	7.98±3.30	8.67±3.54	7.10±2.79	0.102	0.72
Weekly training (hours)	9.04±2.22	9.70±2.13	8.19±2.10	0.019*	0.49

Legend: kg, kilograms; cm, centimeters; m, meters; s, seconds; °, degrees T15, time to cover 15 meters; p, significance level; ** p<0.01; * p<0.05; d, effect size (Cohen's d).

More specifically, the table shows the data obtained for each of the vertical jump tests used to measure the strength of the lower body of the swimmers. It can be observed how the scores obtained as a function of gender were significantly different for all the jumps (p<0.01), with the scores obtained by the male swimmers being always higher than for the female ones. In this same table, we can observed the results obtained for the kinematic variables analyzed in the swim start, with significant differences found as a function of gender only in the variables flight distance (p=0.003, d=0.90), and flight time (p=0.014, d=0.74).

In both cases, the findings were better for the male swimmers, with a flight distance and flight time higher than those obtained by the female swimmers. Lastly, the specific variables related with swimming itself revealed significant differences as a function of gender in: the number of training hours per week (p=0.019), with the number of hours of the female swimmers being 18.44% less than the male ones, and the time recorded in the T15 test (p=0.000), where the female swimmers obtained a higher percentage for the time needed to cover this distance (16.12% more).

Next, Table 4 shows the results obtained for each of the different variables studied in the present investigation. As observed by the results obtained, an inverse and statistically significant correlation was found between the dependent variable T15 and rest of the variables studied (p<0.05). However, when studying the association between the variables related with the vertical jump test and the kinematic variables, statistically significant differences were not always found between every variable.

Table 4. Bivariate correlations between T15 and different variables of the study

	1	2	3	4	5	6	7	8
Dry land vertical tests								
1.CMJ	1							
2.SJ	0.97**	1						
3.SLJ	0.74**	0.69**	1					
Kinematic analysis variables								
4.Exit Knee angle (°)	0.23	0.19	0.16	1				
5.Entry angle into de water (°)	-0.19	-0.19	-0.34*	-0.13	1			
6.Flight distance (m)	0.56**	0.60**	0.50**	0.11	-0.37**	1		
7.Flight time (s)	0.40**	0.38**	0.64**	0.26	-0.15	0.88**	1	
Swimming test specific variables								
8.T15 (sg)	-0.77**	-0.74**	-0.79**	-0.34*	0.39**	-0.69**	-0.59**	1

Legend: m, meters; s, seconds; T15, time to cover 15 meters; ** p<0.01; * p<0.05; °, degrees.

On the other hand, after performing a linear regression study to determine which test (vertical or horizontal) could be the best predictor of the T15 test, the results obtained showed that the SLJ test obtained better predictive values than the vertical jump tests (Table 5).

Table 5. Regression analysis for the best prediction of the T15 test performance

Predictive variables	R ² corrected	F	gl	D-W	Coefficients		t	p
					Non- standardized	Standardized		
Dry land vertical tests					B	ES B		
CMJ (cm)	0.59	69.02	46	1.27	-1.06	0.13 -0.77	-8.31	0.000**
Relative CMJ (cm/kg)	0.54	57.12	46	1.83	-1.02	0.13 -0.74	-7.56	0.000**
SJ (cm)	0.54	55.37	46	1.17	-1.01	0.14 -0.74	-7.44	0.000**
Relative SJ (cm/kg)	0.48	44.41	46	1.75	-0.96	0.14 -0.70	-6.66	0.000**
SLJ (cm)	0.62	76.71	46	1.91	-1.08	0.12 -0.79	-8.76	0.000**

Legend: kg, kilograms; cm, centimeters; T15, time to cover 15 meters; D-W, Durbin-Watson statistics; p, significance level; ** $p < 0.01$.

