THE RELATIONSHIP BETWEEN LOWER-BODY MAXIMUM STRENGTH AND SWIM START PERFORMANCE IN YOUTH ELITE SWIMMERS

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ABSTRACT

Swimmers reach the highest accelerations during starts. These are initiated by a high amount of force produced by the lower limbs in a short amount of time. It is established in senior athletes that there is a relationship between lower-body maximum strength and swim start performance. The aim of this study was to investigate the relationship between lower-body maximum strength and swim start performance up to 5 and 15 m in elite youth swimmers.

Twenty-two (10 females, 12 males) well-trained adolescent swimmers executed a one repetition maximum (1RM) back squat test, a counter movement jump (CMJ), a squat jump (SJ) test, and two trials of a swim start following a freestyle sprint up to 15 m. Bivariate Pearson correlation analyses were used to assess the relationship between strength and jumping performance and start performances up to 5 and 15 m. The level of significance was set at $p < .05$.

Strength and jumping performance explained 55–73% of the variance in start performance up to 5 and 15 m. Strong correlations were found between resulting forces on the block and times to 5 and 15 m as well as between 1RM back squat test, CMJ, and SJ and times to 5 and 15 m (all between $r = -.75$ and $r = -.86$; $p < .01$).

This study demonstrates that strength parameters of the lower limbs affect jumping performance off the block in swimming. Therefore, these parameters are usable predictor variables in assessing start performance up to 5 and 15 m in swimmers.

Keywords: *swimming start, 1RM, back squat, jump performance, strength training*

INTRODUCTION

It is well-recognized that swimming is a complex sport, particularly regarding the athletes' physiological stress profile and biomechanical, morphological, metabolic, and neuromuscular factors. Swimmers must meet a wide range of requirements in order to perform at an elite level. Different physiological skills have to be emphasized depending on the preferred race distance. While short-distance swimmers need a higher maximum strength level, long-distance performance is highly influenced by a higher endurance capacity (Sharp et al., 1982; Tanaka & Swensen, 1998). Moreover, it is suggested that start jump performance significantly influences the final time of swimming distances up to 200 m. Previous research has established that 15% of the final times of the 100 m and up to 30% of the 50 m distances depend on start jump performance (Bishop et al., 2013; Cossor & Mason, 2001; West et al., 2011).

The start performance in swimming requires a combination of reaction time and vertical and horizontal forces off the starting block for a high take-off velocity. Subsequently, a low resistance during the entry and underwater phase is required to maintain a high speed as long as possible (Breed & Young, 2003). During the start and turns phases, the highest accelerations are achieved within a swimming race, which are initiated by the force generated by the lower limbs (West et al., 2011). The maximum force of the lower limbs must be transferred into mechanical power during the swim start. Therefore, a high maximum force must be produced in a short period (i.e., high velocities) (Fuhrmann et al., 2018). Recent research has revealed that start and turn performance is influenced by lower-body-maximum strength,h while swimming performance benefits from a higher maximum strength level of the upper body (Fuhrmann et al., 2018; Keiner et al., 2019; West et al., 2011). Consequently, a high-caliber swimmer must maximize lower-body and upper-body maximum strength.

The vertical and horizontal force during the jump off the block can be improved by maximum strength training of the lower limbs. This suggestion is supported by a significant correlation between vertical jump performance and start jump performance in swimming (Keiner et al., 2019; West et al., 2011). Several studies show that the start jump in swimming has a similar structure as the squat jump (SJ) and countermovement jump (CMJ) in terms of movement and force-velocity profile. The jump height in SJ can be determined by about 56% of the dynamic force maximum of the lower limbs ($R^2 = 0.56$) (Kubo et al., 1999), which is influenced by the general strength level (Baker & Nance, 1999; Barker et al., 1993; Fry & Kraemer, 1991; Kawamori et al., 2006). It is therefore suggested that a greater maximum strength level of the lower limbs and a well-trained jumping performance on land will benefit start jump performance and, consequently, short-distance swimming times (Keiner et al., 2019). On the other hand, Garcia-Ramos et al. (2016) found no significant correlations between the maximum isometric strength of the lower limbs and start performance up to 5 and 15 m. This could be explained due to different study methods, as swim start performance is a dynamic movement. At the same time, maximum strength was assessed by voluntary isometric knee extension and flexion, although only moderate correlations between dynamic and isometric tests have been reported (Murphy et al., 1994).

To date, several studies have investigated the importance of maximum strength in swimming, in particular of the lower limbs during the start and turns (Keiner et al., 2019; Keiner et al., 2015; West et al., 2011). A multiple regression analysis of the one repetition maximum (1RM) squat test and 1RM in bench press explained 50% of the performance variance in start performances (time to 15 m), respectively. Furthermore, maximum strength and jump height of the lower limbs explained 30–42% of start performance at 5 m (Keiner et al., 2019).

