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Research article

The Effects of Plyometric Jump Training on Jumping and Swimming Performances in Prepubertal Male Swimmers

Senda Sammoud [1,2], Yassine Negra [1,2], Helmi Chaabene [3,4], Raja Bouguezzi [1], Jason Moran [5] and Urs Granacher [3]✉

[1] Research Unit (UR17JS01) "Sport Performance & Health" Higher Institute of Sport and Physical Education of Ksar Said, University de "La Manouba", Manouba, Tunisia; [2] Higher Institute of Sports and Physical Education, Manouba University, Tunis, Tunisia; [3] Division of Training and Movement Sciences, Research Focus Cognition Sciences, University of Potsdam, Germany; [4] High Institute of Sports and Physical Education, Kef, University of Jendouba, Tunisia; [5] School of Sport, Rehabilitation and Exercise Sciences, University of Essex, Colchester, UK

Abstract

Swimming performance can be improved not only by in-water sport-specific training but also by means of dry land-training (e.g., plyometric jump training [PJT]). This study examined the effects of an 8-week PJT on proxies of muscle power and swimming performance in prepubertal male swimmers. Participants were randomly allocated to a PJT group (PJT; n = 14; age: 10.3 ± 0.4 years, maturity-offset = -3±0.3) or a control group (CG; n = 12; age: 10.5 ± 0.4 years, maturity-offset = -2.8 ± 0.3). Swimmers in PJT and CG performed 6 training sessions per week. Each training session lasted between 80 and 90 minutes. Over the 8 weeks in-season training period, PJT performed two PJT sessions per week, each lasting between 25 to 30 minutes (~1 hour per week) in replacement of sport-specific swimming drills. During that time, CG followed their regular sport-specific swimming training (e.g., coordination, breathing, improving swimming strokes). Overall training volume was similar between groups. Pre- and post-training, tests were conducted to assess proxies of muscle power (countermovement-jump [CMJ]), standing-long-jump [SLJ]) and sport-specific swimming performances (15-, 25-, and 50-m front-crawl, 25-m kick without push [25-m kick WP], and 25-m front-crawl WP). No training or test-related injuries were detected over the course of the study. Between-group analyses derived from magnitude-based inferences showed trivial-to-large effects in favour of PJT for all tests (ES = 0.28 to 1.43). Within-group analyses for the PJT showed small performance improvements for CMJ (effect-size [ES] = 0.53), 25-m kick WP (ES = 0.25), and 50-m front crawl (ES = 0.56) tests. Moderate performance improvements were observed for the SLJ, 25-m front-crawl WP, 15-m and 25-m front-crawl tests (ES = 0.95, 0.60, 0.99, and 0.85, respectively). For CG, the within-group results showed trivial performance declines for the CMJ (ES=-0.13) and the 50-m front-crawl test (ES = -0.04). In addition, trivial-to-small performance improvements were observed for the SLJ (ES = 0.09), 25-m kick WP (ES = 0.02), 25-m front-crawl WP (ES = 0.19), 25-m front-crawl (ES = 0.2), (SLJ [ES = 0.09, and 15-m front crawl (ES = 0.36). Short-term in-season PJT, integrated into the regular swimming training, was more effective than regular swimming training alone in improving jump and sport-specific swimming performances in prepubertal male swimmers.

Key words: Stretch-shortening cycle, young athletes, rate of force development, sport-specific performance.

Introduction

From a physical, physiological, and technical-tactical point of view, swimming is a highly demanding Olympic sport and elite performances are achieved at an early age (Nugent et al., 2018). Therefore, commitment to training has to start during the early stages of long-term athlete development (LTAD) to increase the likelihood of sporting success as an elite athlete (Nugent et al., 2018). From a performance and health-related perspective, muscle strength should specifically be promoted during all LTAD stages (Lloyd et al., 2012; 2015; Pichardo et al., 2018). In fact, muscle strength should be promoted in young athletes to support motor skill acquisition, to enhance physical fitness and sports performance, to improve markers of health and well-being, and to reduce the risk of sustaining sports-related injuries (Faigenbaum et al., 2013; 2019; Granacher et al., 2016).

