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The Relationship Between the Lower-Body Muscular Profile and Swimming Start Performance

by

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This study aimed to examine the correlation of different dry land strength and power tests with swimming start performance. Twenty international level female swimmers (age 15.3 ± 1.6 years, FINA point score 709.6 ± 71.1) performed the track freestyle start. Additionally, dry land tests were conducted: a) squat (SJ) and countermovement jumps (CMJ), b) squat jumps with additional resistance equivalent to 25, 50, 75 and 100% of swimmers' body weight [BW]), and c) leg extension and leg flexion maximal voluntary isometric contractions. Correlations between dry land tests and start times at 5, 10 and 15 m were quantified through Pearson's linear correlation coefficients (r). The peak bar velocity reached during the jumps with additional resistance was the variable most correlated to swimming start performance (r = -0.57 to -0.66 at 25%BW; r = -0.57 to -0.72 at 50%BW; r = -0.59 to -0.68 at 75%BW; r = -0.50 to -0.64 at 100%BW). A few significant correlations between the parameters of the SJ and the CMJ with times of 5 and 10 m were found, and none with the isometric variables. The peak velocity reached during jumps with external loads relative to BW was found a good indicator of swimming start performance.

***Key words**: swim start, freestyle swimming, dry land test, jumps with additional resistance, isometric test.*

Introduction

A good start time is a key performance indicator during competitive sprint swimming, as has been shown by the significant correlations with sprint race time (Arellano et al., 1994; Vantorre et al., 2014). It has been shown that the differences in the start times between the winner and the last-placed finalist can be greater than the differences in their final race times (De la Fuente and Arellano, 2010).

Overall swimming start performance in competitions is commonly defined as the time to 15 m (Barlow et al., 2014; Seifert et al., 2010; West et al., 2011) and consists of the block, flight, entry, glide and underwater propulsion phases (Vantorre et al., 2014). Two distinct actions must be optimized during the block phase: a reaction to the start signal and a force impulse generated over the starting block (Benjanuvatra et al., 2007; Vantorre et al., 2014). A high force impulse results in a high push-off velocity and long flight distance meaning that the block phase strongly influences the flight and entry phases. However, the swim start is not just limited to the block and flight phases, but continues until the swimmer re-surfaces and reaches the 15 m mark according to FINA rules. During the glide and underwater phases the velocity acquired during the block phase should be maintained at the highest possible level. In summary, the swim start performance strongly depends on the ability to exert force against the starting block as this phase directly or indirectly affects the following phases.

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The ability to exert force against the starting block and during the underwater propulsion phase is related to swimmers' strength and power capabilities which could be evaluated with several different tests (Beretić et al., 2013; Bishop et al., 2013; Potdevin et al., 2011; Rebutini et al., 2014). It has been shown that the time to 15 m, as well as both the vertical and horizontal peak force collected during the starting push-off phase of a track start were significantly correlated with the countermovement jump (CMJ) and the 3-repetition maximum (RM) squat strength in a group of male international sprint swimmers (West et al., 2011). In addition, significant correlations between start performance and leg extension maximal voluntary isometric contraction exercise were reported (Beretić et al., 2013). However, a vertical jump is deemed the movement most related to swimmer's start performance (Bishop et al., 2013; Zatsiorsky et al., 1979).

It is well known that CMJ as well as squat jump (SJ) tests correspond to maximum muscle power produced by the knee extensors (Bosco, 1999). Highly trained athletes produce maximum mechanical power output during jump squats using resistance of ~55% of 1RM of full squat strength (Baker et al., 2001). It was also shown that muscle activation of the prime movers in the squat exercise increases with an increase of the external load (Clark et al., 2012).

Regarding these facts a strong correlation between the swimming start performance and loaded squat jumps could be expected, being more pronounced at 5 m times than at 15 m times. There are no studies that have examined the association between the swim start performance (i. e., times to 5, 10 and 15 m) and jumps with additional loads. Therefore, the first aim of this study was to quantify the relationship between swim start performance (measured by the times to 5, 10 and 15 m) and some kinetic and kinematic variables measured during loaded squat jumps. The second aim was to find the strongest relationship between track swim start performance and commonly used power and strength tests on dry land.