Starting with the results obtained, the final resulting equation that allows predicting the performance obtained in the T15 test is the following:

$$\text{T15 performance} = 8.51 - (0.79 \times \text{SLJ}) \quad (\text{Equation 1})$$

Lastly, as observed in Figure 3, the T15 test (dependent variable) was related with the flight distance in the swim start (independent variable) ($R^2=0.48$, $F=42.40$, $\beta=-0.95$, $SE=0.15$, $t=-6.51$, $p=0.000$, 95% CI=-1.24 to -0.65) and the result obtained in the SLJ test (independent variable) ($R^2=0.74$, $F=64.74$, $\beta=-0.81$, $SE=0.12$, $t=-6.77$, $p=0.000$, 95% CI=-1.05 to -0.57). Also, the result obtained in the SLJ test (dependent variable) was associated with the flight distance at the swim start (independent variable) ($R^2=0.25$, $F=15.78$, $\beta=0.50$, $SE=0.12$, $t=3.93$, $p=0.000$, 95% CI=0.24 to 0.76).

On the other hand, we also analyzed if the distance reached in the SLJ test had a mediating effect on the association between the flight time recorded in the swim start and the performance obtained in the T15 test. After including the distance reached in the SLJ test into the equation, the association between the flight time during the swim start and the performance in the T15 test was still significant, but its effect was reduced ($R^2=0.74$, $F=64.74$, $\beta=-0.54$, $SE=0.128$, $t=-4.52$, $p=0.000$, 95% CI=-0.78 to -0.30), which allows us to identify the distance reached in the SLJ test as a mediating variable with a partial effect. The analysis of the mediation showed a direct and indirect significant effect with a significant value for the Sobel test ($z=-3.34 \pm 0.12$, $p=0.000$).

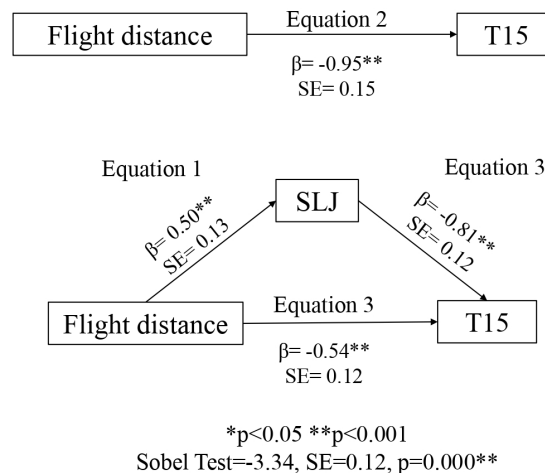


Fig 3. Mediation of flight distance and T15 by SLJ test

Dicussion

The main objective of the present study was to analyze which of the different jump tests: countermovement jump (CMJ), standing long jump (SLJ), or squat jump (SJ) was the most adequate for predicting swimming start performance, and to study the mediating role of this test on the relationship between flight time and time needed to cover the first 15 meters.

After analyzing the results from the different kinematic variables of the swim start obtained in our study, no differences were found as a function of the participant's gender, in agreement with previous studies (Thanopoulos et al., 2012; Tor et al., 2014). As these studies showed, almost all of the kinematic variables did not show significant differences, which seems to demonstrate that the gender of the swimmers will not be a determining factor in the performance of the swim start. In relation to this, the only variable that showed significant differences as a function of gender in our study was the flight distance, which is well in agreement with previous studies (Bishop et al., 2009; Da Silva et al., 2020; Thanopoulos et al., 2012; Tor et al., 2014; Véliz et al., 2020). Out of all the variables analyzed in the present study, flight distance was the only one whose

execution was dependent on the strength of the swimmer, as compared to the technique used (Bishop et al., 2009; Da Silva et al., 2020; Gussakov et al., 2021). Nevertheless, these results could be backed not only by technical differences, but also by differences in maturation and evolution during adolescence, which lead to higher hypertrophy in boys, and may also be responsible for the differences recorded in the strength of the lower body as a function of gender for each of the jump tests performed in the present study, in agreement with those found in the study by Véliz et al. (2020).

