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Analysis of Freestyle Swimming Sprint Start Performance After Maximal Strength or Vertical Jump Training in Competitive Female and Male Junior Swimmers

Dennis-Peter Born,[1,2] Thomas Stöggl,[3] Arpad Petrov,[4] David Burkhardt,[2] Fabian Lüthy,[1] and Michael Romann[1]

[1]Department for Elite Sport, Swiss Federal Institute of Sport Magglingen, Magglingen, Switzerland; [2]Swiss Swimming Federation, Bern, Switzerland; [3]Department of Sport and Exercise Science, University of Salzburg, Salzburg, Austria; and [4]Hungarian Swimming Federation, Budapest, Hungary

Abstract

Born, DP, Stöggl, T, Petrov, A, Burkhardt, D, Lüthy, F, and Romann, M. Analysis of freestyle swimming sprint start performance after maximal strength or vertical jump training in competitive female and male junior swimmers. *J Strength Cond Res* 34(2): 323–331, 2020—To investigate the freestyle swimming sprint start performance before and after 6 weeks of maximal strength compared with vertical jump training. With a between-group repeated-measure design, 21 junior swimmers (12 female and 9 male) competing in national and international championships performed 2 weekly sessions of either maximal strength (heavy-loaded back squat and deadlift exercise) or vertical jump training (unloaded box jumps) for 6 weeks during the precompetition phase of the seasonal main event. Session ratings of perceived exertion were used to compare the load of both training programs. Before and after the training period, sprint start performance was investigated on a starting block equipped with force plates synchronized to a 2-dimensional motion capture system. Total training load did not differ between the 2 groups. Sprint start performance and most kinematic and kinetic parameters remained unaffected. In pooled data of the U17 swimmers, however, 5-m, 15-m, and 25-m split times were improved with maximal strength ($p = 0.02$, 0.03, and 0.01), but not with vertical jump training ($p = 0.12$, 0.16, and 0.28). Although there was no global effect, focus on the subgroup of U17 swimmers showed an improved sprint start performance with 2 sessions of maximal strength training integrated into a 16-hour training week. Although outcomes of the conditioning program seemed to be affected by the training history and performance level of the athletes involved, strength and conditioning coaches are encouraged to introduce maximal strength training at a young age.

Key Words: force production, instrumented starting block, kinematic analysis, plyometrics, weight lifting

Introduction

In the recent Rio 2016 Olympic finals, the men's 50-m freestyle sprint was won with 21.40 seconds and only a 100th of a second ahead of the silver medal winner. The marginal differences in the outcome of modern swimming sprint races have increased the scientific interest in the start performance, which accounts for 25% of the total race time (29,30,41). Analysis of key performance indicators indicated the importance of a high on-block force production of the front and rear foot (29) for a high take-off horizontal velocity (1,37). Because air travel generates substantially less drag forces compared with water, swimmers aim to increase their flight distance (29). During the flight phase, a slight forward rotation promotes a smooth and steep break through the water surface to minimize the hole size and resistance at water entry (39). As swimming underwater at a depth of about 0.5–1.0 m produces less resistance compared with swimming at the surface (36), swimmers prolong their underwater phase with propulsive force of butterfly kicking up to the 15-m mark, indicating the latest allowed point of resurfacing (18).

In Olympic pool swimming, the horizontally oriented jump forward from the elevated block position enables swimmers to kick-start the race with more than twice the actual race velocity and provides a huge initial propulsion for subsequent full-stroke swimming (40,41). Although the start provides one of the few opportunities to push off from a solid base, it is affected by strength abilities of the lower limbs (42). On-land training methods are therefore often used among expert strength and conditioning coaches to prepare for the specific demand of the swimming sprint start with traditional resistance training as the most commonly method used (13). Although plyometric jump training improved the start performance after 6–8 weeks with 2 weekly sessions of 60–75 minutes (7,30), the question arises whether maximal strength training might induce similar or even greater effects. West et al. (42) showed that the 1-repetition maximum in deep squats correlated with sprint start performance. A recent review on strength and conditioning in swimming concluded that in particular the back squat might be of major benefit for sprint starts (6). The squat is one of the most popular exercises for swim-specific strength training among expert strength and conditioning coaches (13) and of special interest

Address correspondence to Dr. Dennis-Peter Born, dennis.born@swiss-swimming.ch.

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for the long-term talent development. Although certain levels of strength might benefit safety and effectiveness of ballistic-like training modalities, an early introduction of maximal strength in an athlete's career seems sound (4,12,27). However, clear evidence for its effectiveness, i.e., heavy-loaded barbell exercises, on swimming sprint start is lacking and warrants detailed investigations.

Therefore, the aim of the study was to investigate swimming sprint start performance for freestyle before and after 6 weeks of maximal strength or vertical jump training in competitive swimmers. We hypothesized that the maximal strength training incorporating heavy back squat and deadlift exercises would improve the swimming sprint start performance and corresponding kinematic and kinetic parameters to a greater extent compared with a vertical jump training, i.e., unloaded box jumps.