Based on these data, there seems to be a relationship between lower-body maximum strength, jumping performance on land, and swim start performance. Therefore, it is hypothesized that a higher maximum force of the lower limbs is significantly related to better swim start performance, defined by a faster time at 5 and 15 m. The aim of this study was to assess the impact of dynamic maximum strength parameters (1RM in the squat, CMJ, SJ) of the lower limbs on the start performance (time to 5 and 15 m) in elite youth swimmers. In terms of long-term athletic development, information from an adolescent sample in this research field could help to specify training methods, especially for short-distance swimmers. It was hypothesized that a significant negative correlation would exist between maximum strength, jump performance on land, and swim start performance.

METHODS

Experimental Approach to the Problem

This study was carried out at the Olympic Training and Testing Center (OSP) in Hamburg/Schleswig-Holstein, Germany, during the youth athletes' general strength, power, and swimming start testing session. The dry-land performance (1RM of the back squat, CMJ, and SJ) and in-water performance (a swimming start followed by a crawl sprint up to 15 m) were assessed to answer the hypothesis. The strength and jump tests were supervised by the athletic coach of the swimmers and the biomechanics expert of the OSP. The swimming start test was conducted by the sports scientist of the OSP. All tests were conducted in the same week on two several days: strength testing was two days prior to jump testing and swim start testing. Athletes (and their guardians, if not 18 years old) were fully informed about the testing procedures and provided written informed consent. This study has been approved by the institutional review board of the University of Applied Science Wiener Neustadt and conformed to the principles of the World Medical Association's Declaration of Helsinki (2013).

Subjects

Twenty-two (10 females and 12 males; age: 16.9 ± 2.2 years; body mass: 73.7 ± 10.5 kg; stature: 1.83 ± 0.01 m) well-trained swimmers of the OSP took part in this study. All swimmers competed in national (German Championships, Youth German Championships, and Northern German Championships) and international championships on a regular basis and are therefore experienced in training and competition. The athletes were familiar with basic strength exercises due to regular strength training 3–4 times per week for at least three years.

Procedures

Strength testing

For strength testing of the 1RM in the back squat, the athletes conducted a standardized warm-up consisting of three repetitions at 80% of their known 1RM. After three minutes of passive rest, the tests started. Between each attempt, athletes had a rest of five minutes. A maximum of three attempts was allowed to determine the 1RM. Each attempt was recorded and observed by the test administrator for exercise-specific criteria. After a successful attempt, the video recording was reviewed by the strength and conditioning (S&C) coach to verify the validity and confirm the repetition.

The test was carried out in a so-called "cage" on solid ground, thereby securing the athletes with safety bars. As usual, the barbell was placed on the musculus trapezius pars descendens for the training sessions. The standing width was chosen individually by the subjects. Athletes started from an upright position, followed by flexing the hip, knee, and ankle joints and then stretching those joints back to the starting position. The S&C coach assessed the execution of the exercise from an angle behind the athlete to evaluate the leg axis. The camera was positioned perpendicular to the athlete at knee height. The exercise was completed when the athlete reached a stable and upright position. The termination criteria for a test series were (1) failing to complete the repetition at a given load correctly, (2) excessive lordosis/kyphosis of the spine during movement, (3) detachment of the heels from the floor, (4) loss of a stable leg axis (valgus position in the knee), (5) strong evasive movements in the torso and/or (6) not being able to reach at least a parallel thigh position in reversal point.

Jump testing

The jumping tests of the CMJ and SJ were measured on a Kistler 9287CA force plate (Kistler, Winterthur, Switzerland) with a frequency of 1000 Hz. The data were analyzed with the TEMPLO software (Contemplas, Kempten, Germany). The jump height was calculated by flight time ($\frac{gt^2}{8}$; g = the gravitational acceleration [9.81 m·s^{-2}] and t = flight time). The participants completed three trials to achieve their best results. The position of the feet was chosen individually by the athlete. For SJ, the participants were told to hold a static position at a knee angle of 90° before the jump. A counter-movement was not allowed. Every attempt was recorded by the software, which gives feedback immediately and evaluates the attempt as invalid. Hands remained on hips during the jump. For CMJ the athletes started in an upright position, lowering their center of gravity while bending their knees. They were instructed to squat quickly to a self-selected depth and push off dynamically in the eccentric-concentric transition phase to initiate a maximal explosive effort. Unlike in the SJ, arm swinging was allowed in the CMJ. In both jumps, participants were instructed to jump to achieve maximal height. During the flight phase and landing of both jumps, the knees and hips had to be extended.

