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Original Article

Horizontal and vertical jumping abilities and kick start performance in competitive swimmers

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Abstract:
Explosive leg power affects start performance and sprint races; thus, it is necessary to look for associations between the leg power in different directions and performance. The purpose of this study was to identify correlations between jumping abilities and time to 5-m distance during the OSB12 kick start. A total of 12 male competitive swimmers (15.7 ± 1.1 years old) performed countermovement jump (CMJ), countermovement jump with arms (CMJA), countermovement jump on left leg with arms (CMJLA), countermovement jump on right leg with arms (CMJRA), squat jump (SJ), and horizontal jumps–triple hop test using the left leg (THTL), triple hop test using the right leg (THTR), and kick start measurements. We used the Dartfish© software, SwimPro cameras, and Optojump Next. The horizontal jumping ability testing showed a weak correlation between the THTL scores and time to 5-m distance. For THTR, a correlation with time to 5-m distance was observed ($p < 0.05$). There was a correlation ($p < 0.05$) between SJ and time to 5-m distance. For CMJRA, a correlation with time to 5-m distance was observed ($p < 0.05$). For CMJLA, there was a weak correlation. The CMJA test reflects the kick start the most because swimmers swing their arms upward during both the CMJ test with an arm swing and kick start. The highest correlation ($p < 0.01$) was found between CMJA and time to 5-m distance. The correlation between right-leg jumping performance and time to 5-m distance confirms the result that leg power contributes to the take-off velocity generation, underlying kick start efficiency and performance.
Key words: kinematic analysis, weighted, start phase, starting platform

Introduction

Vertical jumps are among the most reliable dry-land tests that are administered to assess explosive strength or anaerobic power, respectively. Each test requires certain rules. For example, in the squat jump, it is necessary to maintain a static position with an upright torso and knees bent at a 90° angle. In the countermovement jump, it is necessary to perform a countermovement squat jump with or without an arm swing. The athletes swing their arms backward and then forward and upwards, thus performing a swinging action (Markovic et al. 2004; Gerodimos et al. 2008). In addition to vertical jumps, power limb is determined by administering horizontal jumping tests such as single-leg triple jump, which is a reliable test of lower limb strength and power (Hamilton et al. 2008). In their training, competitive and elite swimmers commonly use both general and special in-water training, including dryland training (Crowley, Harrison, & Lyons, 2017). Dryland resistance training aims to increase the strength and power production of key propulsive muscles in particular swimming races (Dingley, Pyne, Youngson, & Burkett, 2015). In most swimming strokes, upper-body musculature produces the main propulsive forces.

Therefore, dryland resistance exercises are aimed to develop upper-body strength (Martens et al., 2015). However, lower-body strength and explosive leg power need to be developed and are a limiting factor of the swim start performance (Matúš & Kandráč, 2020). Papadopoulos et al. (2009) hypothesized that by improving jumping abilities, especially the lower-body explosive strength, swimming block start and turns may be improved. In swimming sprint races, start may contribute 26–30% to overall race performance (Cossor, Mason, 2001); the abovementioned value decreases as the race length increases. Every swim start consists of phases (i.e., block, flight, and underwater phases) that follow one another (Slawson et al. 2013; Matúš & Kandráč 2020). During the block phase, swimmers have to perform a powerful take-off using arms to achieve the highest possible horizontal take-off velocity (Riewald & Rodeo, 2015). In their study, Breed and Young (2003) reported that countermovement jump with and without arm swing significantly correlated with the flight distance in the grab, swing and rear-weighted track starts. However, West et al. (2011) reported that swim start performance (time to 15-m distance) was inversely related to peak power and predicted 1RM strength. De la Fuente et al. (2003) did not find any correlation between the countermovement jump force and horizontal force during take-off from the starting block. Carvalho et al. (2017) reported an inverse relationship between the 15-m starting time and countermovement jump parameters (i.e., jump height, peak vertical force, and peak power), with no significant correlation between relative peak vertical force and start variables. The results of this study show that swimmers with higher jumps and higher peak vertical force are faster at 15-m distance when using a track start.

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However, none of the abovementioned studies evaluated the correlation between jumping abilities and swim start variables. The purpose of this study was to determine correlations between vertical and horizontal jumping abilities and time to 5-m distance during the OSB12 kick start.

Material and Methods

Participants

A total of 12 male competitive swimmers participated in this study (Table 1). Each tested person read an information leaflet about the testing and gave his written consent.