Methods

Experimental Approach to the Problem

With a between-group repeated-measure design, swimming sprint start performance for freestyle and corresponding kinematic and kinetic parameters was investigated. A starting block, equipped with force plates and synchronized to a 2-dimensional motion capture system, was used to measure sprint start performance before (pre-) and after (post-) 6 weeks of maximal strength compared with vertical jump training. During the training period, subjects performed 11 sessions of either maximal strength, i.e., heavy back squat and deadlift exercise, or vertical jump training, i.e., unloaded box jumps. Both protocols were designed to add 1 hour of strength training immediately before the afternoon swim session and were performed twice a week with at least 1 day in between strength training sessions. In the last week of the intervention period, only 1 strength session was performed 3 days before the post-test to assure sufficient recovery. The study was conducted after the qualification phase from the end of April until the mid of June, which is equivalent to the precompetition phase of the seasonal main event, i.e., European championships, European junior championships, or National championships. After precompetition, athletes were ranked based on their horizontal take-off velocity. Based on the ranking, swimmers were alternatively assigned to the 2 training groups to assure equal baseline levels for both groups at the start of the training period.

Subjects

For this study, 27 adolescent female ($n = 12$) and male ($n = 9$) swimmers (mean ± *SD*: age range: 14.0–23.6) competing at an international and national level with no experience in weight lifting and barbell exercises were recruited. Up to the start of the study, the swimmer's dry-land training included body mass–only exercises to improve core stability, balance, and mobility. Dry-land training that resembled Pilates and Yoga was performed for 45 minutes before the afternoon swim session twice per week and for 20 minutes on the remaining days. Exclusion criteria were any neuromuscular injuries or prolonged absence from training before or during the study period. Therefore, 1 swimmer was excluded from the study because of a shoulder injury and 3 swimmers because of missing more than 2 of the strength training sessions. Based on preparation for their final school examination, 2 swimmers were unable to attend the post-test. The characteristics of the 21 included subjects are presented in Table 1. Before the data collection, all subjects and legal guardians, in the case of minor-aged swimmers, signed the institutionally approved informed consent document to participate in the study after being informed about the risks and benefits of the study involved. The study was preapproved by the Swiss Federal Institute of Sport Magglingen's review board (044_LSP_080218) and is in accordance with the Declaration of Helsinki.

Table 1

Subject characteristics of the maximal strength ($n = 10$) and vertical jump training ($n = 11$) groups indicated as mean ± *SD* (95% confidence interval).*

	Maximal strength training	Vertical jump training
Age (yrs)	17.1 ± 2.6 (15.5–18.7)	17.1 ± 2.7 (15.5–18.7)
Height (m)	1.75 ± 0.1 (1.69–1.81)	1.72 ± 0.07 (1.68–1.76)
Body mass (kg)	65.8 ± 10.1 (59.5–72.1)	62.9 ± 9.1 (57.6–68.3)
50-m FR Pb (s)	26.29 ± 1.87 (25.13–27.45)	26.6 ± 1.4 (25.77–27.42)
FINA points (a.u.)	599 ± 42 (573–625)	559 ± 117 (489–628)
100-m FR Pb (s)	57.2 ± 3.58 (54.98–59.42)	57.29 ± 2.61 (55.75–58.83)
FINA points (a.u.)	617 ± 45 (589–645)	574 ± 113 (507–641)

*FR = freestyle; Pb = personal best; FINA = Fédération Internationale de Natation.

Procedures

Training Programs. Two weeks before the study, all athletes were familiarized with the back squat, deadlift, countermovement jump (CMJ), and squat jump (SJ). As recommended previously (23), the familiarization involved 3 sets with 12 repetitions of the back squat and deadlift as well as 3 sets of 8 CMJ and SJ. The strength and conditioning coach chose weight and box height such that moderate effort from athletes, as well as high-quality technical execution was ensured.

Maximal Strength Training. Workload was gradually increased during the 6-week training period, as recommended previously (23). Heavy back squat and deadlift exercises were performed as 3 sets of 6–8 repetitions in weeks 1–3 and as 4 sets of 2–4 repetitions in weeks 4–6. Sets were separated by a 5-minute rest period. For both the squats and deadlifts, barbell weight was chosen to assure muscular failure during the last 2 repetitions of the targeted repetition range, while maintaining high-quality lifting technique as recommended previously (23). Weight was increased for the next set by 2.5 kg if the athletes reached the upper limit of the targeted repetition range. Training was supervised by a professional strength and conditioning coach. Back squats were performed with a high-bar position and full range of motion, aiming for a knee flexion angle <90°. The eccentric movement was performed with a controlled velocity and immediate reversal at the point of the lowest knee flexion angle. The concentric phase was performed as fast as with the high load possible. Intraset rest periods between repetitions were kept to a minimum. Deadlifts were executed conventionally with a shoulder-wide grip aiming for a full range of motion. Deadlifts were added to the training program to imitate the neuromuscular recruitment pattern of the swim start as a nonstretch-shortening cycle-like movement.

Vertical Jump Training. Vertical jumps were executed as unloaded box jumps, and the training program was designed to match the neuromuscular demand of the maximal strength training. The CMJ was implemented as an exercise with an eccentric-concentric muscle contraction similar to the squat. The SJ aimed to imitate the movement pattern of the deadlift involving no stretch-shortening cycle. For both the CMJ and SJ, athletes were instructed to keep their hands on their hips to isolate leg movement. To eliminate the countermovement for the SJ, athletes had to rest in a static squat position for 2 seconds before the jump. The back of the athletes' thighs had to make contact with a bench positioned behind them. Box height, for the box jumps, was continuously adjusted to challenge the athletes but assure a safe and high-quality landing on top of the box.