Material and Methods

Participants

Twenty international level female swimmers (age 15.3 ± 1.6 years, body height 166.9 ± 5.9 cm, body mass 57.2 ± 7.4 kg) volunteered to participate in this study. The sports level of the subjects was quantified by the FINA Point Scoring (FPS) system (data from 2012). The mean FPS value of the study sample was 709.6 ± 71.1. All participants were informed of the procedures to be utilized and signed a written informed consent form prior to investigation. For swimmers under 18 years old, consent was obtained from their legal guardians. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the University of Granada Institutional Review Board.

Study design

A correlation study was designed to examine the relationship between different dry land strength and power tests and freestyle track start performance (times to 5, 10 and 15 m) in experienced female swimmers. All tests were carried out the same day in random order.

Measures
A) Swimming start

After completing a standard warm–up, swimmers were instructed to perform a freestyle track start until a distance further than 15 m to ensure representative values of the time to 15 m (Barlow et al., 2014), however, respecting the FINA rules which determine that by the 15 m point the head must have broken the surface. A standardized starting procedure was used. Swimmers waited standing on the starting block. When they were ready, a tester gave the command ''take your mark'', and then a sound was made by shutting a clapperboard to signal the start of the trial. The acoustic starting signal emitted by the clapperboard was activated at the same time and synchronously with a light system that was extended from the beginning to the end of the swimming pool at a depth of 1 m. False starts were discarded and the trial was repeated.

Two underwater cameras (GoPro Hero 3, 100 fps) and one overwater camera (Casio Exilim Pro EX-FX1, 300 fps) were set up such that their optical axes were perpendicular to the direction of swimming at 5, 10 and 15 m from the starting position, respectively (García-Ramos et al., 2015a). These cameras were synchronized with the starting signal. Each camera was positioned to record at least one of the LEDs that were illuminated together with the acoustic starting

signal. This mechanism allowed us to determine the start point in each camera (first lighted LED frame). A 2D reference system was built with non-elastic lead ropes hooked on the roof of the swimming pool at the distances analyzed.

The times to 5 (T5), 10 (T10) and 15 (T15) m were defined as the time elapsed from the starting signal until the swimmer's head crossed the 5, 10 and 15 m marks, respectively. The analysis was done by Ultimate Pen Software (St Paul, Minnesota, USA) which allowed us to play the video image as well as to plot the spatial references determined from the 2D reference system. The implementation of a routine (Script) in Filemaker Pro v.12 (Santa Clara, California, USA) software made it possible to get the time code of the video image run in with QuickTime Player v7 (Cupertino, California, USA) and set this time in its specific database field for further processing.

B) Squat and countermovement jumps

Three trials of the SJ and other three of the CMJ were performed on a force plate (Kistler 9253A11, Winterthur, Switzerland) with 1 min of recovery between them. The ground reaction force data were collected at a frequency of 1000 Hz and used to calculate the vertical take–off velocity, peak force and peak power by the impulse-momentum approach. The impulse (force x time) of each time point (1 ms) was divided by the subject's body mass to determine change in velocity of the subject's center of body mass, which was then added to the previous velocity to produce a new instantaneous velocity for that time interval. Only the trial with the highest take–off velocity of each type of the jump was analyzed. The characteristics of the jumps, which were performed in a counterbalanced order, were as follow:

- *Squat Jump:* Subjects began from a half squat position (knees and hips flexed at 90º), with hands placed on hips. The subject executed the jump with maximum effort without countermovement and without the swing of the arms.

 - *Countermovement Jump:* Subjects began from a fully extended position (knees and hips at 180º) with hands on hips. On the tester's command, a countermovement (knee and hip flexion to 90º) was performed prior to a maximal vertical jump.

The knee angle was measured with a goniometer to 90º, and an elastic cord was set at

the participant's buttocks. A trial was deemed successful if the participant reached the depth of the elastic cord. The trial was repeated if the participant was too shallow or squatted deeper than the elastic cord (García-Ramos et al., 2015b).