Swimming start test

The tests took place in a 50 m pool. The swimmers warmed up individually on land as well as in water, approx. for 15–20 minutes. The start test was performed on a portable starting block (OSB11, OMEGA, Swiss Timing Ltd., Switzerland) with four custom-made two-axis load cells (ALTHEN, DMS F307-Z3065, Germany [1000 Hz]) performed to determine the vertical (F_x) and horizontal (F_y) ground reaction forces. Furthermore, the starting block record vertical (v_x) and horizontal (v_y) take-off velocities, block time (BT), and reaction time (RT). Special software was used to analyze the incoming signals (Holder, Petersberg, Germany). In each case, the maxima of F_x, F_y, v_x and vy were used. Subsequently, the resulting values of the ground reaction forces and take-off speeds were calculated. The maximum of the resultant force is abbreviated as F_{res}, and the resulting take-off speed with v_{res}. Subsequently, the reaction time was subtracted from the block time to obtain the so-called pure block time (BT_{pure}). It includes only the time frame in which the push-off force was performed on the starting block. The video recording was started when the athlete entered the starting block. Cameras were positioned perpendicular to the swimming pool at 2.5, 5, 10, and 15 m 3 m above the water surface and underwater (Sony SNC VB 603 [50 Hz, full HD 1080p]). Camera system data was processed using Utilius Kiwano software (version 1.5.2.0; CCC software, Leipzig, Germany). The times of up to 5, 10, and 15 m (t_{5m}, t_{10m} and t_{15m}) and their respective speeds ($v_{5–10m}$ and $v_{10–15m}$) were recorded via the camera system. However, only the time up to 5 m and the time up to 15 m were used to evaluate start performance.

The athlete was asked to stand upright without any major movement on the starting block so that the measurement could be started and the force plate could assess the athlete's body mass. They were then allowed to settle into their starting position (staggered stance), whereupon the sport scientist gave the start command "take your marks" and shortly afterwards triggered the start signal. This consisted of a sound and light signal to ensure data synchronization with the video system.

The swimmers conducted two (or three, if one attempt was invalid) starts and were instructed to swim a competition-like maximum crawl sprint to a minimum of 15 m, including their usual underwater phase consisting of dolphin kicks. For evaluation, the head position at the 15 m mark is used. The athletes had a passive rest of about five minutes between each jump.

Statistical Analyses

Data were tested for normal distribution using the Shapiro-Wilk test. The correlation strength between the collected parameters was analyzed using Pearson's product-moment correlation. The following classification of the correlation was chosen according to Untersteiner (2005, p. 87) ($0 < |r| \leq 0.2$: no or very weak correlation, $0.2 < |r| \leq 0.4$: weak correlation, $0.4 < |r| \leq 0.7$: moderate correlation, $0.7 < |r| \leq 0.9$: strong correlation, $0.9 < |r| \leq 1.0$: very strong or perfect correlation). All data are presented in mean ± standard deviation. The alpha level of statistical significance was set a priori at $p < .05$. Statistical analysis was performed using SPSS Statistics 26 (SPSS Inc., Chicago, USA).

RESULTS

All data were normally distributed ($p > .05$). Start performance parameters are displayed in Table 1. The absolute performance in SJ, CMJ, and 1RM squat is presented in Table 2.

Table 1. *Descriptive statistic of start performance of the best 5 m trial and the best 15 m trial*

		N	Min	Max	M ± SD
Best 5 m trial	Resulting force peak (N)	22	830.95	1824.26	1294.36 ± 277.46
	Resulting take-off velocity (m/s)	22	3.86	4.92	4.37 ± 0.29
	Pure block time (s)	22	0.52	0.68	0.59 ± 0.05
	Time 5 m (s)	22	1.42	1.74	1.56 ± 0.11
	Time 10 m (s)	22	3.37	4.72	4.04 ± 0.39
	Time 15 m (s)	22	5.83	7.66	6.79 ± 0.55
	Velocity 5-10 m (m/s)	22	1.67	2.62	2.05 ± 0.26
	Velocity 10-15 m (m/s)	22	1.65	2.40	1.83 ± 0.17
Best 15 m trial	Resulting force peak (N)	22	830.95	1824.26	1289.67 ± 279.26
	Resulting take-off velocity (m/s)	22	3.83	4.92	4.37 ± 0.30
	Pure block time (s)	22	0.52	0.68	0.59 ± 0.05
	Time 5 m (s)	22	1.41	1.77	1.56 ± 0.11
	Time 10 m (s)	22	3.37	4.72	4.04 ± 0.39
	Time 15 m (s)	22	5.83	7.66	6.79 ± 0.54
	Velocity 5-10 m (m/s)	22	1.67	2.62	2.05 ± 0.26
	Velocity 10–15 m (m/s)	22	1.65	2.40	1.83 ± 0.16

Min = minimum; Max = maximum; M = mean; SD = standard deviation

Table 2. *Absolute performance in 1RM squat and jump performances*

	N	Min	Max	M ± SD
SJ (cm)	21	23	59	38 ± 9
CMJ (cm)	22	31	68	46 ± 11
Squat 1RM (kg)	20	47.5	140.0	85.3 ± 26.3

SJ = squat jump; CMJ = counter movement jump; 1RM = oner repetition maximum; Min = minimum; Max = maximum; M = mean; SD = standard deviation

Correlations between start and strength and jump performances of the best 5 m and the best 15 m trial are displayed in Table 3 and Table 4.