The aim was to match the load of both training protocols as close as possible. During the training period, Foster's session ratings of perceived exertion (RPE) were used to monitor and adjust the training load between the 2 protocols on a weekly basis. Athletes were instructed to rate their perceived exertion within the first 30 minutes after the training sessions on a 1–10 Likert scale with 1 indicating no and 10 indicating heavy exertions (19). Initially, the total number of repetitions for the vertical jump program was set at twice the number of repetitions of the maximal strength training, assuming time-under-tension is about half for vertical jumps compared with back squats or deadlifts. Aiming for similar total training time, the rest period for the vertical jump training was set half the maximal strength training's rest period. Based on session RPE, training load for the vertical jump group needed a slight adjustment after the first week of training to match the load of the maximal strength training. Therefore, 2 additional sets per session were added, and from week 2 onward, athletes performed 7 sets with 6–7 jumps of both the CMJ and SJ. Sets were separated by a 2.5-minute rest period. The total number of jumps per training session was 60–98, which is in line with previous research recommending a total of 50–120 jumps per training session, performed twice per week with junior athletes (3).

Testing Procedures. Before and after the training period, all athletes performed 5 regular freestyle competition starts up to the 25-m mark. The tests were performed from 09:00 hours until 15:00 hours in an outdoor Olympic distance pool with a water temperature of 27° C. Ambient temperatures at the beginning and end of the tests were 16° C and 17° C (87 and 84% humidity with 0–3 $\text{km}\cdot\text{h}^{-1}$ wind speed) on the day of the pre-test and 17° C and 21° C (81 and 78% humidity with 5–6 $\text{km}\cdot\text{h}^{-1}$ wind speed) on the day of the post-test. One hour before the in-water testing, athletes started a standardized full-competition warm-up routine. The 50-minute warm-up with a total distance of 2.300 m involved low-intensity swimming, technical drills, 25-m splits with gradually increasing speed, and sprint starts from the block. The warm-up was standardized for all athletes for the pre-test and post-test. After the warm-up, the sprints were performed from the starting block, and the underwater phase was allowed for a maximum of 15 m (18). All athletes used the kick start technique with inclined rear foot support. After 2 familiarization trials, the best of 3 was used for statistical analysis. Tests were performed in groups of 5 athletes, which allowed 4–5 minutes of rest between the trials. Athletes were tested in the same order for both the pre-test and post-test to minimize daily variations in performance.

Swim start performance was assessed on an instrumented starting block (PAS-S; Kistler, Winterthur, Switzerland) that was synchronized to a 2-dimensional motion capture system with 5 cameras (Prosilica GC660C; Allied Vision Technologies, Stadtroda, Germany). The block platform involved 2 force plates to capture forces of the front and rear foot separately. Each plate had four 3-dimensional force sensors, collecting force data with a 500-Hz sampling rate. A third force plate positioned underneath the platform collected the grab forces. The starting block was designed with the dimensions of the Omega OSB series with adjustable rear foot support according to the official FINA rules (18). The block was positioned on the third lane with a distance of 6.6 m from the side wall to which the camera system was attached.

Cameras in waterproof housing collected digital images with 100 frames per second. At the 1.5-m mark, 2 cameras (cam 1 and 2) were positioned to capture the video footage at 0.6 m over and 0.8 m under the water surface. At the 5-m, 10-m, and 15-m marks, cameras were positioned 0.8 m under the water surface (cam 3 to 5). Each sprint start was initiated by the official signal using a starting device with a microphone, sound, and light trigger (Infinity Start System; Colorado Time Systems, Loveland, CO). The starting device was connected to the starting block and camera system to synchronize all 3 systems. Hence, the kinematic and kinetic data were measured simultaneously to the starting signal. An external camera (FDR-AX700E; Sony, Tokyo, Japan) was positioned perpendicularly to the lanes at the 25-m mark of the 50-m pool, at a height of 1.5 m above the water surface (cam 6). The 25-m sprint time was measured from the starting signal (light trigger of the starting device visible in the video footage) until the head of the swimmer passed the 25-m mark. A detailed illustration of the setup is presented in Figure 1.

Before the tests, the motion capture system was calibrated in 2 dimensions using markers arranged vertically on a pole that was fixed to a tripod. Seven markers were positioned from 1.5 m above to 1.5 m below the water surface in 0.5-m intervals. The pole was moved horizontally along the middle of the test lane. The markers were digitalized in 1-m intervals from the starting block up to 17 m, which marked the end of the range of vision of the camera system. At each 1-m interval, distance of the pole to the front edge of the starting block was measured with a thousandth of a meter accuracy, using a laser-beam distance measurer (Disto D2; Leica Geosystems, Inc., Heerbrugg, Switzerland). A detailed description of the calibration procedure is provided elsewhere (26).

Postprocessing of the video images from cam 1 to 5 was performed using the semiautomated procedure of the PAS-S analysis software (version 8.4; Kistler, Winterthur, Switzerland). The center of the head at the start, the center of the head and gravity at toe-off, far and rear edge of the entry hole, top of the head at entry, center of the head at deepest point of the underwater phase, as well as top of the head at breakout and when passing the 5-m, 10-m, and 15-m marks, were digitalized manually. Afterward, kinematic and kinetic data were calculated by an automated procedure. In addition, the butterfly kicking rate was determined from the underwater video image of the PAS-S analysis software, and the distance per butterfly kick was calculated using Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA). Video images from cam 6 were used to measure the 25-m split-time, stroke rate, and distance per stroke between the 15-m and 25-m mark (Kinovea, version 0.8.15; Joan Charmant & Contrib., kinovea.org).