More specifically, it has been reported that well-developed levels of muscle strength and power play an important role in achieving high swimming performances (Crowley et al., 2018; Girold et al., 2007; Potdevin et al., 2011). In fact, there is evidence that the ability to exert force in the water is a decisive factor, particularly in sprint swimming (e.g., 50-m, 100-m, and 200-m) (Morouço et al., 2011). Moreover, the swimming start contributes up to 30% of the total race time (Cossor et al., 1999). The shorter the distance the more important becomes an explosive start. West et al. (2011) showed that a successful swimming start depends on a number of factors including reaction time, vertical and horizontal forces generated by lower limb muscles during the push-off phase from the block, and a low resistance during the underwater gliding phase. In addition, during front-crawl swimming, lower limb muscles contribute up to 12% of the propulsion (Ribeiro et al. 2015).

Swimming performance cannot only be improved through sport-specific in-water training but also by means of dry land-training (i.e., strength and/or power training) (Crowley et al., 2018; Potdevin et al., 2011). Previous studies have shown that particularly plyometric jump training (PJT) is a widely used, safe, and effective training regime to improve muscle strength and power as well as sport-specific performance in prepubertal athletes (Bedoya et al., 2015; Bouguezzi et al., 2018; Chaabene and Negra, 2017; Nugent et al., 2018). In this context, Granacher et al. (2016) introduced a conceptual model for the implementation of resistance training during the different LTAD stages. The

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same authors suggested a variety of resistance training approaches that can be used across the different maturation stages, among them PJT (Granacher et al., 2016). However, it is noteworthy that PJT should not be used as a stand-alone component of an exercise program and the advisable approach is to incorporate supervised and progressive power training into a well-rounded program that also involves other types of strength and conditioning (Behm et al., 2008; 2017).

Only a few studies examined the effects of PJT executed outside the pool on swimming performance (Bishop et al., 2009; Potdevin et al., 2011; Rejman et al., 2017). For instance, Bishop et al. (2009) studied the effects of an 8-week combined PJT and swimming training on swim start performance in adolescent swimmers and observed significant improvements in velocity from take-off to water contact (Δ15.6%) and 5.5-m performance time (15.4%). Rebutini et al. (2016) conducted a 9-week PJT program with adolescent male and female swimmers and showed improvements in peak torque and rate of torque development of the hip (Δ47% and 108%, respectively) and knee joints (Δ24% and 41%, respectively) during swim start performance.

Most of the available studies focused on the effects of PJT on swim start performance and the underpinning kinetic and kinematic parameters (Bishop et al., 2009; Rebutini et al., 2016). Notably, Potdevin et al. (2011) examined the effects of a 6-week PJT on particularly sport-specific swim performances in adolescent male swimmers (age =14.3 ± 0.2 years). These authors revealed significant increases in 50-m (ES = 0.1, Δ3.1%) and 400-m (ES = 0.15, Δ4.2%) average swimming speed as well as in countermovement jump and squat jump performances (ES = 1.66 and 2.37, respectively). To the authors' knowledge, there is no study available that investigated the effects of PJT on proxies of muscle power and sport-specific swimming performance in prepubertal male swimmers. Therefore, it is timely and imperative to elucidate whether the findings of Potdevin et al. (2011) in adolescent swimmers can be translated to prepubertal swimmers as well. Accordingly, this study sought to examine the effects of an 8-week PJT program in combination with swimming compared with swimming only on proxies of muscle power (i.e., countermovement jump [CMJ], standing long jump [SLJ]) and sport-specific swimming performances in prepubertal male swimmers. With reference to the relevant literature (Potdevin et al., 2011; Rebutini et al., 2016), we hypothesized that the combination of PJT and swimming results in larger jump and sport-specific performance improvements than regular swimming training alone in prepubertal male swimmers.

Methods

Experimental approach to the problem

A randomized controlled trial was conducted to examine the effects of an 8-week PJT program on proxies of muscle power and sport-specific swimming performances in prepubertal male swimmers. One week before baseline testing, two familiarization sessions were performed to get participants accustomed to the physical fitness tests and the plyometric drills. The respective test sessions were 5 days apart. Before and after the intervention, tests were conducted to assess jump (i.e., CMJ, SLJ) and swimming performances. Sport-specific testing included a timed 15, 25, and 50-m front crawl tests with a diving start, a timed 25-m front crawl test without push-off from the wall (25-m WP), and a 25-m kick timed test without push-off from the wall (25-m KWP). All tests were conducted in an indoor swimming pool with a water temperature of 26°C which is in agreement with recommendations from the Federation Internationale de Natation (2014). Testing was conducted 48 hours after the last training session and at the same time of the test day (7:30-9:30 p.m.).