As for the comparison of the results obtained in the different jump tests as a function of the gender of the swimmers, as previously mentioned, significant differences were found as a function of gender, with the mean values found for the male swimmers being higher than those recorded for female swimmers in each of the jump tests (CMJ, SJ, and SLJ), in absolute values and relative ones. Also, when comparing our results with those obtained by García-Ramos et al. (2016) y Véliz et al. (2020) great differences were found in the strength values obtained in absolute terms in the CMJ, as well as relative terms as a function of the weight of the swimmer. The same was found for the SJ. In both cases, the differences observed could be due to the different competitive levels that exists between the sample studied in our research and the rest of the research studies. More specifically, García-Ramos et al. (2016) utilized professional swimmers who were more experienced and with a higher competitive level (709.6 ± 94.44 FINA points), which implies greater and more specific strength training that the swimmers in our study (432.02 ± 135.67 FINA points). Along the same line, when comparing our results with those obtained by Véliz et al. (2020), it is possible that the differences observed were due to the different stages of training within which the measurements were taken in our sample, especially if considering the similarity in the results observed in both cases for aspects such as age and/or anthropometric variables between samples.

On the other hand, when analyzing the correlations obtained between the different variables analyzed and the performance in the start (T15), it was observed how the CMJ and the SJ had a very high and statistically significant correlation with the performance of the swim start, as other studies have shown (Carvalho et al., 2017; Keiner et al., 2015; Loturco et al., 2016). This seems to corroborate once again, the great influence and importance of the production of power on the sporting performance of swimming trials, especially in short or speed tests (Bishop et al., 2009; Da Silva et al., 2020; García-Ramos et al., 2015; Gussakov et al., 2021; Véliz et al., 2020). This seems to be also true when applying the SLJ test, as a high correlation ($r=-0.79$) with T15 was observed in the results found in the present research. In fact, the high correlations found suggest that this could be the most adequate test for the prediction of a better T15 time, and therefore, for the prediction of the performance in these short swimming trials. This is a very important finding, given that until now, we have not found any study that relate the SLJ with swim start performance. In fact, the SLJ has the greatest technical similarity to the swim start technique, as it is a based on propulsion on a horizontal plane, just as the swim start, while the CMJ and SJ are jumps on a vertical plane. Thus, taking into account the common features or the possible differences in the mechanics of execution between this jump and the swim start, it must be considered that for the execution of the SLJ, in the present study, we opted for a small modification, which was the elimination of the balancing movement of the arms during the execution of the SLJ jump. The result is that the mechanics of execution between the swim start and the jump test become even more similar, as the balancing with the arms is more associated with a flying (dynamic) start, as utilized in the relay trials, given the mechanics of the trial itself, an individual trial in which one starts from a static position.

Next, if we analyze the results obtained for the kinematic variables, we verified that existence of significant differences as a function of the gender of the swimmer, in both the flight distance, as well as the flight time. The possible explanation seems to be associated with the results found in the strength tests performed in the 3 tests applied, the CMJ, SJ, and SLJ tests. As observed in these results, the male swimmers had stronger values of lower body power than the group of female swimmers, which could be translated into better times, given the greater launching speed, and the greater horizontal movement of the swimmer's body when entering the water (Da Silva et al., 2020; Véliz et al., 2020). On the other hand, given the mean values obtained in our study (3.21 ± 0.028 m) for the flight distance parameter, it was observed that the mean value found was greater than that found in the study by Beretic et al. (2013), which obtained a mean value of 2.41 ± 0.15 m. This could mean that, according to the complementary recording of data for the kinematic study, a lower exit angle, along with a lower flight distance, results in the swimmers tracing a very parabolic trajectory in the air, which is associated with a first phase of ascent to a greater height above the surface. As a consequence of this, the entrance into the water is made with a greater angle of entry, as shown by the results ($+7.33^\circ$), and therefore, a smaller flight distance, as confirmed by the results (-0.8 m). By contrast, as observed in the results found in our sample of swimmers, the analysis of the flight trajectory showed that it was more horizontal, without a previous rising phase from the start of the jump, resulting in a greater flight distance and lower angle of entry into the water. A more horizontal trajectory will allow the swimmer to reach less depth in the underwater phase, so that along with a faster speed of entry, it will be possible for the swimmer to lose less speed due to the less resistance from the water encountered if more depth was achieved (Bishop et al., 2009; Espada et al., 2016; Garrido et al., 2010; Tor et al., 2014; Véliz et al., 2020; Yang, 2018). On the other hand, with respect to this finding, we could think that the angle of the front leg in the initial start position could define the rest of the entry variables, as it is the starting point of the execution of the technique. However, after the analysis of our results, it was observed

that this angle did not have any type of correlation with the performance of the start (T15), just as shown in a study by García-Ramos et al. (2015).