Statistical Analyses

The data are presented in mean ± *SD* and corresponding 95% confidence interval. Normal distribution was investigated with the Shapiro-Wilk test. Non-normally distributed data confirmed a Gaussian distribution after logarithm transformation. A 2-way analysis of variance (ANOVA)—group (maximal strength vs. vertical jump training) × time (pre- vs. post-)—was performed with partial eta^2 and statistical power calculation. Main effects over time that reached the level of significance were further analyzed using a paired *t*-test. Swim training data between the 2 groups were compared with an unpaired *t*-test. An alpha level of

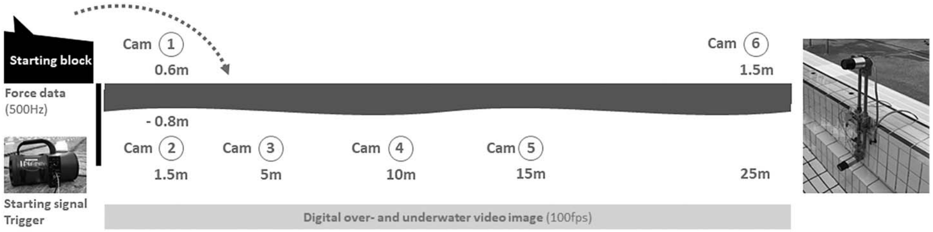

Figure 1. Performance analysis of the freestyle swimming sprint start before and after 6 weeks of training with the starting block equipped with force plates and synchronized to a 2-dimensional motion capture system (cameras: cam 1 to 6).

≤0.05 confirmed a statistical significant effect. Additional analysis was performed for the pooled data of the U17 swimmers. With respect to the reduced number of subjects, an alpha level of ≤0.1 was interpreted as a trend-like effect. All data were collected and prepared using Microsoft Excel 2016 and analyzed with SPSS statistical software package for Windows Version 24.0 (IBM Corporation, Armonk, NY).

Results

Strength Training Data

During maximal strength training, barbell weight from the first to the sixth training session increased within the targeted range of 6–8 repetitions from 43 ± 11 to 52 ± 11 kg ($p < 0.01$) and from 48 ± 15 to 62 ± 20 kg ($p < 0.01$) for the back squats and deadlifts, respectively. From the seventh to the 11th training session within the targeted range of 2–4 repetitions, barbell weight increased from 61 ± 11 to 65 ± 12 kg ($p = 0.02$) and from 71 ± 19 to 79 ± 20 kg ($p < 0.01$) for the back squats and deadlifts, respectively. During the vertical jump training, from the first to the 11th training session, box height increased from 75 ± 9 to 96 ± 7 cm ($p < 0.01$). Total workload, determined as the sum of session RPEs accumulated during the training period, did not statistically differ between the 2 groups performing either maximal strength or vertical jump training (4,743 ± 714 vs. 4,241 ± 641 a.u., $p = 0.11$).

Swim Training Data

With a total weekly training volume of 16:26 ± 03:21 hh:mm, swim-specific training was 13:19 ± 03:01 and 11:19 ± 03:27 hh:mm corresponding to 40.4 ± 9.2 and 34.9 ± 11.1 km for the maximal strength and vertical jump training, respectively. There was no significant difference between the groups ($p = 0.23$). Swim training included a total of 20 ± 12 and 18 ± 8 starts ($p = 0.74$) and 26 ± 7 and 25 ± 9 sprints ($p = 0.62$) for the maximal strength and vertical jump training group, respectively. In addition, the swimmers performed 02:29 ± 00:44 and 02:30 ± 00:42 hh:mm mobility, stretching, and activation exercise ($p = 0.96$) before swim training sessions.

Sprint Start Performance

There was no difference in baseline horizontal take-off velocity between the maximal strength and vertical jump training group ($p = 0.66$). From pre- to post-, sprint start performance, i.e., the 5-m, 10-m, 15-m, and 25-m split times, remained unchanged in both groups (main time effect: $p = 0.65$, 0.64, 0.53, and 0.74, respectively; Table 2). Vertical jump training indicated an improved peak resultant horizontal force times body mass (BM) after 6 weeks of training ($p = 0.03$). The remaining kinematic and kinetic parameters were unaffected (Table 3).

Pooled data of the U17 swimmers revealed a main time effect for the 5-m, 15-m, and 25-m split times ($p = 0.03$, 0.03, and 0.05, respectively; Figure 2). No interaction effect was evident, but the pairwise comparison indicated an improved 5-m (1.72 ± 0.07 to 1.68 ± 0.09 seconds, $p = 0.02$), 15-m (7.76 ± 0.19 to 7.55 ± 0.12 seconds, $p = 0.03$), and 25-m split time (13.19 ± 1.02 to 13.15 ± 0.86 seconds, $p = 0.01$) for the maximal strength training group. With the vertical jump training, the 5-m (1.66 ± 0.06 to 1.64 ± 0.07 seconds, $p = 0.12$), 15-m (7.61 ± 0.42 to 7.53 ± 0.42 seconds, $p = 0.16$), and 25-m split times (13.33 ± 0.78 to 13.40 ± 0.71 seconds, $p = 0.28$) remained unaffected. Delta changes between the pre-test and post-test increased from the 5-m to 25-m split time (0.03 ± 0.02 and 0.29 ± 0.18 seconds; $p = 0.02$) with maximal strength but not vertical jump training (0.02 ± 0.04 and 0.09 ± 0.33 seconds; $p = 0.31$).