Participants

A total of twenty-six prepubertal male swimmers participated in this study. They were randomly allocated to a PJT group (PJT; n = 14; age = 10.3 ± 0.4 years; maturity offset = -3.1 ± 0.3) or an active control group CG (n = 12; age = 10.5 ± 0.4 years; maturity offset = -2.8 ± 0.3). The PJT performed six training sessions per week, including two PJT sessions, which were integrated into the regular sport-specific training schedule in replacement of some swimming specific drills. The remaining training time comprised technical drills. CG followed their regular sport-specific swimming training (i.e., six sessions per week) throughout the intervention period. Training volume was similar between groups. Prior to the start of the study, all young athletes performed twice per week strength endurance exercises for muscles of the upper and lower limbs and the trunk using the own body-mass. The strength training program included push-ups, abdominal curls, back extensions, and squats. Participating athletes completed up to 5 sets of 15 repetitions each with a 30 seconds rest in-between sets. Training was conducted over 3 weeks to get the participants prepared for the subsequent plyometric training program.

All participants were competing on a national level within their respective age category. They had a background of 2.0 ± 1.6 years of systematic swimming training involving five to six training sessions per week throughout the season. Further, all participants were healthy and free of musculotendinous injuries over the last 6 months prior to the start of the study. Participants who missed more than 20% of the total PJT sessions and/or more than two consecutive PJT sessions were excluded from the study. The maturation status was determined at the beginning and after 8 weeks of training according to the maturity offset method (Malina et al., 2014). Maturity offset (expressed in years) was defined as the time before or after peak-height-velocity. All participants and their legal representatives were properly informed about all testing and training procedures, as well as potential benefits and harms related to the study. Verbal and written informed consent (legal representatives) and assent (children) were obtained before the start of the experiment. All procedures were approved by the local Institutional Review Committee of the Higher Institute of Sport and Physical Education, Ksar Said, Tunisia. All procedures were in accordance with the latest version of the Declaration of Helsinki.

Anthropometric measures

Anthropometrical measurements (i.e., body-mass, height) were taken by a trained anthropometrist assisted by a recorder. Standardized procedures were applied in accordance with the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart et al., 2011) (Table 1).

Proxies of muscle power

Countermovement jump: For CMJ testing, participants started from an upright erect standing position, performed a fast downward movement by flexing the knees and hips immediately followed by a rapid leg extension resulting in a maximal vertical jump. Throughout the execution of the test, participants maintained their hands on the hips and elbows turned outward. CMJ techniques were visually controlled by the first author of this study. Jump height was recorded using an Optojump photoelectric system (Microgate, SRL, Bolzano, Italy). The intraclass correlation coefficient (ICC) for test-retest reliability was 0.98 and the typical error of measurement (TEM) was 2.9%.

Standing long jump: The starting position of the SLJ required subjects to stand with their feet shoulder-width apart behind a starting line and their arms loosely hanging down at the sides of their body. On the command ready, set, go, participants executed a countermovement with their legs and arms and jumped at maximal effort in horizontal direction. Participants had to land with both feet simultaneously and could not fall forward or backward. The horizontal distance between the starting line and the heel of the rear foot was recorded via tape measure to the nearest 1-cm. The ICC for test-retest reliability was 0.96 and the TEM was 0.5%.

Sport-specific swimming tests

Swimming time trials expressed in seconds were adopted as our measures of sport-specific performance. All tests were conducted in a 50-m indoor-swimming pool. Swimmers performed two front crawl swimming trials with a diving start (15, 25, and 50-m) and two trials with a water start without a push-off from the wall (25-m WP and 25-m KWP). All starts were voluntarily initiated by the swimmers. Two independent observers recorded performance times using stop-watches. The average of the two recorded values was used for further statistical analyses. The start signal for the observer was the moment as the swimmers' feet left the block. For the water start without push-off, swimmers' first lower limb movement was used as an indicator to start timing. The distance was standardized using markers at the bottom of the pool. The final signal for the observer was the moment when the swimmers' hand touched the wall. The ICC for test-retest reliability ranged between 0.89 and 0.91 and the TEM ranged between 1.2 and 2.5% for all swimming tests.