Table 3. *Correlations between start and strength and jump performance of the best 5 m trial (Pearson r)*

	v_{res}(m/s)	BT_{pure}(s)	t_{5m}(s)	t_{10m}(s)	t_{15m}(s)	v_{5-10m}(m/s)	v_{10-15m}(m/s)	SJ (cm)	CMJ (cm)	1RM (kg)
F_{res} (N)	.647**	-.204	-.748**	-.805**	-.794**	.803**	.460*	.693**	.781**	.795**
v_{res} (m/s)		-.122	-.843**	-.753**	-.758**	-.675**	.447*	.764**	.785**	.855**
BT_{pure} (s)			.292	.147	.111	-.100	.037	-.222	-.262	-.237
t_{5m} (s)				.910**	.900**	-.807**	-.505*	-.811**	-.858**	-.827**
t_{10m} (s)					.939**	-.974**	-.443*	-.779**	-.835**	-.785**
t_{15m} (s)						-.899**	-.723**	-.796**	-.846**	-.796**
v_{5-10m} (m/s)							.398	.754**	.798**	.749**
v_{10-15m} (m/s)								.487*	.526*	.463*
SJ (cm)									.968**	.779**
CMJ (cm)										.816**

*F_{res} = resulting force off the block; v_{res} = resulting velocity off the block; BT_{pure} = pure block time; t_{5m} = time to 5 m; t_{10m} = time to 10 m; t_{15m} = time to 15 m; v_{5-10m} = velocity between 5 and 10 m; v_{10-15m} = velocity between 10 and 15 m; SJ = squat jump; CMJ = counter movement jump; 1RM = one repetition maximum; ** = $p < .01$; * = $p < .05$*

Table 4. *Correlations between start and strength and jump performance of the best 15 m trial (Pearson r)*

	v_{res}(m/s)	BT_{pure}(s)	t_{5m}(s)	t_{10m}(s)	t_{15m}(s)	v_{5-10m}(m/s)	v_{10-15m}(m/s)	SJ (cm)	CMJ (cm)	1RM (kg)
F_{res} (N)	.694**	−.209	−.763**	−.829**	−.818**	.824**	.457*	.717*	.801**	.797**
v_{res} (m/s)		−.075	−.854**	−.766**	−.773**	−.685**	.445*	.776**	.802**	.861**
BT_{pure} (s)			.225	.128	.102	−.096	.031	−.188	−.248	−.244
t_{5m} (s)				.907**	.897**	−.800**	−.487*	−.811**	−.856**	−.811**
t_{10m} (s)					.939**	−.973**	−.423*	−.779**	−.837**	−.786**
t_{15m} (s)						−.899**	−.707**	−.795**	−.844**	−.788**
v_{5-10m}(m/s)							.379	.752**	.799**	.751**
v_{10-15m}(m/s)								.468*	.505*	.455*
SJ (cm)									.968**	.779**
CMJ (cm)										.816**

*F_{res} = resulting force off the block; v_{res} = resulting velocity off the block; BT_{pure} = pure block time; t_{5m} = time to 5 m; t_{10m} = time to 10 m; t_{15m} = time to 15 m; v_{5-10m} = velocity between 5 and 10 m; v_{10-15m} = velocity between 10 and 15 m; SJ = squat jump; CMJ = counter movement jump; 1RM = one repetition maximum; ** = $p < .01$; * = $p < .05$*

Correlations between start and strength parameters are displayed in Figures 1–4. Individual velocity changes between 5–10 m and 10–15 m can be seen in Figure 4.

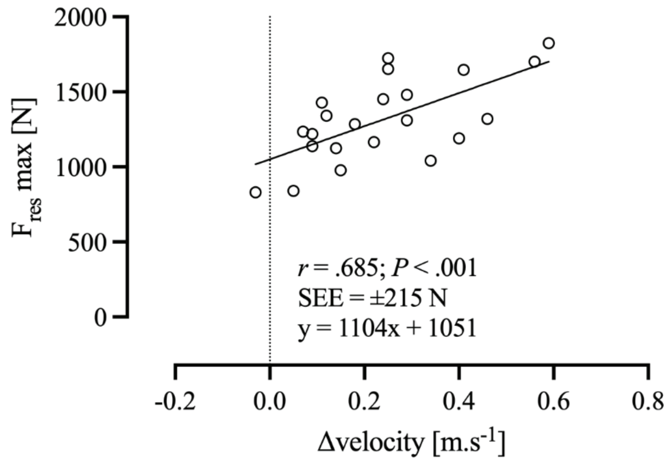

Figure 1. *Correlation between F_{res} (N) and decrease in velocity (m.s.$^{-1}$)*