Along the same line, after analyzing the data from the kinematic variables of the swim start, the different jump tests, and the T15, it was observed that for T15, after the regression analysis, the only variables that seemed to predict the time obtained in this trial were those associated with the flight distance and the flight time. These results are similar to those obtained by García-Ramos et al. (2015). As a result of this, the flight distance and flight time could be determining factors when trying to achieve a shorter time in the performance of the swim start (Bishop et al., 2009; Da Silva et al., 2020; García-Ramos et al., 2015; Gussakov et al., 2021; Véliz et al., 2020). In fact, greater values of the strength exerted on the stand at the start imply greater flight times, as well as a longer distance before entry into the water. These data indicate that the swimmers who had a greater strength on the jump tests will exert a greater force onto the platform, resulting in greater flight speeds. With respect to these results, the greater the speed obtained in the flight phase, and the greater distance reached by the swimmers when entering the water, the less time needed to reach T15, which means a better performance in the start. Based on these previous results, we believe that the level of strength of the swimmer could also be a determining factor in the technical execution of the start (Bishop et al., 2009; Gussakov et al., 2021). Nevertheless, other complementary variables could exist that could explain these results, such as for example, the peak of vertical or horizontal strength exerted on the stand during take-off, the index of friction of the swimmer in the underwater phase, the underwater swimming speed of the swimmer, or the swimming speed until reaching 15 meters. Thus, more research is needed on these aspects to complement the present findings.

As for the regression analysis performed to obtain an equation that could predict the performance at the start, through the result obtained in a jump test, it was observed that the test that could predict a greater performance was the SLJ ($R^2=0.62$, $p=0.000$). As previously mentioned, the SLJ is a type of jump whose technical aspects is very similar to that of the swim start. This type of test has natural execution mechanics that are present in many games and sports throughout the development of motor patterns and improvement of basic motor and coordination skills, within the area of general education and sport as well (Almuzaini & Fleck, 2008; Fernández-Santos et al., 2015; Moresi et al., 2022). This is why, along with its similarity to the mechanics of the swim start, that its execution will not only be easier when developing different, specific evaluation tests to measure the strength of the lower body, but it may also be considered as the most specific and simple test to be executed at this age range in sports. As far as we know, this is the first study that utilizes the SLJ to evaluate the strength of the lower body in swimmers, and to predict the performance of the swim start (Moresi et al., 2011). As opposed to our results, other studies in the field have opted for the CMJ or SJ to predict swim start performance (Beretić et al., 2013; Bishop et al., 2009; Carvalho et al., 2017; Espada et al., 2016; García-Ramos et al., 2016; Garrido et al., 2010; Keiner et al., 2019; Loturco et al., 2016; Morouco et al., 2011; Pérez-Olea et al., 2018; Véliz et al., 2020). If we take into account that the results obtained showed that all the jump tests analyzed here had a high correlation, as demonstrated in previous studies (Almuzaini & Fleck, 2008), it should not be strange that based on the above, we consider the use of the SLJ test as useful and relevant as a predominant test that could be performed in the field to predict performance in the swim start, especially at these ages, where perhaps other types of tests could present some problems in their mechanics or development due to their technical character or equipment needed (Almuzaini & Fleck, 2008; Fernández-Santos et al., 2015). Independently of the type of test, it is true that all the authors that were previously mentioned are in agreement in that the specific work of lower body strength should be a fundamental part of the specific training of swimmers, given the benefits it provides in the improvement of the execution of the swim start.