Plyometric jump training

The PJT intervention was conducted during the competitive period of the year (March-April 2018). The program lasted 8 weeks with two sessions per week (Table 1). Plyometric jump training sessions were integrated into the regular training routine of the swimmers in replacement of some swimming specific drills. The remaining training time comprised technical drills (coordination, breathing, improving swimming strokes). The second PJT session was completed 72 hours after the first one to provide a sufficiently long enough recovery period between sessions. Each swimming training session lasted between 80 and 90 minutes. PJT drills lasted between 25 and 30 minutes. During that time, CG conducted their regular sport-specific training. Thus, both experimental groups experienced similar training volumes. Overall, 6 training sessions were conducted per week, each lasting between 80 to 90 minutes. No competitions were scheduled over the entire study period. Our PJT protocol was in accordance with previously published PJT recommendations for young athletes (Bedoya et al., 2015). At the beginning of the intervention, a focus was placed on proper exercise technique (e.g., landing). All jump exercises were performed on a stable surface (i.e., grass) and at maximal effort (CMJs) with minimal ground contact time. Both PJT sessions comprised 8-12 sets with 6–10 repetitions each. The total ground contacts per week gradually increased from 50 during the first week to 120 during the last week of training (Bouguezzi et al., 2018; Negra et al., 2017). A 90-second rest was provided between each set of exercise to allow sufficient recovery time.

Table 1. Characteristics of the plyometric jump training programs.

Week	Plyometric exercises	Volume (sets×reps)	Ground contacts
1	Bilateral ankle hops (hurdle height: 20 cm)	4 × 6-7	50
	CMJs	4 ×6-7	
2	Bilateral ankle hops (hurdle height: 20 cm)	4 × 7-8	60
	CMJs	4 × 7-8	
3	Bilateral ankle hops (hurdle height: 20 cm)	4 × 8-9	70
	CMJs	4 × 9	
4	Bilateral ankle hops (hurdle height: 20 cm)	4 × 10	80
	CMJs	4 × 10	
5	Bilateral ankle hops (hurdle height: 20 cm)	4 × 10	90
	CMJs	6 × 8-9	
6	Bilateral ankle hops (hurdle height: 20 cm)	6 × 8-9	100
	CMJs	6 × 8-9	
7	Bilateral ankle hops (hurdle height: 20 cm)	6 × 8	110
	CMJs	6 × 10	
8	Bilateral ankle hops (hurdle height: 20 cm)	6 × 10	120
	CMJs	6 × 10	

Reps: repetitions; Notes: CMJ: countermovement jump

Statistical analyses

Between-group baseline differences in anthropometric characteristics, maturity-offset, and physical fitness were verified using t-tests for independent samples. Magnitude-based inferences were applied to calculate and interpret effect sizes. In this regards, effect sizes <0.2 were considered trivial, between 0.2–0.6 small, between 0.6–1.2 moderate, between 1.2–2.0 large, between 2.0–4.0 = very large and finally >4.0 = extremely large (Hopkins et al., 2009). The estimates were considered unclear when the chance of a beneficial effect was high enough to justify the use of the intervention, yet the risk of being harmful was unacceptable. An odds ratio of benefit to harmful of <66 indicated such unclear effects (Hopkins, 2017). This odds ratio corresponds to an effect that is borderline possibly beneficial (25% chance of benefit) and borderline most unlikely detrimental (0.5% risk of harm). This was calculated using a publicly available spreadsheet (Hopkins, 2017). Otherwise, the effect was clear and was interpreted as the magnitude of the observed value, with the qualitative probability that the true value was at least of this magnitude. The scale used to interpret the probabilities was as follows: possible = 25–75%; likely = 75–95%; very likely = 95–99.5%; most likely >99.5% (Hopkins et al., 2009). Uncertainty in effect sizes was represented by 90% confidence limits. Effects were considered unclear if the confidence interval crossed thresholds for substantial positive and negative values. Otherwise, the effect was clear and reported as the magnitude of the observed value with a qualitative probability (Hopkins et al., 2009). Before the start of the training intervention, relative and absolute test-retest reliability was assessed for all tests prior to the start of the study using ICC, and TEM.

Results

Adherence rates to swimming training were 96% for both groups. Of note, no training- or test-related injuries occurred during the study. All participants in the PJT and the CG received treatments as allocated. Two participants from CG were excluded because of their high absence rate. The computed ICC values indicated excellent reliability with ICCs ranging from 0.89 to 0.96. Table 3 displays data of pre-post tests for proxies of muscle power and sport-specific swimming performances. There were no statistically significant between-group baseline differences for chronological age, body height, body-mass, maturity-offset or swimming expertise (Table 2). Additionally, no between-group differences were recorded at baseline regarding proxies of muscle power and sport-specific swimming performances (Table 3).