C) Squat jumps with additional weights

Individual load–velocity relationships were determined during an incremental loading test at 25, 50, 75 and 100% of subject's BW in the SJ exercise. A linear velocity transducer (T-Force System; Ergotech, Murcia, Spain) was attached to the bar to collect the data at a sampling frequency of 1000 Hz. Two trials for each load were performed, but only the jump with the highest peak velocity was used for subsequent analysis. Rest periods of 1 min between trials with the same load and 5 min between trials of different loads were implemented. All jumps were performed on a Smith machine, which allows only vertical movements of the bar.

The jump technique involved the subjects standing with the knees and hips fully extended, feet approximately shoulder-width apart and the barbell resting across the back at the acromion level. Participants then slowly descended until the back of the thigh touched an elastic cord set at a knee angle of 90º previously measured with a manual goniometer (García-Ramos et al., 2015b). Participants were required to maintain this static position for 2 s before performing a purely concentric action in order to jump as high as possible. Movements such as countermovement or throwing the bar over the shoulders were not allowed. Trained spotters were present and lifting belts were used to ensure safety.

Peak vertical force (PF), peak vertical velocity (BV), and peak vertical power (PP) were determined as the maximum instantaneous value achieved during the concentric phase for each load. In addition, PF and PP values were normalized with respect to swimmer's body mass (PF_{rel} and PP_{rel}).

D) Maximal voluntary isometric contractions

The maximum voluntary isometric knee extension and flexion were performed at 60º and 40º of the knee angle (0° = full extension), respectively. The hip angle was fixed at 110°. Subjects sat in the isometric knee torque measuring device equipped with a force transducer (MES, Maribor, Slovenia) (Tomazin et al., 2008). The back was supported and the hips

were firmly fixed, the rotational axis of the dynamometer was visually aligned to the rotational axis of the knee (i. e., lateral femoral epicondyle) and the lower leg was attached to the dynamometer lever arm above the ankle joint (i. e., lateral malleolus). During the measurements the subjects were also instructed to hold onto arm supports on both sides of the rigid chair to further stabilize the pelvis.

Two progressive and two explosive isometric knee extensions and flexions in random order were performed. The rest periods between the contractions were 1 min. During progressive contraction the maximum torque was achieved in 2 s and maintained afterwards for 3 s. However, during the explosive contractions the subjects were instructed to develop maximal torque as soon as possible and maintain it for 3 s. The trial corresponding to the maximum torque (progressive contraction) and the trial corresponding to the highest average torque obtained in the first 200 ms (explosive contraction) were analyzed. The variables analyzed in these tests were the maximum torque determined within an interval of 500 ms (progressive contraction) and the average torque from the onset of the contraction to 200 ms (explosive contraction). Both variables were also normalized according to subject's body mass. The torque signals were recorded with the PowerLab system (16/30 - ML880/P, ADInstruments, Bella Vista, Australia) at a sampling frequency of 2000 Hz.

Statistical analysis

Data are presented as mean ± standard deviations (SD). Normal distribution for all variables was confirmed by the Shapiro–Wilk test. Correlations between the different variables collected during the dry land tests and freestyle start performance (times to 5, 10 and 15 m) were quantified through the Pearson's linear correlation coefficient (*r*). Qualitative interpretations of the *r* coefficients as defined by Hopkins (2002) (0–0.09 trivial; 0.1–0.29 small; 0.3–0.49 moderate; 0.5–0.69 large; 0.7–0.89 very large; 0.9–0.99 nearly perfect; 1 perfect) were provided for all significant correlations. Significance was set at an alpha level of $p < 0.05$. All statistical analysis was performed using SPSS version 20.0 (SPSS, Chicago, Illinois).

Results

The average swim start times were 1.77 ± 0.12 s, 4.83 ± 0.23 s and 8.10 ± 0.37 s at 5 (T5), 10 (T10) and 15 (T15) m, respectively.