Lastly, the SLJ test seems to condition the flight distance covered after the swim start, which will directly affect the possibility of increasing or reducing the times used by the swimmer to cover the first 15 meters in a swim trial. As already demonstrated by some previous studies, in short trials, the execution technique of the swim start is a determinant factor of the final performance of the trial (Bishop et al., 2009; Da Silva et al., 2020; García-Ramos et al., 2015; Gussakov et al., 2021; Pradas-Valverde et al., 2022; Tor et al., 2014; Véliz et al., 2020; Yang, 2018). In fact, these same authors seem to directly associate the improvements in the strength and power parameters of the lower body with certain changes and improvements in the kinematic variables associated with the exit angle, the flight distance and time, and/or the angle of entry into the water of the swimmer. As observed in the results obtained in the present study, these kinematic parameters are all highly correlated with the times obtained in T15, so that our findings seem to be in agreement with existing scientific evidence. Along the same line, and in a more specific manner, it can be observed how the angle of entry into the water, as well as the flight distance and time, are correlated with the results obtained in the SLJ test. In light of this, it seems evident that these three elements or components of the swim start will have a preponderant role in the final result that could be obtained in the short swim trials (Bishop et al., 2009; García-Ramos et al., 2015; Véliz et al., 2020). More specifically, the study on the strength and power of the lower body will allow predicting the time results that could be obtained when covering these first 15 meters, as greater values in the SLJ test indicates greater propulsion force applied to the stand during the swim start. This fact provokes alterations in the kinematic parameters mentioned previously (Bishop et al., 2009; Pradas-Valverde et al., 2022; Véliz et al., 2020), and overall, indirectly allows us to explain the relationship found in the analysis of the flight distance and T15 variables, as mediated by the SLJ.

Conclusions

As far as we know, this is the first study that considers the SLJ test as an element that could be used to predict performance of the swim start. Also, it is the first study which considers the mediating role of the SLJ on the flight distance and time used to cover a distance of 15 meters (T15) after the swim start in swimming trials. These findings provide novel information on the role of the power and strength of the lower body of swimmers, with respect to the improvement in their times, and therefore, their performance especially in short-distance trials.

On the other hand, the different jump tests used to estimate the strength of the lower body in the present study (SJ, CMJ, and SLJ), had a very high correlation with the performance of the start (T15). As a function of this, any of these jump tests could be used as a tool for the estimation of the swimmer's performance. Nevertheless, considering the mechanics of the execution of the jumps, along with the equipment required for their development, we believe that at this age group, the most recommended test that could be used when trying to measure the power of the lower body, and the performance in the start, would be the SLJ. This affirmation is backed by the results obtained, which have allowed us to obtain a regression equation to predict the performance of the start through the measurement of this SLJ test, which was deemed to be more appropriate given its significance, its goodness-of-fit, and its similarity with the execution of the start technique, than the rest of the jumps (CMJ and SJ).

Based on these results, we can affirm the validity of the hypothesis that the SLJ would be the best test to predict the T15 result given its technical similarity with the swim start technique in swimming.

Of all the variables that were studied, and which form part of the swim start, we verified that the one that may have the most influence on the performance of the swim start was the flight distance. More specifically, the greater the flight distance, the less time needed by the swimmer to reach the distance of 15 meters. Also, the direct relationship between the flight time and distance should be highlighted, as the greater the flight time, the greater the flight distance reached, and therefore, the lower the T15 time.

These results allow us to better understand the importance of the different variables studied, as well as their relationship with the swim start, which demonstrates the need to perform good strength training of the lower body during the training of the swimmers, to improve the force exerted on the stand during the start, to increase the lift-off speed, and to therefore improve all the values associated with the flight distance and time obtained by the swimmer, which will improve their performance on the swim start.

By understanding the different phases and variables that compose the swim start, the coach will be able to understand the technical execution of the swimmer and know how to focus the training needed for its improvement. Likewise, and by observing the relationship between the strength of the lower body, and the performance in the swim start, the specific training used to improve the strength of the lower body, especially plyometrics, must be one of the main objectives within the planning of dryland training of the swimmer.

Conflicts of interest. The authors declare that there is no conflict of interest.

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