In addition, a main time effect was evident for the freestyle stroke rate in the U17 swimmers ($p = 0.04$). The pairwise comparison demonstrated an increased freestyle stroke rate from pre-test to the post-test for the vertical jump training group (49.5 ± 4.89 to 50.3 ± 5.38 b·min^{-1}, $p = 0.04$) but not the maximal strength training group (50.4 ± 4.67 to 51.0 ± 5.09 b·min^{-1}, $p = 0.17$). However, the time × group interaction was nonsignificant. The ANOVA showed a trend-like time effect for the butterfly kicking rate ($p = 0.07$) and distance per freestyle stroke ($p = 0.10$). The pairwise comparison revealed an increased butterfly kicking rate and reduced distance per freestyle stroke within the vertical jump training group (138 ± 13 to 148 ± 14 b·min^{-1}, $p = 0.01$ and 2.04 ± 0.14 to 2.00 ± 0.18 m, $p = 0.03$) but not the maximal strength training group (145 ± 15 to 149 ± 12 b·min^{-1}, $p = 0.28$ and 2.01 ± 0.13 to 1.99 ± 0.14 m, $p = 0.48$, respectively). The remaining kinematic and kinetic parameters were unaffected.

Discussion

The main findings of the study were that there was no global effect and that sprint start performance remained unchanged after 6 weeks of training in both groups. With focus on the subgroup, however, the pooled data of the junior U17 swimmers revealed an improved sprint start performance over the 5-m, 15-m, and 25-m split times after 6 weeks of maximal strength but not vertical jump training with 2 weekly sessions that were integrated into a 16-hour training week.

Although there was no global effect, the focus on the subgroup of the junior U17 swimmers showed an improved sprint start

Table 2

Freestyle swimming sprint start performance before (pre-) and after (post-) 6 weeks of training performing either maximal strength (n = 10) or vertical jump training (n = 11).*†‡

	Training program		ANOVA				
	Maximal strength training	Vertical jump training		F value	p	Partial eta^2	Test power
Sprint start							
5-m split time (s)							
Pre-	1.60 ± 0.14 (1.51–1.69)	1.62 ± 0.07 (1.58–1.66)	(a)	$F_{(1,19)} = 0$	0.74	0.01	0.06
Post-	1.60 ± 0.12 (1.53–1.67)	1.61 ± 0.07 (1.57–1.65)	(b)	$F_{(1,19)} = 0$	0.65	0.01	0.07
			(c)	$F_{(1,19)} = 0$	0.65	0.01	0.07
10-m split time (s)							
Pre-	4.26 ± 0.36 (4.04–4.49)	4.36 ± 0.29 (4.19–4.54)	(a)	$F_{(1,19)} = 1$	0.41	0.04	0.13
Post-	4.27 ± 0.29 (4.09–4.45)	4.39 ± 0.26 (4.23–4.54)	(b)	$F_{(1,19)} = 0$	0.64	0.01	0.07
			(c)	$F_{(1,19)} = 0$	0.83	0.00	0.06
15-m split time (s)]							
Pre-	7.28 ± 0.62 (6.89–7.66)	7.36 ± 0.45 (7.09–7.62)	(a)	$F_{(1,19)} = 0$	0.59	0.02	0.08
Post-	7.21 ± 0.50 (6.90–7.52)	7.36 ± 0.37 (7.14–7.59)	(b)	$F_{(1,19)} = 0$	0.53	0.02	0.09
			(c)	$F_{(1,19)} = 1$	0.40	0.04	0.13
25-m split time (s)							
Pre-	13.29 ± 1.10 (12.61–13.97)	13.38 ± 0.80 (12.91–13.86)	(a)	$F_{(1,19)} = 0$	0.73	0.01	0.06
Post-	13.23 ± 0.94 (12.65–13.81)	13.41 ± 0.74 (12.97–13.85)	(b)	$F_{(1,19)} = 0$	0.74	0.01	0.06
			(c)	$F_{(1,19)} = 1$	0.47	0.03	0.11

*ANOVA = analysis of variance.

†The data are presented as mean ± *SD* (95% confidence interval).

‡(a) Main effect group: maximal strength vs. vertical jump training; (b) main effect time: pre- vs. post-; (c) interaction effect: group × time.

performance with maximal strength training. Owing to 4 additional years of training history, older swimmers probably had a more advanced movement pattern for freestyle sprint starts compared with the junior U17 swimmers. The literature from neuroscience and motor learning shows that the initial stage of a complex movement pattern is learned quickly, especially with the higher neuroplasticity at a young age (11). However, it may take years to execute a complex movement pattern, i.e., the freestyle sprint start, at a high standard (14,16). Changing a well-established movement pattern after years of training on the other hand is a challenging task (10). The less-automated movement pattern of the sprint start might have allowed the junior U17 swimmers to implement strength gains quicker and therefore improve their sprint start performance after 6 weeks of maximal strength training.

In the underlying study, maximal strength and vertical jump training was implemented in the precompetition phase to assist the peaking toward the seasonal main event. However, owing to preparatory competitions and tapering, the intervention period had to be reduced to 6 weeks. In future studies and when designing conditioning programs for swimmers, coaches should aim for training periods of >8 weeks to maximize effects (35). Some research even recommended a 6-month period to optimally transfer strength gains into specific movement patterns, thus improving performance of endurance athletes (2). Simultaneously to the strength training, in-water training should focus on technical adaptations. Specific skill-oriented training, including video feedback (9) and task variations, may help transfer strength gains to the specific and complex movement pattern of the freestyle sprint start (34).