Table 1 Participant characteristics

Age (years)	15.7 ± 1.1
Height (cm)	176.1 ± 3.0
Mass (kg)	75 ± 1.2
Performance	Competitive swimmers
Disciplines	50-m and 100-m distances

Swimmers attended testing sessions at the diagnostic center of the Faculty of Sports, Presov, performing vertical jumping tests in the morning of the first day and horizontal jumping tests in the morning of the next day. The following tests were administered to test jumping abilities of swimmers:

Vertical jumping ability

Optojump next (Microgate) - is an optical measurement system consisting of a transmitting and receiving bar (96 LED; 1/1000-s). Each swimmer started separately and performed three jumps with a rest of 30-s. The highest jump was recorded as a distance score. The results were reported to the nearest 0.1 cm. There was a rest of 5-min between tests. After the third test, swimmers rested for 15 min. The following tests were administered to assess vertical jumping ability (Table 2).

Table 2 Vertical jumping tests

Variable		
CMJ	(cm)	Double-leg vertical countermovement jump is a test that involves a single jump starting from an upright position with hands on hips and with countermovement.
CMJA	(cm)	Double-leg vertical countermovement jump with an arm swing
SJ	(cm)	Double-leg squat jump is a test that involves a single jump from a squat position (90° knee angle) with hands on hips and without countermovement.
CMJLA	(cm)	Single-leg vertical countermovement jump with an arm swing – left leg
CMJRA	(cm)	Single-leg vertical countermovement jump with an arm swing – right leg

Horizontal jumping ability

For the horizontal jumping tests, swimmers performed the tests in a jumping sector to endure fast and exact measurements. The takeoff line was marked on the carpet with tape. A tape measure was place perpendicular to the take-off line in the jumping direction (zero mark was on the take-off line). The swimmers stood 20 to 30-cm next to the tape measure and performed three consecutive horizontal jumps. The distance was measured from the take-off line to the heel of the landing leg. Before the testing session, swimmers were allowed to perform a single practice jump. A substitute trial was permitted when swimmers fell backwards or touched the ground with a body part other than their legs. Each swimmer performed three trials, and the best of three trials was recorded as the longest distance jumped. The trials were measured to the nearest cm. The rest period between trials and tests was 30-s and 5-min, respectively (Figure 1). The tests of horizontal jumping abilities of the swimmers are summarized in Table 3.

Table 3 Horizontal jumping tests

Variable		
THTL	(cm)	Triple hop test using the left leg – In this test, the aim was to jump as far as possible on a single leg three consecutive times without losing balance and landing firmly. The distance was measured from the start line to the heel of the landing leg.
THTR	(cm)	Triple hop test using the right leg – In this test, the aim was to jump as far as possible on a single leg three consecutive times without losing balance and landing firmly. The distance was measured from the start line to the heel of the landing leg.

Kick start measurements

Kick start measurements took place in the swimming pool, over two days. Swimmers first had to determine their preferred starting position on the OSB12 starting block, followed by a general and specific warm-up. After the warm-up, sixteen waterproof adhesive markers were applied to the swimmers' bodies (Formicola et al., 2015; Table 4).

Table 4 Marker-based approach

Medial sides of the 5th metacarpal–phalanx joint
Lateral margins of the left and right transverse tarsal joint
Lateral left and right malleolus; ulnar styloid processes of the left and right wrist
Lateral left and right knee condyles
Lateral left and right elbow epicondyles
Lateral margin of the left and right scapular spine
Left and right greater trochanters

To determine the starting position, we placed a bar perpendicular to the starting block's front edge. The body position in the starting block's basic position was determined according to the spot marked on the scapular spine as front-weighted (located in front of the bar), neutral-weighted (overlapped with the bar), and rear-weighted (located behind the bar). The swimmers started from starting positions and adjusted the kick plate to positions 1-5. Each swimmer performed three starts from all positions.

During the first testing session, swimmers determined their optimal start positions on the OSB12 starting block. The testing session consisted of a morning session and an afternoon session. Swimmers performed 23 kick starts during the 1st day kick start trials and 22 kick start trials during the 2nd day. The rest period between starts was 30-s. The rest period between kick plate positions was 2-min. After swimmers performed 9 kick starts, they were allowed to rest for a 5 min (Figure 1).