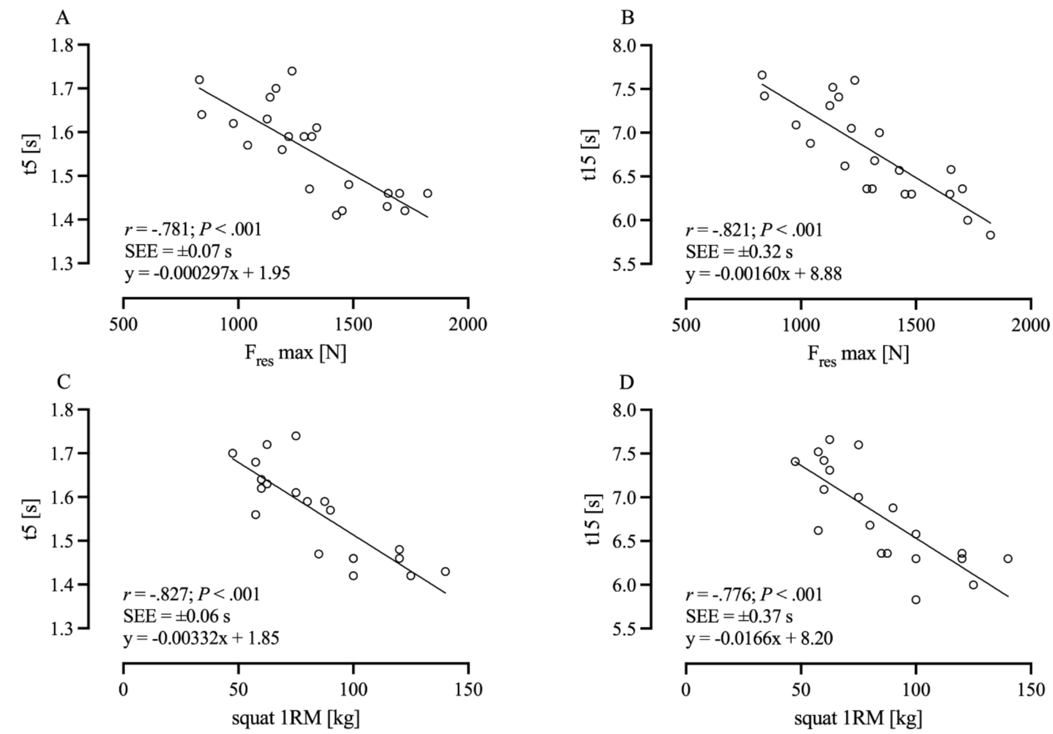

Figure 2. *(A) Correlation between t_5 (s) and F_{res} (N); (B) Correlation between t_{15} (s) and F_{res} (N); (C) Correlation between t_5 (s) and squat 1RM (kg); (D) Correlation between t_{15} (s) and squat 1RM (kg)*

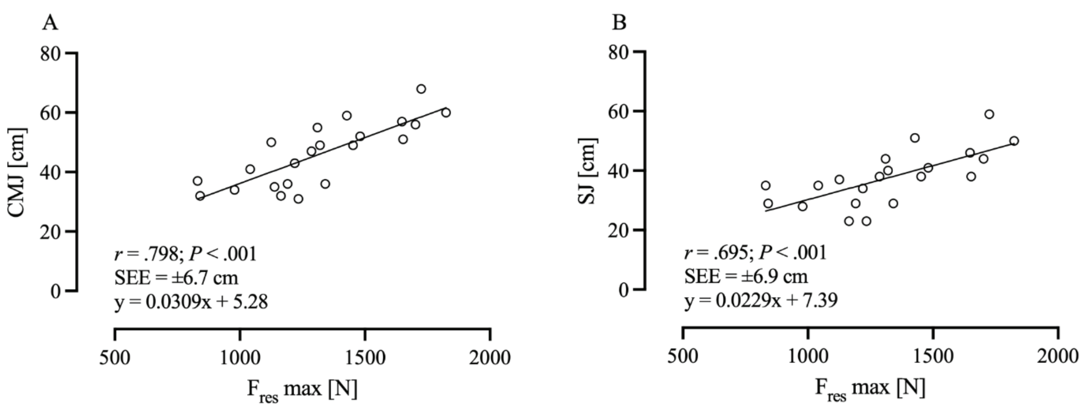

Figure 3. *(A) Correlation between CMJ (cm) and F_{res} (N); (B) Correlation between SJ (cm) and F_{res} (N)*

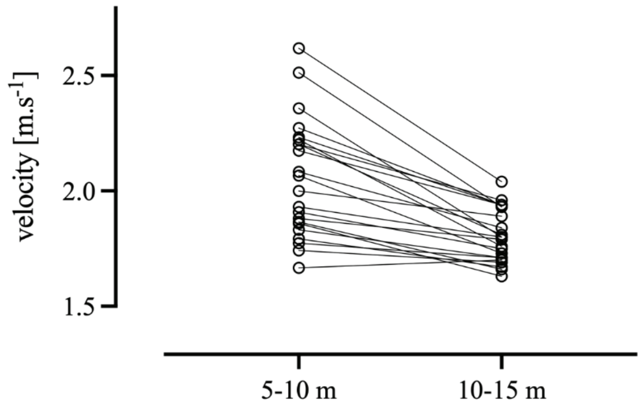

Figure 4. *Individual values for velocities between 5-10 m and 10-15 m (m.s^{-1})*