Table 2. Anthropometric characteristics of the included subjects. Data are presented as means ± standard deviations.

	PJT (n=14)		CG (n=12)	
	Pre-test	**Post-test**	**Pre-test**	**Post-test**
Age (years)	10.3±0.4	10.5±0.4	10.5±0.4	10.7±0.4
Body height (m)	1.43±.08	1.43±.08	1.46±.07	1.46±.07
Body mass (kg)	36.2±8.4	36.66±8.2	38.2±5.9	38.7±5.9
Maturity offset	-3.1±0.4	-3.09±0.4	-2.88±0.4	-2.8±0.4
Predicted APHV	13.4±0.5	13.61±0.5	13.40±0.3	13.5±0.4

PJT: Plyometric jump training; CG: Control group; APHV: Age at peak-height-velocity.

The between-group analyses revealed trivial to large effect sizes in favour of PJT$_G$ for all physical fitness tests (Table 4). Within-group analyses for the PJT$_G$ group showed small effect sizes for the CMJ, 25-m KWP, and 50-m front crawl test (Table 3). In addition, moderate performance improvements were observed for the SLJ, 25-m WP, 15-m and 25-m front crawl tests. Regarding the CG group, trivial effect sizes were observed for the CMJ, SLJ, 25-m KWP, and 25-m WP test. In the 50-m front crawl test, a small performance decline was noted. For the 15-m front crawl, small improvements were recorded.

Table 3. Within-group effect sizes, confidence limits, likelihood effects and odds ratio for performance data.

Variable	Baseline	Post-test	Effect size	Confidence limits	Likelihood effect is beneficial (%)	Likelihood effect is trivial (%)	Likelihood effect is harmful (%)	Effect description	Odd ratio of benefits to harm
Plyometric jump training group (n= 14)									
CMJ (cm)	19.7±3.8	21.7±3.7	0.53	-0.1 to 1.2	85.5%	13.0%	1.5%	Likely beneficial	389
SLJ (cm)	134.3±15.7	148.4±13.9	0.95	0.3 to 1.6	90.7%	6.7%	2.6%	Likely beneficial	380
25-m KWP (s)	29.0±2.7	28.4±2.5	0.25	-0.9 to 0.4	63.6%	36.1%	0.4%	Possibly beneficial	487
25-m WP (s)	20.3±1.0	19.7±1.0	0.60	-1.2 to 0.0	87.1%	11.2%	1.7%	Likely beneficial	383
15-m front crawl (s)	10.1±0.5	9.6±0.4	0.99	-1.6 to -0.3	90.9%	6.4%	2.6%	Likely beneficial	369
25-m front crawl (s)	18.2±0.9	17.52±0.7	0.85	-1.5 to -0.2	90.1%	7.6%	2.4%	Likely beneficial	372
50-m front crawl (s)	40.0±1.7	39.1±1.5	0.56	-1.2 to 0.1	86.2%	12.2%	1.6%	Likely beneficial	386
Control group (n=12)									
CMJ (cm)	19.9±3.7	19.4±3.0	0.13	-0.8 to 0.5	17.7%	82.2%	0.0%	Likely trivial	526
SLJ (cm)	140.2±27.3	142.7±25.5	0.09	-0.6 to 0.8	2.5%	97.5%	0.0%	Very likely trivial	426
25-m KWP (s)	25.3±2.3	25.2±1.8	0.02	-0.7 to 0.7	0.0%	100.0%	0.0%	Most unlikely trivial	8
25-m front crawl WP (s)	18.6±1.9	18.9±1.7	0.19	-0.5 to 0.9	46.3%	53.5%	0.2%	Possibly trivial	480
15-m front crawl (s)	9.53±0.8	9.3±0.8	-0.36	-1.0 to 0.3	77.9%	21.2%	0.9%	Likely beneficial	400
25-m front crawl (s)	17.17±1.2	16.9±1.4	0.20	-0.9 to 0.5	50.0%	49.8%	0.2%	Possibly beneficial	472
50-m front crawl (s)	37.5±2.8	37.6±4.0	0.04	-0.6 to 0.7	0.0%	100%	0.0%	Most likely trivial	51

CMJ: countermovement jump; SLJ: standing long jump; 25-m KWP: 25-m kick without push; 25-m WP: 25-m front crawl without push.