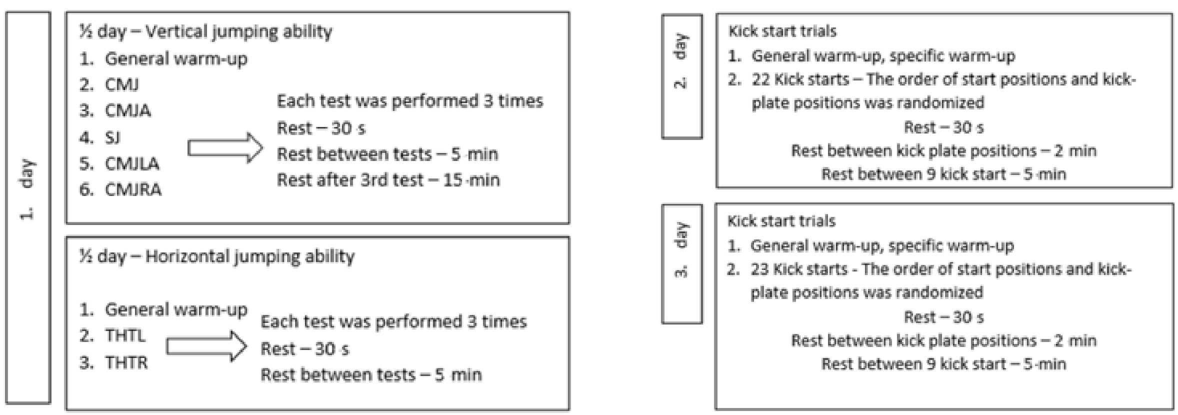

Figure 1 Testing protocol

According to Torr et al. (2015), swimmers should hold their glide for longer and commence their first kick after 6.6-m distance. In this study, swimmers were not allowed to perform any kicking movement to 5-m distance with the block times ranging from 0.5 to 0.7-s. The camera system was used to measure the swim start parameters (Figure 2).

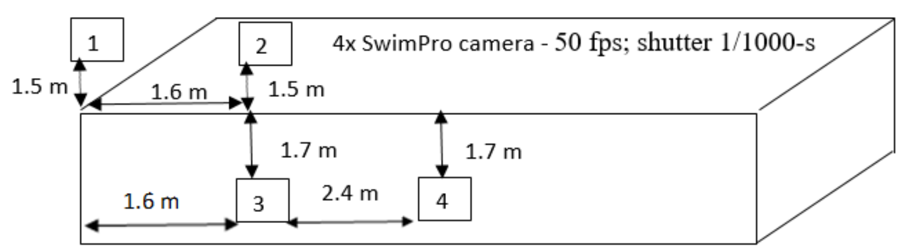

Figure 2 Setup of cameras

Using the Dartfish© software (Dartfish ProSuite4.0, 2005; Switzerland), the 2D analysis of video recordings was performed to evaluated the following phases and kick start parameters (Seifert et al., 2010; Norris & Olson, 2011) (Table 5).

Table 5 Kick start parameters

Block phase			*Definition*
Front knee angle	FKA	(°)	Hip/ankle at the set positon
Front ankle angle	FAA	(°)	Knee/ankle/finger toe at the set position
Rear knee angle	RKA	(°)	Hip/ankle at the set positon
Rear ankle angle	RAA	(°)	Knee/ankle/finger toe at the set position
Hip angle	HA	(°)	Ankle/hip/shoulder
Shoulder position	SP	(°)	Shoulders in front of/above/behind the hands
Block time	BT	(s)	Starting signal – separation of feet from the platform
Flight phase			
Take-off angle	TA	(°)	Ankle/hip/horizontal
Take-off head position	HP	(m)	Water surface/head
Time to 2 m	T2	(s)	Starting signal/head crosses the 2-m distance
Entry angle	EA	(°)	Horizontal/fingertips/hip joint
Flight time	FT	(s)	Take-off/entry of hands
Flight distance	FD	(m)	Take-off/hands touch the water
Underwater phase			
Glide time	GT	(s)	Entry hands/head cross the 5-m distance
Glide distance	GD	(m)	Hands touch the water/head crosses the 5-m distance
Maximal depth	MaxH	(m)	Head reaches the maximum depth
Time to 5 m	T5	(s)	Starting signal – head crosses the 5-m distance

Note. ° – degree; m – meter; s – second

To determine relationships between jumping ability parameters and kick start parameters, the Pearson's product-moment correlation was computed using the Statistica 12 software.