Table 1

The Pearson's correlation coefficient between the squat and countermovement jumps and times to 5, 10, and 15 m

Jump	Variable	Mean ± SD	T5	T10	T15
	PF (N)	1273.1 ± 191.5	0.01	-0.03	-0.14
	PF_{rel} (N·kg^{-1})	21.59 ± 2.80	-0.06	0.02	-0.12
SJ	PP (W)	2728.5 ± 361.7	-0.40	-0.39	-0.23
	PP_{rel} (W·kg^{-1})	46.24 ± 4.97	-0.57**	-0.42	-0.28
	TOV (m·s^{-1})	2.216 ± 0.15	-0.56*	-0.34	-0.23
	PF (N)	1403.3 ± 176.4	-0.02	-0.14	-0.12
	PF_{rel} (N·kg^{-1})	23.72 ± 1.46	-0.19	-0.17	-0.17
CMJ	PP (W)	2676.7 ± 384.3	-0.37	-0.43	-0.34
	PP_{rel} (W·kg^{-1})	45.27 ± 4.73	-0.61**	-0.55*	-0.43
	TOV (m·s^{-1})	2.344 ± 0.17	-0.62**	-0.49*	-0.36

*SJ, squat jump; CMJ; countermovement jump; PF, peak force; PF$_{rel}$, peak force normalized to body mass; PP, peak power; PP$_{rel}$, peak power normalized to body mass; TOV, take-off velocity; T5, time to 5 m; T10, time to 10 m; T15, time to 15 m; Significant correlations: * $p < 0.05$, ** $p < 0.01$.*

Table 2

The Pearson's correlation coefficient between the squat jumps
with additional loads and times to 5, 10, and 15 m

Load	Variable	Mean ± SD	T5	T10	T15
	PF (N)	1346.8 ± 157.5	-0.03	-0.20	-0.16
	PF$_{rel}$ (N·kg^{-1})	23.7 ± 1.9	-0.20	-0.25	-0.22
25% BW	PP (W)	2232.7 ± 315.3	-0.44	-0.49*	-0.49*
	PP$_{rel}$ (W·kg^{-1})	39.3 ± 4.4	-0.62**	-0.55*	-0.57**
	BV (m·s^{-1})	2.016 ± 0.15	-0.66**	-0.57**	-0.63**
	PF (N)	1408.7 ± 182.2	-0.02	-0.15	-0.13
	PF$_{rel}$ (N·kg^{-1})	24.7 ± 1.4	-0.28	-0.34	-0.31
50% BW	PP (W)	2168.9 ± 327.1	-0.41	-0.42	-0.43
	PP$_{rel}$ (W·kg^{-1})	38.1 ± 4.2	-0.63**	-0.51*	-0.54*
	BV (m·s^{-1})	1.784 ± 0.14	-0.72**	-0.57**	-0.63**
	PF (N)	1497.6 ± 186.5	-0.01	-0.13	-0.12
	PF$_{rel}$ (N·kg^{-1})	26.2 ± 1.0	-0.38	-0.42	-0.43
75% BW	PP (W)	2040.4 ± 312.5	-0.31	-0.38	-0.43
	PP$_{rel}$ (W·kg^{-1})	35.7 ± 3.5	-0.57**	-0.54*	-0.64**
	BV (m·s^{-1})	1.539 ± 0.11	-0.63**	-0.59**	-0.68**
	PF (N)	1632.9 ± 184.1	0.04	0.03	-0.08
	PF$_{rel}$ (N·kg^{-1})	28.2 ± 1.1	-0.25	-0.22	-0.39
100% BW	PP (W)	1978.4 ± 289.4	-0.33	-0.29	-0.45
	PP$_{rel}$ (W·kg^{-1})	34.2 ± 3.6	-0.54*	-0.47*	-0.64**
	BV (m·s^{-1})	1.352 ± 0.11	-0.57*	-0.50*	-0.64**

PF, peak force; PF$_{rel}$, peak force normalized to body mass; PP, peak power;
PP$_{rel}$, peak power normalized to body mass; BV, peak velocity. T5, time to 5 m;
T10, time to 10 m; T15, time to 15 m; BW, body weight;
*Significant correlations: * $p < 0.05$, ** $p < 0.01$.*

Table 3

The Pearson's correlation coefficient between the leg extension
and leg flexion maximal voluntary isometric contractions and times to 5, 10, and 15 m