Table 4. **Between-group effect sizes, confidence limits, likelihood effects and odds ratios for performance data.**

Variable	Mean difference	Effect size	Confidence limits	Control is beneficial (%)	Similar (%)	Plyometric is beneficial (%)	Effect description	Odd ratio of benefits to harm
CMJ (cm)	-2.2	-0.66	-1.32 to 0.00	1.8%	10.5%	87.7%	Likely beneficial	399
SLJ (cm)	-5.7	-0.28	-0.93 to 0.37	0.4%	31.1%	68.5%	Possibly beneficial	605
25-m KWP (s)	-3.1	-1.43	-2.15 to -0.71	3.1%	4.6%	92.3%	Likely beneficial	369
25-m WP (s)	-0.8	-0.62	-1.28 to 0.04	1.6%	11.3%	87.1%	Likely beneficial	404
15-m front crawl (s)	-0.4	-0.60	-1.26 to 0.06	1.6%	11.7%	86.7%	Likely beneficial	407
25-m front crawl (s)	-0.6	-0.58	-1.24 to 0.08	1.5%	12.2%	86.3%	Likely beneficial	411
50-m front crawl (s)	-1.5	-0.50	-1.16 to 0.15	3.2%	4.4%	92.4%	Likely beneficial	368

CMJ: countermovement jump; SLJ: standing long jump; 25-m KWP: 25-m kick without push; 25-m WP: 25-m front crawl without push.

Discussion

This study is the first to examine the effects of an 8-week PJT in combination with swimming training compared with swimming training only on proxies of muscle power and swimming performances in prepubertal male swimmers. The main findings showed that equal volume PJT combined with regular swimming training is more effective than regular swimming training alone in improving jump and swim performances.

Muscle power

Findings of this study showed that PJT combined with swimming training induced small (ES = 0.53) and moderate (ES = 0.95) improvements for CMJ height and SLJ while regular swimming training alone produced trivial changes in CMJ height and SLJ (ES = -0.13, and 0.09, respectively) only. Improvements in vertical and horizontal jump performances were expected considering the large number of studies that reported performance enhancements in prepubertal children following this type of intervention (Bedoya et al., 2015; de Villarreal et al., 2009; Negra et al., 2018). For instance, Potdevin et al. (2011) studied the effects of PJT on proxies of muscle power (i.e., CMJ, SJ) in adolescent male and female swimmers aged 13 to 15 years. These authors revealed significant improvements in CMJ and squat jump height (ES = 1.73, and 0.73, respectively) after 6 weeks of training. In agreement with the findings of Potdevin et al. (2011), de Villarreal et al. (2015) showed a significant improvement in CMJ height (ES = 0.66) after 6 weeks of PJT in professional male water-polo players aged 23 years. The marked jump height improvements could mainly be caused by neural adaptations (Hakkinen and Komi, 1985; Markovic and Mikulic, 2010) in the form of enhanced motor unit activation of lower extremity muscles (i.e., intramuscular coordination) (Taube et al., 2007) and improved intermuscular coordination in conjunction with decreased co-activation of antagonistic muscles (Taube et al., 2007). However, further studies are needed that examine the underlying neuromuscular mechanisms responsible for training-induced performance improvements.

Sport-specific swimming performances

Results of the present study showed that PJT combined with regular swimming training induced small-to-moderate improvements in the 50-m front crawl test (ES = 0.56), and the 15-m (ES = 0.99) as well as 25-m front crawl tests (ES = 0.85). The regular swimming training generated trivial-to-small benefits in the 25-m (ES = 0.20) and 15-m front crawl (ES = 0.36) only. Of note, trivial performance declines were found for the 50-m front crawl test (ES = 0.04). There is controversy in the literature as to the potential contribution of PJT on swimming performance enhancements. For instance, Cossor et al. (1999) showed non-significant improvements in the 50-m front crawl test after a 20-week PJT program in young swimmers aged 12 years. Unlike the previous study, Potdevin et al. (2011) revealed significant increases in 50-m, and 400-m average swimming speed after a 6-week PJT program in adolescent male and female swimmers (ES=0.1, and 0.15 for 50-m, and 400-m, respectively). Similarly, in elite female water-polo players, Veliz et al. (2015) observed increases in 20-m sprint swim time (ES = 0.56) after 16 weeks of combined lower-body resistance and PJT training. These contradictory findings are most likely due to differences in the applied methods and study cohorts (prepubertal vs. adolescent, male swimmers vs. male and females, type of plyometric exercises, frequency, duration, and progression of training). According to the aforementioned studies (Potdevin et al., 2011; Veliz et al., 2015), improvements in swimming performances have been associated with increases in lower limbs power output, which may translate to a higher force application in the water. In addition, improvements observed after the PJT program may have been induced by an increased neural drive to the agonist muscles, improved intermuscular coordination, changes in musculotendinous stiffness, and changes in single-fiber mechanics (Markovic and Mikulic, 2010).