Results

The analysis of vertical jumping abilities showed that jump distances for CMJA were greater than those for SJ. The swimmers achieved lower SJ scores. In the vertical single-leg jump, the swimmers jumped higher when the right-leg take-off was used. Similar results were obtained for horizontal jumping abilities. Single-leg triple jump scores for the right leg were higher than those for the left leg (Table 6).

The shortest time to 5-m distance was recorded when the swimmers assumed the basic starting position and set the kick plate to position 3. The difference between knee angles in the basic starting position was that we found an obtuse angle for the front leg and a sharp knee angle for the rear leg. A sharp knee angle during the take-off and water entry phases was also observed. When the flight and glide phases at a 5-m distance were compared, a shorter flight time and a longer flight distance were observed. Regarding temporal variables, block time accounted for approximately half of the time to 5-m distance (Table 7).

Table 6 Measured distances during vertical and horizontal jumping abilities

Variable		*M*	*SD*
CMJ	(cm)	33.54	3.52
CMJA	(cm)	40.31	3.88
SJ	(cm)	30.03	3.12
CMJLA	(cm)	20.76	2.44
CMJRA	(cm)	21.03	3.26
THTR	(cm)	559.30	54.60
THTL	(cm)	537.70	66.50

Note: CMJ – double-leg vertical countermovement jump; *CMJA* – double-leg vertical countermovement jump with an arm swing; *SJ* – double-leg squat jump; *CMJLA* – single-leg vertical countermovement jump with an arm swing – left leg; *CMJRA* – single-leg vertical countermovement jump with an arm swing – right leg; *THTL* – triple hop test using the left leg; *THTR* – triple hop test using the right leg

Table 7 Kinematic parameters in the shortest time to 5-m distance

	FKA (°)	FAA (°)	RKA (°)	RAA (°)	HA (°)	SP (°)	BT (s)	TA (°)	HP (m)	T2 (s)	EA (°)	FT (s)	FD (m)	GT (s)	GD (m)	MaxH (m)	T5 (s)
M	132.1	127.2	78.5	95.1	43.6	5.5	0.80	39.8	1.2	1.06	36.5	0.36	2.71	0.57	2.29	−0.89	1.73
SE	1.1	0.8	1.0	1.5	1.0	0.4	0.08	1.2	0.0	0.05	0.8	0.03	0.10	0.03	0.10	0.03	0.07

Note: FKA – front knee angle; *FAA* – front ankle angle; *RKA* – rear knee angle; *RAA* – rear ankle angle; *HA* – hip angle; *BT* – block time; *TA* – take-off angle; *HP* – take-off head position; *T2* – time to 2 m; *EA* – entry angle; *FT* – flight time; *FD* – flight distance; *GT* – glide time; *GD* – glide distance; *MaxH* – maximal depth; *T5* – time to 5 m

Using a correlation analysis, we determined the relationships between the jumping test scores and the variables measured during the kick start from the OSB12 starting platform. For the countermovement jump (CMJ) test, we found a strong indirect linear correlation ($r = -0.80$; $p < 0.01$) with time to 5-m distance. In the CMJ test with an arm swing, we found the highest indirect linear correlation ($r = -0.83$; $p < 0.01$) with time to 5-m distance, a direct linear correlation during the flight phase with flight time (FT, $r = 0.65$; $p < 0.05$), and an indirect correlation during the underwater phase with glide time (GT, $r = -0.70$; $p < 0.05$). There was a moderate indirect linear correlation ($r = -0.64$; $p < 0.05$) between the SJ test and the time to 5-m distance. For the right-leg and left-leg vertical jumps, a medium indirect linear correlation with time to 5-m distance was observed for the right leg (CMJRA, $r = -0.70$; $p < 0.05$), a moderately strong direct linear correlation during the flight phase with front knee angle (FKA, $r = 0.70$; $p < 0.05$), and a strong indirect linear correlation during the underwater phase with glide time (GT, $r = -0.78$; $p < 0.01$). For the left leg vertical jump (CMJLA), there was a weak indirect linear correlation.

The testing of horizontal jumping ability showed that there was a weak indirect linear correlation between the THTL scores with time to 5-m distance and a moderate indirect linear correlation during the block phase with block time (BT, $r = -0.67$; $p < 0.05$). For THTR, a moderately strong indirect linear correlation ($r = -0.64$; $p < 0.05$) with time to 5-m distance was observed. However, there was a moderately strong indirect linear correlation with BT ($r = -0.64$; $p < 0.05$) (Table 8).