DISCUSSION

This study examined the relationship between the maximum dynamic strength of the lower limbs and various parameters of swim start performance in well-trained youth swimmers. The results of this work demonstrated that all dynamic strength parameters (i.e., 1RM back squat, SJ, CMJ) were significantly and positively related to swim start performance (r = −.795 to −.858; p < .05), except those with pure block time (r = .102 to .292; p > .05). It was found that lower body maximum strength was strongly correlated with swim start performances up to 5 and 15 m. The moderate to strong correlations between strength and jump performances of the lower limbs and swim start performances are consistent with the results of other studies (Garcia-Ramos et al., 2016; Keiner et al., 2019; West et al., 2011). The data suggest that enhancing maximum strength of the lower limbs in young athletes should be a major goal for (short distance) swimmers to improve swim start performance, thus allowing coaches and practitioners to take an informed decision concerning on-land lower body strength training in terms of long-term athletic development.

Concerning the influence of the maximum strength of the legs on the time to 5 m, the strongest correlation was found with the CMJ (r = −.858; p < .01). Also, the force generated directly on the starting block showed a great influence on the time to reach 5 m (r = −.748; p < .01). The resulting maximum force at the starting block explained 55.9% of the variance in t_{5m}. Furthermore, the maximum strength parameters measured on land (SJ, CMJ, and 1RM of the squat) explained 65.7%, 73.3%, and 68.4% of the variance of the start performance up to 5 m. Time to 15 m also correlated most strongly with CMJ (r = −.844; p < .01) and can be thus explained by 71.3% of the variance. The resulting maximum force at the starting block has, as with the time to 5 m, a strong influence on the time to 15 m (r = −.818; p < .01). Thus, the start performance up to 15 m can be explained by 66.9% of the variance of the resulting force maximum at the starting block. Also, the SJ and the 1RM of the squat lead to better results in time to 15 m (r = −.795 and r = −.788; p < .01). This shows that 63.2% and 62.1% of the variance in t_{15m} can be explained by performance in the SJ and the squat, respectively. These results are consistent with Keiner et al. (2019), where 1RM in squat explained 50% of the performance variance in start performance (15 m), and maximum strength and jump height of the lower limbs explained 30−42% of start performance at 5 m.

The data show that the maximum strength parameters of the lower extremities correlate with t_{5m} and t_{15m}. Even if other factors, such as immersion and underwater phase, play a role between 5 and 15 m, a powerful force development at the starting block notably contributes to a short t_{15m}. This was also found in studies by Keiner et al. (2019) and West et al. (2011). These results support the statement that dynamic movements should not be explained by isometric strength tests, which may explain the nonsignificant result of Garcia-Ramos et al. (2016).

One interesting finding is that the force output on the starting block influences the speed in the water. It seems that the resulting force on the block has a greater influence on speed between 5 and 10 m (r = .803 – .824; p < .01) than on speed between 10 and 15 m (r = .457 – .460; p < .05). It can be concluded that influence of immersion, underwater and possibly swimming phase (depending on the length of the immersion phase) might increase in longer distance. Considering in general the velocities measured in this study, it is clear that they decrease over time and distance. The resulting take-off velocity was 4.37 ± 0.30 m/s. In comparison, the velocity between 5 and 10 m was measured to be 2.05 ± 0.26 m/s and decreased between 10 and 15 m to 1.83 ± 0.17 m/s. This is consistent with the results of Houel et al. (2013), who also observed a decrease in the velocity of the body's center of gravity between the start and 7.5 m. A significant relationship between the relative decline in velocity between 5–10 m and 10–15 m could be detected (r = –.636; p < .001). This means that more powerful athletes have a higher decrease in velocity due to higher starting velocity off the block and in the first meters because of a stronger take-off performance. One athlete even increased velocity between 5–10 and 10–15 m but also had the lowest Fres off the block and a low starting velocity. This can be seen in Figures 1 and 4.

Interestingly, pure block time was the only parameter that did not show any correlation with the strength parameters. Block time could be considered in which the force-generating action was executed. It is suggested that there is no advantage for performance up to 5 or 15 m if the block time is executed as shortly as possible. Consequently, swimmers need a certain time frame to produce a high force (impulse) to accelerate their center of mass and to enter the water with a high velocity. Besides on-land strength training, it is necessary to train the reaction speed on a neuronal level to ensure a quick reaction to the starting signal in order to improve starting performance (Vantorre et al., 2014).

The block times (including reaction time) of the take-off jump in the present study ranged from 0.68 to 0.81 s (Garcia-Ramos et al., 2016; Tanner, 2001; Valvassori et al., 2017). Similarities can be found when comparing these times to other types of jumping. In the SJ, the force is produced in a time frame of approximately 0.36–0.54 s (Bobbert et al., 1996), whereas the dynamic force maximum in the SJ is applied in 0.20 ± 0.07 s (McLellan et al., 2011). In CMJ, the execution time is approximately 0.85 ± 0.15 s, depending on the jumping strategy and initiation of the reversal point (Cappa & Behm, 2013). Accordingly, the conditions during the take-off jump can be compared to those during the jump tests in the SJ and at the CMJ. This was demonstrated in a study by Cossor et al. (2011), in which the force maxima of the CMJ and those of single-leg jumps on land were correlated with the force maxima of both legs during the execution of the swim start. Both the forces on the block and on the footrest were collected. As a result, significant correlations of r = .526 – .885 were found between jumps on land and those on the starting block. In accordance with previous research, the present results suggest that strength and jump diagnostics on land are a good predictor variable for start jump performance in youth swimmers.