This study has some limitations that warrant discussion. First, we were only able to assess performance but not physiological data, which is why we cannot provide evidence on the underlying neuromuscular mechanisms responsible for the observed findings. Future studies are advised to include electrophysiological testing apparatus. Second, the training load was not directly monitored in both groups. Nevertheless, all participating athletes performed on the same competition level and followed the same swimming training program which consisted of five to six training sessions per week. As such, we are confident that both groups experienced comparable overall training loads. In addition, while waiting in-water for the tests to be started, a slight drift forward and / or backward while floating on the water may have occurred. Furthermore, the rather small sample size may constitute another limitation. However, having access to a larger sample of young swimmers is challenging due to the reduced number of young subjects competing on the national level. Finally, given that the currently applied PJT program induced small-to-moderate improvements in the experimental group, it is possible that a longer training intervention (i.e., >8 weeks) may induce even larger performance enhancements. However, this needs to be examined in future studies given that dose-response relations for PJT are not yet established in prepubertal athletes.

Conclusion

In conclusion, results from this study showed that the combination of a short-term in-season PJT program with regular swimming training is more effective than regular swimming training alone in improving jump and swimming performances in prepubertal male swimmers. Accordingly, practitioners should consider PJT during the competitive period of the season to improve swimming performance in prepubertal male swimmers. Of note, a special emphasis should be placed on landing biomechanics and technical execution during training to avoid acute and/or overload injuries. This is, particularly, needed with young athletes who are unfamiliar with PJT. To further improve the effectiveness and safety of PJT in young athletes, coaches are advised to incorporate strength training prior to PJT. This can be realized during the pre-season to lay an adequate foundation for more power-based training (Behm et al. 2017).

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There is no conflict of interest. The experiments comply with the current laws of the country in which they were performed.

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Key points

- Short-term (i.e., 8 weeks) plyometric jump training conducted during the in-season period is safe and it resulted in substantial improvements in jumping and swimming performances in prepubertal male swimmers.
- Practitioners should consider plyometric jump training when designing their training strategies to improve swimming performance of prepubertal male athletes.

AUTHOR BIOGRAPHY

Senda SAMMOUD
Employment
Swimming coach
Degree
PhD
Research interests
Exercise physiology, fitness testing and exercise prescription, youth athletes
E-mail: senda.sammoud@gmail.com

Yassine NEGRA
Employment
Conditioning trainer
Degree
PhD
Research interests
Exercise physiology, anthropometric and performance, fitness training, strength and conditioning
E-mail:yassinenegra@hotmail.fr

Helmi CHAABENE
Employment
Post-doctoral researcher in the Division of Training and Movement Sciences, University of Potsdam, Germany
Degree
PhD
Research interests
Exercise physiology, fitness testing and exercise prescription, martial arts, youth athletes
E-mail: chaabene@uni-potsdam.de

Raja BOUGUEZZI
Employment
Physical education teacher
Degree
MSc
Research interests
Exercise physiology, fitness testing, exercise prescription, youth athletes
E-mail: rajabouguezzi@hotmail.com

Jason MORAN
Employment
Lecturer, sports performance and coaching
Degree
PhD
Research interests
Strength and conditioning, youth physical development
E-mail: jmorana@essex.ac.uk

Urs GRANACHER
Employment
Full Professor in Training and Movement Sciences, University of Potsdam, Germany
Degree
PhD and habilitation
Research interests
Biomechanics, exercise science and physiology, muscular fitness
E-mail: urs.granacher@uni-potsdam.de

✉ **Prof. Urs Granacher**
Division of Training and Movement Sciences, Research Focus Cognition Sciences, University of Potsdam, Am Neuen Palais 10, 14469 Potsdam, Germany