The question arises whether task-specific strength training, i.e., tethered freestyle sprint starts, may enhance training adaptations. In track running, for example, specificity of the movement pattern benefited from resisted starts, while explosive power production also improved (28). In swimming, tethered sprint starts may improve explosive power production on the block but interfere with kinematics of the flight phase, water entry angle, and initial underwater trajectory. Therefore, performance benefits of such training methods warrant further investigations.

In this study, deadlifts and SJs were implemented into the training programs to account for the specific neuromuscular demands of the freestyle sprint start. Similar to the sprint start, deadlifts and SJs involve a noncountermovement-like neuromuscular recruitment pattern. To further account for the specificity of the freestyle sprint start's movement pattern, the asymmetric step-like foot position of the kick-start could be adopted in strength training. Although earlier research showed the benefits of unilateral strength training for unilateral exercise tasks (8,20), future studies could investigate the influence of 1-legged squats and split SJs performed with the specific foot positions of the kick-start on the freestyle sprint start performance.

Effects of strength training on sprint start performance were smaller than expected in the underlying study. This may be due to the large volume of concurrent aerobic training interfering with strength adaptations. Previous studies demonstrated that considerable development of maximal strength abilities is possible, even when trained concurrently to large volumes of aerobic exercise (5,21,32). However, explosive strength abilities, i.e., rate of force development, seem to be negatively affected (21), which may explain the missing effects of on-block force production during the freestyle sprint start. The benefits of separating the strength and aerobic training sessions by a day or at least a couple of hours to maximize quality of training, improve energy availability, and aid neuromuscular adaptations are clear (15,31). Yet, the busy training schedule of our swimmers limited the application of this approach. Early morning sessions were used for in-water training, while most swimmers attended school lessons throughout the day. After a common approach in competitive swimming, strength sessions were performed twice a week in the afternoon. Therefore, the subsequent swimming sessions may have interfered with the optimal adaptation of explosive strength. Delta changes from pre-test to post-test increased with distance from the 5-m to 25-m split time. Therefore, improvements in

Table 3

Kinematic and kinetic parameters before (pre-) and after (post-) 6 weeks of training performing either maximal strength ($n = 10$) or vertical jump training ($n = 11$).*†‡

