

Senda Sammoud | Yassine Negra | Raja Bouguezzi | Younes Hachana |
Urs Granacher | Helmi Chaabene

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The effects of plyometric jump training on jump and sport-specific performances in prepubertal female swimmers

Senda Sammoud^a, Yassine Negra^a, Raja Bouguezzi^a, Younes Hachana^a, Urs Granacher^b, Helmi Chaabene^{b,*}

^a Research Unit (UR17JS01) "Sport Performance, Health & Society" Higher Institute of Sports and Physical Education of Ksar Said, University de "La Manouba", Manouba, Tunisia

^b Division of Training and Movement Sciences, Research Focus Cognition Sciences, University of Potsdam, Am Neuen Palais 10, 14469, Potsdam, Germany

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ABSTRACT

Background/objective: Dry land-training (e.g., plyometric jump training) can be a useful mean to improve swimming performance. This study examined the effects of an 8-week plyometric jump training (PJT) program on jump and sport-specific performances in prepubertal female swimmers.

Methods: Twenty-two girls were randomly assigned to either a plyometric jump training group (PJT_G; n = 12, age: 10.01 ± 0.57 years, maturity-offset = -1.50 ± 0.50, body mass = 36.39 ± 6.32 kg, body height = 146.90 ± 7.62 cm, body mass index = 16.50 ± 1.73 kg/m²) or an active control (CG; n = 10, age: 10.50 ± 0.28 years, maturity-offset = -1.34 ± 0.51, body mass = 38.41 ± 9.42 kg, body height = 143.60 ± 5.05 cm, body mass index = 18.48 ± 3.77 kg/m²). Pre- and post-training, tests were conducted for the assessment of muscle power (e.g., countermovement-jump [CMJ], standing-long-jump [SLJ]). Sport-specific-performances were tested using the timed 25 and 50-m front crawl with a diving-start, timed 25-m front crawl without push-off from the wall (25-m WP), and a timed 25-m kick without push-off from the wall (25-m KWP).

Results: Findings showed a significant main effect of time for the CMJ (d = 0.78), the SLJ (d = 0.91), 25-m front crawl test (d = 2.5), and the 25-m-KWP (d = 1.38) test. Significant group × time interactions were found for CMJ, SLJ, 25-m front crawl, 50-m front crawl, 25-m KWP, and 25-m WP test (d = 0.29–1.63) in favor of PJT_G (d = 1.34–3.50). No significant pre-post changes were found for CG (p > 0.05).

Conclusion: In sum, PJT is effective in improving muscle power and sport-specific performances in prepubertal swimmers. Therefore, PJT should be included from an early start into the regular training program of swimmers.

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Introduction

Swimming is an aquatic locomotion technique defined by periodic actions of the upper and lower limbs to overcome the drag force and propel the body forward.^{1,2} Muscle strength and power of the propelling muscles are important determinants of swimming performance.³ Moreover, there is evidence that muscle strength (i.e., pull-ups until muscular failure) and power (i.e., CMJ height) highly correlate with swimming performance (i.e., 50-m front crawl time) in adolescent swimmers (age = 19 ± 3 years).⁴ Well-

developed levels of muscle strength and power help swimmers to generate propelling forces.^{5,6}

Several studies have previously suggested that swimming performance cannot only be improved through sport-specific in-water training but also by means of adequate dry land-training (i.e., strength and/or power training).^{7,8,9} For example, Amaro et al.¹⁰ recommended that swimming coaches and physical trainers should include a dry land-training focusing on power-relating actions.

Plyometric jump training (PJT) activates the stretch-shortening cycle (SSC) of the musculotendinous system. The cycle starts with an eccentric muscle action, directly followed by a concentric shortening of the same muscle.¹¹ The purpose of PJT is to produce maximal forces within the shortest possible time. Accordingly, PJT

* Corresponding author.