Variable	Mean ± SD	T5	T10	T15
Maximum torque leg extension (N·m)	165.8 ± 17.4	-0.24	-0.16	-0.15
Relative maximum torque leg extension (N·m·kg^{-1})	2.937 ± 0.42	-0.28	-0.11	-0.13
Maximum torque leg flexion (N·m)	75.0 ± 16.3	-0.23	-0.20	-0.18
Relative Maximum torque leg flexion (N·m·kg^{-1})	1.310 ± 0.21	-0.38	-0.25	-0.23
Explosive torque leg extension (N·m)	12.6 ± 3.3	-0.19	-0.21	-0.13
Relative Explosive torque leg extension (N·m·kg^{-1})	0.224 ± 0.06	-0.20	-0.18	-0.11
Explosive torque leg flexion (N·m)	5.1 ± 1.7	-0.20	-0.19	-0.02
Relative Explosive torque leg flexion (N·m·kg^{-1})	0.089 ± 0.03	-0.25	-0.19	-0.04

T5, time to 5 m; T10, time to 10 m; T15, time to 15 m

Large correlations between the SJ's and CMJ's take-off velocity (TOV) and T5 were found, while only a moderate correlation between the CMJ's TOV and T10 was obtained (Table 1). No correlations between the TOV and T15 were found. Similar results were obtained for PP_{rel}, while other variables (PF, PP and PF_{rel}) showed no significant correlations.

The BV reached during the jumps with additional resistance was the variable most related with swimming start performance (Table 2). Generally, the Pearson's product–moment correlations coefficient ranged from large to very large in the four loads used ($r = -0.57$ to -0.66 at 25%BW; $r = -0.57$ to -0.72 at 50%BW; $r = -0.59$ to -0.68 at 75%BW; $r = -0.50$ to -0.64 at 100%BW).

In contrast, there were no correlations between measured parameters of progressive and explosive maximal isometric knee contractions (i. e., extension and flexion) and swimming start performance (Table 3).

Discussion

The present study aimed to examine the correlation between swimming start performance evaluated by the times required to reach 5, 10 and 15 m and different strength and power tests in female competitive swimmers. The main findings were: i) the SJ with additional resistance showed the highest correlation to swimming start performance. In addition, PPrel and BV during loaded jumps were the only variables that showed a significant correlation to all observed starting times (T5, T10 and T15); (ii) PPrel and TOV during the CMJ showed a correlation to T5 and T10; (iii) meanwhile, PPrel and TOV during the SJ were related only to T5; (iv) no significant correlation between measured times and isometric leg extension and flexion torques were found; (v) among many variables collected during vertical jump tests PPrel and mostly velocities (BV and TOV) were the ones most related to the starting times. Taken together, the results of the present study showed that loaded jumps were the test that showed the strongest correlation to swimming start performance, i.e. times at 5, 10 and 15 m. The best indicator of overall swimming start performance was the assessment of BV during the SJ with additional resistance.

It is interesting to note that the correlations between variables obtained during the two jumps without additional loads (SJ and CMJ) and start performance tended to decrease with increasing distances (Table 1, correlation to T5 > correlation to T10). Both jumps presented significantly large correlations to T5, while T10 only presented a moderate correlation with the CMJ. On the other hand, there were no significant correlations between T15 and both jumps. Our results do not support the findings of West et al. (2011) who found correlations of the start time to 15 m with CMJ height. Discrepancy between the obtained results could be due to the differences in the subject sample, e.g. a highly specific group of subjects consisting only of elite male sprint crawl specialists was used in that study, while our sample consisted of the whole female national squad, regardless of their distance and swimming style preferences. On the other hand our results confirm the findings of some previous studies which showed that on land tests were more related to shorter times, i.e. time to swim to 5 m or solely to the above water phase of start (Benjanuvatra et al., 2007).

By failing to show a significant correlation with T15 these results could indicate that the jumps without additional resistance are not optimal indicators of overall starting performance (commonly defined as the time to 15 m) in female competitive swimmers. As was previously pointed out by De la Fuente et al. (2003), it seems that apart from the starting action on the block, other factors that are mainly related to underwater gliding and swimming contribute to the final starting performance time (T15). Tor et al. (2015) reported that parameters evaluating underwater swimming during the starting action (time underwater in descent and ascent, time at first kick and time to 10 m) accounted for the 96% of the variance of the start time to 15 m, while above-water parameters accounted for 81% of the total variance, suggesting that underwater parameters were more important than above-water parameters for the evaluation of the overall starting performance. The rationale for this fact is also that the underwater phase lasts longer than the above-water phase and therefore presents a greater proportion of the overall starting time (Elipot et al., 2009).