Table 8 Correlation between the jumping ability and kick start parameters

Variable		CMJ (cm)	CMJA (cm)	SJ (cm)	CMJLA (cm)	CMJRA (cm)	THTL (cm)	THTR (cm)
FKA	(°)	0.32	0.36	0.29	0.13	0.70*	−0.39	−0.27
FAA	(°)	−0.10	−0.02	−0.06	−0.26	0.54	−0.38	−0.16
RKA	(°)	−0.19	−0.25	−0.12	0.04	−0.59	0.46	0.41
RAA	(°)	−0.27	−0.27	−0.24	0.04	−0.57	0.51	0.40
HA	(°)	−0.23	−0.31	−0.09	−0.07	−0.08	0.48	0.55
BT	(s)	−0.53	−0.60	−0.52	−0.38	0.01	−0.67*	−0.64*
TA	(°)	0.05	0.03	−0.10	−0.18	0.50	−0.59	−0.50
HP	(m)	0.36	0.50	0.14	0.25	0.44	−0.09	−0.06
T2	(s)	−0.06	−0.10	−0.02	−0.22	0.30	−0.32	−0.32
EA	(°)	0.03	0.06	−0.06	−0.24	−0.25	−0.25	−0.53
FT	(s)	0.43	0.65*	0.26	0.36	0.47	0.13	0.15
FD	(m)	0.37	0.46	0.24	0.44	0.43	−0.34	−0.27
GT	(s)	−0.59	−0.70*	−0.35	−0.57	−0.78**	0.11	−0.21
GD	(m)	−0.37	−0.46	−0.24	−0.44	−0.43	0.34	0.27
MaxH	(m)	−0.18	−0.18	0.05	−0.15	−0.48	0.19	0.15
T5	(s)	−0.80**	−0.83**	−0.64*	−0.50	−0.70*	−0.36	−0.64*

Note: * – significant at $p < .05$; ** – significant at $p < .01$; *CMJ* – double-leg vertical countermovement jump; *CMJA* – double-leg vertical countermovement jump with an arm swing; *SJ* – double-leg squat jump; *CMJLA* – single-leg vertical countermovement jump with an arm swing – left leg; *CMJRA* – single-leg vertical countermovement jump with an arm swing – right leg; *THTL* – triple hop test using the left leg; *THTR* – triple hop test using the right leg; *FKA* – front knee angle; *FAA* – front ankle angle; *RKA* – rear knee angle; *RAA* – rear ankle angle; *HA* – hip angle; *BT* – block time; *TA* – take-off angle; *HP* – take-off head position; *T2* – time to 2 m; *EA* – entry angle; *FT* – flight time; *FD* – flight distance; *GT* – glide time; *GD* – glide distance; *MaxH* – maximal depth; *T5* – time to 5 m

Discussion

Studies using dryland exercises including CMJ (Breed & Young, 2003; De la Fuente, Garcia, & Arellano, 2003; Benjanuvatra, Edmunds, & Blanksby, 2007; Garcia-Ramos et al., 2016), (SJ), back squat (BS) (West et al., 2011; Garcia-Ramos et al., 2016) and leg extension maximum voluntary isometric contraction (Miyashita, Takahashi, Troup, & Wakayoshi, 1992; Beretić, Đurović, Okičić, & Dopsaj, 2013) significantly correlated with start performance. In this study, correlations were determined between jumping ability tests and kinematic parameters of the kick start during which the shortest time to 5-m distance was measured.