	Training program		ANOVA				
	Maximal strength training	Vertical jump training		*F* value	*p*	Partial eta^2	Test power
Kinematic data							
Time on the block (s)							
Pre-	0.72 ± 0.06 (0.68–0.76)	0.72 ± 0.04 (0.70–0.75)	(a)	$F_{(1,19)} = 0$	0.61	0.01	0.08
Post-	0.73 ± 0.06 (0.70–0.77)	0.71 ± 0.04 (0.69–0.73)	(b)	$F_{(1,19)} = 0$	0.89	0.00	0.05
			(c)	$F_{(1,19)} = 3$	0.11	0.13	0.36
Take-off horizontal velocity ($m \cdot s^{-1}$)							
Pre-	4.32 ± 0.31 (4.13–4.51)	4.27 ± 0.18 (4.16–4.38)	(a)	$F_{(1,19)} = 0$	0.64	0.01	0.07
Post-	4.32 ± 0.28 (4.15–4.49)	4.27 ± 0.18 (4.16–4.37)	(b)	$F_{(1,19)} = 0$	0.94	0.00	0.05
			(c)	$F_{(1,19)} = 0$	0.98	0.00	0.05
Take-off angle (°)							
Pre-	16.2 ± 4.5 (13.4–19.0)	13.8 ± 6.2 (10.1–17.5)	(a)	$F_{(1,19)} = 1$	0.48	0.03	0.11
Post-	15.8 ± 4.8 (12.8–18.8)	15.0 ± 5.0 (12.1–17.9)	(b)	$F_{(1,19)} = 1$	0.46	0.03	0.11
			(c)	$F_{(1,19)} = 2$	0.15	0.11	0.30
Size of entry hole (m)							
Pre-	0.60 ± 0.25 (0.45–0.76)	0.76 ± 0.24 (0.61–0.90)	(a)	$F_{(1,19)} = 3$	0.09	0.15	0.40
Post-	0.62 ± 0.15 (0.52–0.71)	0.78 ± 0.24 (0.64–0.92)	(b)	$F_{(1,19)} = 0$	0.72	0.01	0.06
			(c)	$F_{(1,19)} = 0$	0.96	0.00	0.05
Maximal swimming depth (m)							
Pre-	0.93 ± 0.22 (0.79–1.07)	0.93 ± 0.23 (0.80–1.06)	(a)	$F_{(1,19)} = 0$	0.99	0.00	0.05
Post-	0.94 ± 0.14 (0.85–1.03)	0.94 ± 0.19 (0.83–1.05)	(b)	$F_{(1,19)} = 0$	0.69	0.01	0.07
			(c)	$F_{(1,19)} = 0$	0.99	0.00	0.05
Butterfly kicking rate ($b \cdot min^{-1}$)							
Pre-	149 ± 13 (141–157)	147 ± 21 (135–159)	(a)	$F_{(1,19)} = 0$	0.86	0.00	0.05
Post-	150 ± 11 (143–157)	150 ± 18 (139–161)	(b)	$F_{(1,19)} = 1$	0.49	0.03	0.10
			(c)	$F_{(1,19)} = 0$	0.67	0.01	0.07
Distance per butterfly kick (m)							
Pre-	0.87 ± 0.13 (0.79–0.95)	0.85 ± 0.10 (0.79–0.91)	(a)	$F_{(1,19)} = 0$	0.52	0.02	0.10
Post-	0.86 ± 0.11 (0.79–0.93)	0.82 ± 0.11 (0.75–0.88)	(b)	$F_{(1,19)} = 2$	0.21	0.08	0.23
			(c)	$F_{(1,19)} = 1$	0.38	0.04	0.14
Breakout distance (m)							
Pre-	11.0 ± 1.2 (10.3–11.8)	10.5 ± 1.9 (9.3–11.6)	(a)	$F_{(1,19)} = 0$	0.56	0.02	0.09
Post-	10.8 ± 1.0 (10.2–11.4)	10.5 ± 2.1 (9.3–11.8)	(b)	$F_{(1,19)} = 0$	0.66	0.01	0.07
			(c)	$F_{(1,19)} = 1$	0.48	0.03	0.11
Freestyle stroke rate ($b \cdot min^{-1}$)							
Pre-	49 ± 4 (47–52)	49 ± 5 (46–52)	(a)	$F_{(1,19)} = 0$	0.98	0.00	0.05
Post-	50 ± 5 (47–53)	50 ± 6 (47–54)	(b)	$F_{(1,19)} = 3$	0.09	0.15	0.40
			(c)	$F_{(1,19)} = 0$	0.56	0.02	0.09
Distance per freestyle stroke (m)							
Pre-	2.04 ± 0.12 (1.96–2.11)	2.04 ± 0.14 (1.96–2.13)	(a)	$F_{(1,19)} = 0$	0.92	0.00	0.05
Post-	2.02 ± 0.14 (1.93–2.10)	2.00 ± 0.18 (1.89–2.10)	(b)	$F_{(1,19)} = 3$	0.12	0.12	0.34
			(c)	$F_{(1,19)} = 0$	0.55	0.02	0.09
Kinetic data							
Peak power ($W \cdot kg^{-1}$ BW)							
Pre-	48.0 ± 7.8 (43.1–52.9)	50.9 ± 4.2 (48.4–53.4)	(a)	$F_{(1,19)} = 1$	0.24	0.07	0.21
Post-	47.1 ± 5.3 (43.8–50.4)	50.1 ± 6.0 (46.5–53.6)	(b)	$F_{(1,19)} = 1$	0.38	0.04	0.14
			(c)	$F_{(1,19)} = 0$	0.97	0.00	0.05
Peak resultant horizontal force (×BW)							
Pre-	1.15 ± 0.19 (1.03–1.27)	1.30 ± 0.18 (1.19–1.41)	(a)	$F_{(1,19)} = 4$	0.06	0.17	0.47
Post-	1.18 ± 0.18 (1.06–1.29)	1.34 ± 0.19§ (1.23–1.46)	(b)	$F_{(1,19)} = 6$	0.03	0.23	0.62
			(c)	$F_{(1,19)} = 0$	0.57	0.02	0.09
Peak resultant vertical force (×BW)							
Pre-	1.18 ± 0.13 (1.10–1.26)	1.27 ± 0.14 (1.19–1.35)	(a)	$F_{(1,19)} = 2$	0.17	0.10	0.27
Post-	1.17 ± 0.09 (1.11–1.22)	1.25 ± 0.19 (1.14–1.36)	(b)	$F_{(1,19)} = 0$	0.51	0.02	0.10
			(c)	$F_{(1,19)} = 0$	0.77	0.00	0.06
Peak horizontal rear foot force (×BW)							
Pre-	0.91 ± 0.16 (0.81–1.01)	0.91 ± 0.11 (0.84–0.98)	(a)	$F_{(1,19)} = 1$	0.81	0.00	0.06
Post-	0.92 ± 0.14 (0.84–1.01)	0.95 ± 0.14 (0.87–1.03)	(b)	$F_{(1,19)} = 4$	0.06	0.18	0.49
			(c)	$F_{(1,19)} = 1$	0.36	0.05	0.15
Peak resultant grab force (×BW)							
Pre-	0.93 ± 0.19 (0.82–1.05)	0.89 ± 0.22 (0.76–1.03)	(a)	$F_{(1,19)} = 0$	0.57	0.02	0.09
Post-	0.92 ± 0.20 (0.79–1.05)	0.86 ± 0.18 (0.75–0.97)	(b)	$F_{(1,19)} = 2$	0.23	0.07	0.22
			(c)	$F_{(1,19)} = 0$	0.62	0.01	0.08

*ANOVA = analysis of variance.

†The data are presented as mean ± *SD* (95% confidence interval).

‡(a) Main effect group: maximal strength vs. vertical jump training; (b) main effect: time pre-vs. post-; (c) interaction effect: group × time.

§Significant difference compared with pre-.