In our study jumps with additional resistance were the only test which showed significant correlation to overall swimming

performance (T15) as presented in Table 2. In addition, significant correlations to T5 and T10 were also found. In other words, this test was found to be universal as it showed correlations to all observed starting times. Among the large number of variables analyzed in the present study, BV reached during the SJ performed with different external loads relative to swimmers' body mass, was the one that showed the highest correlation with swimming start performance. The magnitudes of the correlations were similar in the four loads analyzed (large or very large). While three of the variables collected (PF, PP and PFrel) were not significantly correlated to swimming start performance, PPrel and BV always presented significant correlations to start performance (Table 2). Our results are consistent with the findings of Jidovtseff et al. (2014) who compared eight different vertical jumps and reported that during a CMJ with an additional 20 kg load the highest total impulse (corresponded to the area under the force curve) was produced. Based on this fact and despite the decreased eccentric and concentric velocities measured during loaded jumps compared to other jumps, the authors concluded that loaded jumps were an excellent exercise to produce a great amount of force. In this context, the greater impulse associated with this jump may be important to improve the initial acceleration phase in actions such as the swimming start push-off phase.

Some parameters obtained during loaded jumps (PPrel, BV) showed correlations not only to T5, but also to T10 and T15 (Table 2). This implies that perhaps the ability of efficiently executing underwater kicks was covered by this parameter (i. e., BV). Namely, to efficiently perform underwater crawl and/or undulatory movement, frequent and strong leg flexion and extension movements against the resistance of the water must be executed (Arellano et al., 2003). It is possible that in some way the efficiency of underwater kicking movements was also assessed by the evaluation of dry land loaded jumps in our study (i.e. BV and PPrel). Further research should be conducted to verify this assumption.

Although knee and hip extension muscles are of paramount importance for a vertical or any other jump (Spägele et al., 1999) (e. g., the push-off action on the starting block), our results failed to demonstrate a significant correlation between

isometric strength tests and T5, T10 and T15 (Table 3). The fact that the two-joint muscles activated during the jump, m. rectus femoris and the hamstring group contract at very low velocities and therefore work nearly isometrically (Umberger, 1998), should justify the use of knee extension and flexion isometric strength tests to search for a correlation to different jumping performances. Indeed, it was reported that swimmers who were able to develop greater maximal force and a greater rate of force development during isometric leg extension tend to achieve better times in the initial 10 m (Beretić et al., 2013). However the results of the present study are not consistent with these findings as the knee extension and flexion isometric torque assessed failed to show significant correlations with swimming start performance (Table 3). Lower specificity of our isometric tests could be responsible for these discrepancies; while force during simultaneous knee and hip extension was measured by Beretić et al. (2013), knee extension and knee flexion were measured separately in our study. Therefore, a hip extension isometric test would be a better choice for the evaluation of hamstring muscles than a knee flexion test. On the other hand, Baker et al. (1994) have already questioned the validity of isometric tests to monitor dynamically induced training adaptations, as they found that the measures of dynamic and isometric strength were unrelated and therefore, assumed that mechanisms that contribute to enhanced dynamic strength appeared unrelated to the mechanisms that contribute to enhanced isometric strength. In addition, Thomas et al. (2015) have recently suggested that dynamic strength tests should be preferred over isometric tests to assess the relationship between relative strength and dynamic performance.

In conclusion, based on the results of the present study, the periodic assessment of the BV reached against an external load representing a fixed percentage of BW, could provide valuable data to monitor swimmers' training status in swimming start performance. However, we also have to consider that beside strength abilities, starting times are also affected by swimmers' technical efficiency, and therefore, a perfect cause-effect relationship between start time and swimmers' strength/power capabilities should not

be expected (Breed and Young, 2003; De la Fuente et al., 2003). Further studies are needed to examine if the relationships observed in the present study are maintained in a more homogeneous sample (e. g., sprint athletes).

Acknowledgements

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