A study (Zatsiorsky et al., 1979) on the relationship between vertical jumping (VJ) ability and start performance found an indirect correlation ($r = -0.68$) between VJ and FT including the glide velocity and between the take-off horizontal velocity and underwater velocity ($r = 0.60$). A study by West et al. (2011) found similar results; the authors examined start performance (as defined by the time to 15-m distance) and strength by administering the CMJ (BT – Hjump, $r = 0.69$; BT – Ppower, $r = -0.85$; BT – Rpower, $r = -0.66$). In contrast, De la Fuente et al. (2002) studied whether the vertical peak force in CMJ and horizontal peak forces of the swimming start were interrelated; the authors found that peak forces correlated very little with the start time variables. However, the study participants were not swimmers but students. Sioutas et al. (2010) also found low correlation ($r = 0.29$) between simulated SJ performance; the participants' arm position and body velocity was similar to their position during the start from the starting block and their body velocity when entering water. In addition, Garrido et al. (2010) determined that the 25-m and 50-m freestyle tests were not significantly associated with VJ height in CMJ ($r = 0.15$ and $r = 0.20$, respectively). Cronin et al. (2007) studies whether leg power during SJ, CMJ, and VJ would be significantly correlated with tumble turn ability. All independent variables were significantly related to the initial turn velocity (V2–4 m), but the correlations could only be described as low to moderate ($r = 0.28-0.41$). The authors concluded that other parameters, such as the reduction of resistance of the aquatic environment by assuming an optimal body position, can lead to an increase in the speed of the swimmer's body during gliding. Lower limbs also play an important role because swimming movements first follow the glide phase, where undulatory movements are mainly used. Likewise, improvement in VJ performance cannot be directly transformed into start performance regardless of the start jump technique used. Carvalho et al. (2017) studied whether CMJ could predict swim start performance; the obtained results showed an inverse relationship between time to 15-m distance and jump variables (Hjump, $r = -0.86$; PVforce: $r = -0.64$; Ppower: $r = -0.92$; regression Hjump and PVforce, $r = 0.89$, adjusted $r^2 = 0.73$). This study revealed a gradual indirect linear relationship between the jumping ability tests and time to 5-m distance in kick start. Significant correlations were strongest ($p < 0.01$) for CMJ ($r = -0.80$) and CMJA ($r = -0.83$). The strongest correlation between CMJA and time to 5-m distance can be explained by the similarity of the take-off because the arms are also used at take-off from the block phase during the kick start. The correlation of CMJA was also observed during the flight phase (FT, $r = 0.65$) and the underwater phase, especially during the glide phase (GT, $r = -0.70$). Regarding the single-leg VJ testing, there was an indirect linear correlation between right-leg VJ and time to 5-m distance. In this study, horizontal jumping ability tests were administered. An indirect linear correlation between the time to 5-m distance and right-leg triple jump (THTR) was determined ($r = -0.64$). The primary role of lower limbs is to generate horizontal take-off velocity, which is one of the factors limiting the swim start performance (Tor et al., 2015).

Some studies aimed to determine relationships between VJ ability and swimming velocity. Strzała and Tyka (2009) reported that the total work in the CMJ test had the strongest influence on 25-m ($r = 0.75$) and 100-m ($r = 0.76$) swimming velocity. It seems that variables measured during the CMJ test may be suitable for determining swimming velocity. Some studies examined the correlation of different dry-land strength and power tests with swimming start performance. For example, in a study by Garcia-Ramos et al. (2016), a few significant correlations between the parameters of SJ and CMJ with times to 5 m (SJ – Ppower $r = – 0.57$, $p < 0.01$; CMJ – Ppower, $r = -0.61$ and TOvelocity, $r = -0.62$, $p < 0.01$) and 10 m (CMJ – Ppower, $r = -0.55$ and TOvelocity, $r = -0.49$, $p < 0.05$) were found. Sammoud et al. (2021) determined a significant group time interactions for CMJ, SLJ (standing long jump), 25-m and 50-m front crawl, 25-m front crawl without push-off from the wall and kick without push-off from the wall in favor of the plyometric jump training group. No significant pre–post changes were found for the control group ($p > 0.05$). Therefore, plyometric jump training is effective in improving muscle power and sport-specific performance in prepubertal swimmers.

The absence of homogeneity regarding the training level and age of participants in the abovementioned studies may partially explain the variation in presented data. This problem can be further compounded by the fact that the number of participants can influence the results. Not all studies provide the necessary number of participants to achieve sufficient statistical power. In addition, in the abovementioned studies, swimmers used the track start, not the kick start, or started from OSB11, not from OSB12.

Conclusion

This study aims to determine relationships between jumping ability tests and time to 5-m distance after a kick start. The results showed an indirect linear correlation between the standard vertical jumping tests and the time to 5-m after the kick start for SJ, CMJ and CMJ tests with arm swing. The strongest correlational relationship was found for the CMJ test with an arm swing. This test reflects the kick start the most, although in the vertical direction, because swimmers swing their arms in the upward direction during both the CMJ test with an arm swing and the kick start.

In the single-leg vertical jumping tests, there was a correlation between the time to 5-m distance after the kick start and CMJRA. Similar results have been found for the horizontal jumping tests. The correlation between the right-leg jumping performance and the time to 5-m distance confirms the results that the lower limb contributes to the generation of the take-off velocity, and this parameter is one of the key parameters underlying the kick start.

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