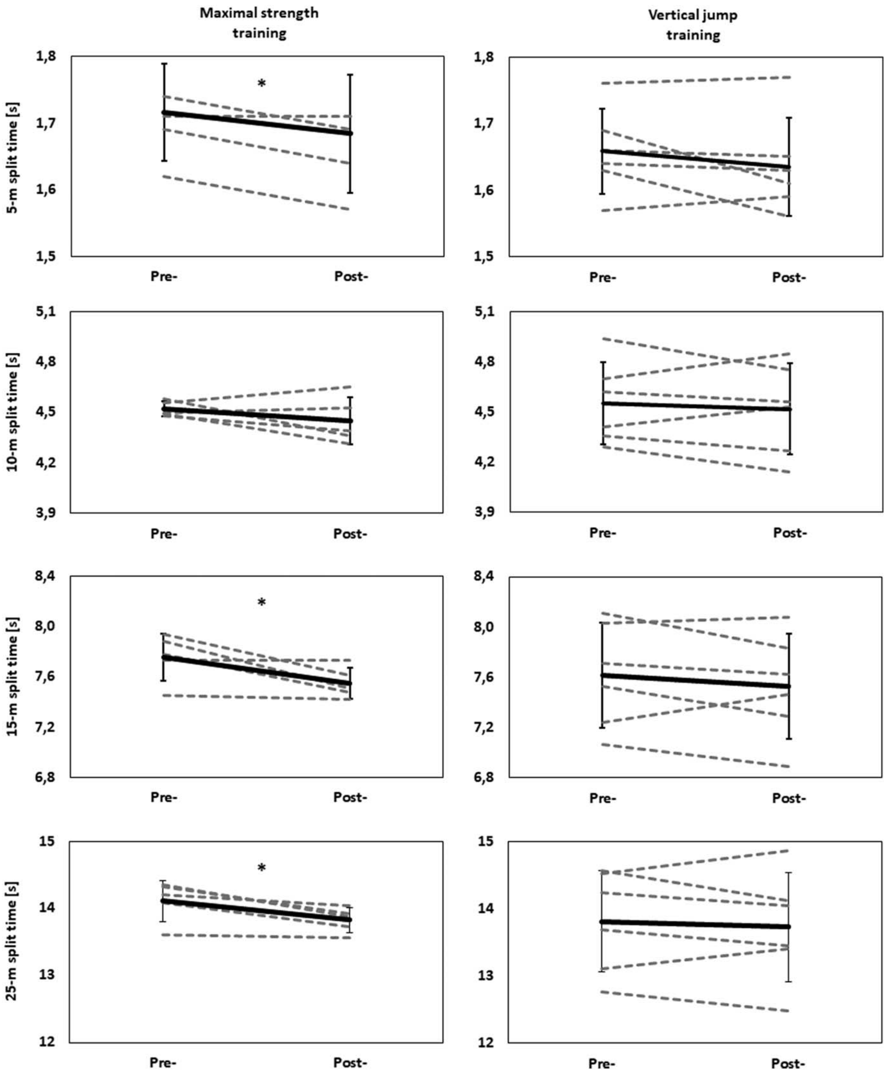

Figure 2. Mean freestyle swimming sprint start performance (bold black line) ± *SD* and individual response (grey dotted) of the junior U17 swimmers in response to 6 weeks of maximal strength (heavy back squats and deadlifts) or vertical jump training (unloaded box jumps executed as countermovement and squat jumps). *Significant difference between pre- and post-.

freestyle sprint start performance might primarily been based on an altered underwater and full-stroke swimming phase, as result of improved movement economy rather than explosive force production during the on-block phase. From a practical perspective, block periodization could help to reduce the inference effect. A recent original investigation showed better adaptations in both strength and endurance capacities when alternating strength and endurance training on a weekly basis compared with the traditional mixed approach (33).

Previous research showed the importance of core stability and lower-body power for the undulating movement of the butterfly kick during the underwater phase (43), as well as for the efficiency of the flutter kick during full-stroke swimming (24). This is of importance, as an effective flutter kick leads to a higher and more stable position in the water. Consequently, efficiency of the arm stroke is improved, which is the major propulsive force during full-stroke swimming (24). Heavy-loaded barbell exercises were shown to improve core stability in addition to leg strength (25). Specifically, back squats (22,38) and deadlifts (22) lead to an even larger activation of the core muscles than conventional core exercises, for example side bridge and loaded front plank. In addition, deadlifts have been shown to induce high muscle activation of the upper back, i.e., lower and medial trapezius (17), with important implications for swimmers shoulder stability and power production during full-stroke swimming (24). In the underlying study, heavy back squats and deadlifts may have contributed to improved strength of the core and upper back in addition to leg muscles, thus possibly contributing to improved butterfly kicking and full-stroke swimming, especially with the junior U17 swimmers. However, the exact mechanisms of improved sprint start performance in the absence of altered on-block force production require further investigations.

In this study, missing assessment of maximal and explosive strength before and after the training period limits the understanding of the underlying mechanisms. Future studies need to investigate movement economy and technical changes that occur with maximal strength training during the underwater and full-stroke swimming phase. Foster's session RPE was used to compare and monitor loads of the maximal strength and vertical jump training. Future studies might further develop methodologies for load comparison between strength training protocols based on their neurological, hormonal, and metabolic demand.

Practical Applications

There was no global effect for an improved sprint start performance in both groups after 6 weeks of training. From a practical perspective, however, the training history and performance level of the athletes seem to affect the outcome of conditioning programs. Therefore, the pooled group of the junior U17 swimmers revealed improved 5-m, 15-m, and 25-m split times with 2 sessions of heavy back squats and deadlifts per week, but not with unloaded box jumps, i.e., countermovement and SJs, implemented into a 16-hour training week. Although the strength training commonly is performed for the entire season, strength and conditioning coaches might introduce the maximal strength training earlier and extend it beyond the peaking phase that prepares for the seasonal main event. In addition, maximal strength training should be introduced to the swimmers at a young age. Specific skill-oriented training during the in-water sessions could help transfer strength gains to the complex movement pattern of the freestyle sprint start. Benefits of task-specific strength training with resisted on-block sprint starts are a matter of future investigations.

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