CONCLUSION

However, it should be noted that vertical jumping performance is primarily determined by the level of the maximum strength of the legs (Taber et al., 2016). Accordingly, for practical application in the long-term training process, the increase of maximum strength is to be aimed for. The strong correlations between both jumps (CMJ and SJ) and the 1RM of the squat make clear, that a pronounced maximum strength level is associated with a better jumping performance, which has also been stated by previous studies (Barker et al., 1993; Fry & Kraemer, 1991). Maximum strength represents the base for power performance. Therefore, it is important to emphasize that improving lower extremity maximum strength is an essential aspect of the long-term training process to optimize take-off performance in (short distance) swimmers. Even though power training (e.g., jumps) may produce a short-term improvement, strength training is necessary for long-term benefits in the maximum strength level and muscle cross-section (Haff & Nimphius, 2012). Accordingly, high relative squat performance is to be seen as a prerequisite for good jump performances and to be included in the long-term training process in order to improve the start jump performance (Baker & Nance, 1999; Barker et al., 1993; Fry & Kraemer, 1991; Fukunaga et al., 2001; Ikai & Fukunaga, 1968; Taber et al., 2016).

PRACTICAL APPLICATIONS

Maximum strength and jumping performance of the lower limbs are good predictors of swim start performance. Therefore, the 1RM of the squat, SJ, and CMJ should be included in regular strength tests for sprint swimmers. Furthermore, these data suggest that especially sprint swimmers must include lower body maximum strength and power training into their training schedule to improve their swim start performance and therefore lower their final time. Further studies, in particular long-term studies, should be conducted with young competitive swimmers to draw conclusions on long-term training interventions.

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REFERENCES

Baker, D. G., & Nance, S. (1999). The relation between strength and power in professional rugby league players. *The Journal of Strength & Conditioning Research, 13*(3), 224–229. https://journals.lww.com/nsca-jscr/Fulltext/1999/08000/The_Relation_Between_Strength_and_Power_in.8.aspx

Barker, M., Wyatt, T. J., Johnson, R. L., Stone, M. H., O'Bryant, H. S., Poe, C., & Kent, M. (1993). Performance factors, psychological assessment, physical characteristics, and football playing ability. *The Journal of Strength & Conditioning Research, 7*(4), 224–233. https://journals.lww.com/nsca-jscr/Fulltext/1993/11000/Performance_Factors,_Psychological_Assessment,.7.aspx

Bishop, C., Cree, J., Read, P., Chavda, S., Edwards, M., & Turner, A. (2013). Strength and conditioning for sprint swimming. *Strength and Conditioning Journal, 35*(6), 1-6.

Bobbert, M. F., Gerritsen, K. G., Litjens, M. C., & Van Soest, A. J. (1996). Why is countermovement jump height greater than squat jump height? *Medicine and Science in Sports and Exercise, 28*(11), 1402–1412. https://doi.org/10.1097/00005768-199611000-00009

Breed, R. V., & Young, W. B. (2003). The effect of a resistance training programme on the grab, track and swing starts in swimming. *Journal of Sports Sciences, 21*(3), 213–220. https://doi.org/10.1080/0264041031000071047

Cappa, D. F., & Behm, D. G. (2013). Neuromuscular characteristics of drop and hurdle jumps with different types of landings. *The Journal of Strength and Conditioning Research, 27*(11), 3011-3020. https://doi.org/10.1519/JSC.0b013e31828c28b3

Cossor, J., & Mason, B. (2001). Swim start performances at the Sydney 2000 Olympic Games. *XIX International Symposium on Biomechanics in Sports.*

Cossor, J., Slawson, S., Shillabeer, B., Conway, P., & West, A. (2011). Are land tests a good predictor of swim start performance? *Portuguese Journal of Sport Sciences.*

Fry, A. C., & Kraemer, W. J. (1991). Physical performance characteristics of american collegiate football players. *The Journal of Strength & Conditioning Research, 5*(3), 126–138. https://journals.lww.com/nsca-jscr/Fulltext/1991/08000/Physical_Performance_Characteristics_of_American.4.aspx

Fuhrmann, S., Kunz, M., Lambertz, H., Wirth, K., Keiner, M., Hartmann, H., Czasche, M., Jankowski, A., & Berndt, R. (2018). *Rahmentrainingsplan zum Krafttraining im Beckenschwimmen – vom Anschluss- bis zum Hochleistungstraining.*

Fukunaga, T., Miyatani, M., Tachi, M., Kouzaki, M., Kawakami, Y., & Kanehisa, H. (2001). Muscle volume is a major determinant of joint torque in humans. *Acta Physiologica Scandinavica, 172*(4), 249–255. https://doi.org/10.1046/j.1365-201x.2001.00867.x

Garcia-Ramos, A., Tomazin, K., Feriche, B., Strojnik, V., de la Fuente, B., Arguelles-Cienfuegos, J., Strumbelj, B., & Stirn, I. (2016). The relationship between the lower-body muscular profile and swimming start performance. *Journal of Human Kinetics, 50,* 157–165. https://doi.org/10.1515/hukin-2015-0152

Haff, G., & Nimphius, S. (2012). Training principles for power. *Strength and Conditioning Journal, 34*(6), 2–12. https://doi.org/10.1519/SSC.0b013e31826db467

Houel, N., Elipot, M., Andre, F., & Hellard, P. (2013). Influence of angles of attack, frequency and kick amplitude on swimmer's horizontal velocity during underwater phase of a grab start. *Journal of Applied Biomechanics, 29*(1), 49–54. https://doi.org/10.1123/jab.29.1.49

Ikai, M., & Fukunaga, T. (1968). Calculation of muscle strength per unit cross-sectional area of human muscle by means of ultrasonic measurement. *Internationale Zeitschrift for Angewandte Physiologie, 26*(1), 26–32. https://doi.org/10.1007/bf00696087

Kawamori, N., Rossi, S. J., Justice, B. D., Haff, E. E., Pistilli, E. E., O'Bryant, H. S., Stone, M. H., & Haff, G. G. (2006). Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *The Journal of Strength and Conditioning Research, 20*(3), 483–491. https://doi.org/10.1519/18025.1

Keiner, M., Wirth, K., Fuhrmann, S., Kunz, M., Hartmann, H., & Haff, G. (2019). The influence of upper- and lower-body maximum strength on swim block start, turn, and overall swim performance in sprint swimming. *The Journal of Strength and Conditioning Research*. Advance online publication. https://doi.org/10.1519/JSC.0000000000003229.

Keiner, M., Yaghobi, D., Sander, A., Wirth, K., & Hartmann, H. (2015). The influence of maximal strength performance of upper and lower extremities and trunk muscles on different sprint swim performances in adolescent swimmers. *Science & Sports, 30,* 147–154. https://doi.org/10.1016/j.scispo.2015.05.001

Kubo, K., Kawakami, Y., & Fukunaga, T. (1999). Influence of elastic properties of tendon structures on jump performance in humans. *Journal of Applied Physiology, 87*(6), 2090-2096. https://doi.org/10.1152/jappl.1999.87.6.2090

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011). The role of rate of force development on vertical jump performance. *The Journal of Strength and Conditioning Research, 25*(2), 379–385. https://doi.org/10.1519/JSC.0b013e3181be305c

Murphy, A. J., Wilson, G. J., & Pryor, J. F. (1994). Use of the iso-inertial force mass relationship in the prediction of dynamic human performance. *European Journal of Applied Physiology and Occupational Physiology, 69*(3), 250–257. https://doi.org/10.1007/bf01094797

Sharp, R. L., Troup, J. P., & Costill, D. L. (1982). Relationship between power and sprint freestyle swimming. *Medicine and Science in Sports and Exercise, 14*(1), 53–56. https://doi.org/10.1249/00005768-198201000-00010

Taber, C., Bellon, C., Abbott, H., & Bingham, G. E. (2016). Roles of maximal strength and rate of force development in maximizing muscular power. *Strength and Conditioning Journal, 38*(1), 71–78. https://doi.org/10.1519/ssc.0000000000000193

Tanaka, H., & Swensen, T. (1998). Impact of resistance training on endurance performance. A new form of cross-training? *Sports Medicine, 25*(3), 191–200. https://doi.org/10.2165/00007256-199825030-00005

Tanner, D. A. (2001). Sprint performance times related to block time in olympic swimmers. *J. Swimming Research, 15.*

Untersteiner, H. (2005). *Biostatistik - Datenauswertung mit Excel und SPSS : für Naturwissenschafter/innen und Mediziner/innen. Facultas-Verl.- u. Buchhandels-AG.* https://ubdata.univie.ac.at/AC04586200

Valvassori, R., Mezêncio, B., Arruda, A., Arruda, S., & Soncin, R. (2017). Influence of block time in the final 50 and 100 meter swimming events classification. *Journal of Physical Education and Sport, 17,* 2593–2598. https://doi.org/10.7752/jpes.2017.04295

Vantorre, J., Chollet, D., & Seifert, L. (2014). Biomechanical analysis of the swim-start: a review. *Journal of Sports Science and Medicine, 13*(2), 223–231.

West, D. J., Owen, N. J., Cunningham, D. J., Cook, C. J., & Kilduff, L. P. (2011). Strength and power predictors of swimming starts in international sprint swimmers. *The Journal of Strength and Conditioning Research, 25*(4), 950–955. https://doi.org/10.1519/JSC.0b013e3181c8656f

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