E-mail address: chaabene@uni-potsdam.de (H. Chaabene).

is a well-suited means to bridge the gap between strength and speed adaptations.¹¹ PJT can elicit varied training effects depending on the characteristics of the training program (e.g., training surface, training volume, and training period).^{5,12–14} There is compelling evidence on substantial performance enhancements following PJT.^{7,9,12–16} Only a few studies^{9,17} examined the effects of PJT executed outside the pool on swimming performance. Most of these focused on the effects of PJT on swim start performance and the underpinning kinetic and kinematic parameters.^{17,18} However, a recently published study by Sammoud and colleagues¹⁹ showed that 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. Similarly, Potdevin et al.⁹ revealed significant increases in average swimming speed as well as in countermovement jump and squat jump performances after 6 weeks of PJT in adolescent male swimmers.

Most studies examined the effects of PJT in male young athletes which is why there is a need to conduct additional research with female young athletes.^{20–22} Moreover, a recent systematic review with meta-analysis²³ outlined that studies on the effects of PJT on physical fitness in female young athletes suffered from numerous methodological shortcomings (e.g., lack of information about maturation status, absence of a control group). Given these shortcomings in the literature, more studies including female participants are needed to provide sex-specific in-depth knowledge for coaches and practitioners. To the authors' knowledge, there is no study available that examined the effects of PJT on physical fitness and sport-specific performance in prepubertal female swimmers. In an attempt to fill this void in the literature, we studied the effects of an 8-week PJT program in combination with regular swimming training compared with swimming training alone on measures of muscle power and sport-specific performances in prepubertal female swimmers. Based on the literature,¹⁹ we hypothesized that 8 weeks of PJT results in greater improvements in jump and sport-specific performances compared with swimming training alone.

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 female swimmers. Two familiarization sessions were performed one week prior to baseline testing to accustom participants to the physical fitness tests and the plyometric drills. Before and after the intervention, tests were conducted for the assessment of jump (i.e., countermovement jump [CMJ], standing long jump [SLJ]) and swimming performances. Sport-specific tests included a timed 25- and 50-m front crawl trials with a diving start, a timed 25-m front crawl trial without push-off from the wall (25-m WP), and a timed 25-m kick trial 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).²⁴ Testing was performed 48 h after the last training session and at the same time of day during pre and post-testing (7:30–9:30 p.m.).

Participants

A total of twenty-two prepubertal female swimmers participated in this study. They were randomly allocated to a PJT group (PJT_G; n = 12; age = 10.0 ± 0.6 years; maturity offset = -1.5 ± 0.5) or an active control group CG (n = 10; age = 10.5 ± 0.3 years;

maturity offset = -1.3 ± 0.5). All participants competed on a national level and they had a background of 2.0 ± 1.4 years of systematic swimming training involving five to six training sessions per week throughout the season. The sample size was estimated using data from a previous study on the effects of PJT on horizontal jump performance in prepubertal male swimmers.¹⁹ An a priori power analysis indicated that 10 swimmers per group would be sufficient to yield 80% statistical power at a significance level of p < 0.05. Participants who missed more than 20% of the total PJT sessions and/or more than two consecutive PJT sessions were excluded from the study. Maturity offset was assessed at the beginning and after 8 weeks of training by predicting age at peak-height-velocity (PHV) based on age, body mass, height, leg-length, and sitting-height using the predictive equation established by Mirwald et al.²⁵:

Maturity offset = -9.376 + 0.0001882•leg length and sitting height interaction + 0.0022•age and leg length interaction + 0.005841•age and sitting height interaction - 0.002658•age and weight interaction + 0.07693•weight by height ratio•100.

All participants and their legal representatives were 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 (Table 2).

Plyometric jump training

Our PJT protocol was in accordance with previously published PJT recommendations for young athletes.^{13–16} 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. The PJT_G performed six training sessions per week, including two PJT sessions. The two PJT sessions were integrated into the regular training routine of the swimmers in replacement of some swimming specific drills (i.e., the water warm-up). The remaining training time comprised technical drills (e.g., coordination, breathing, skill-related improvement of swimming strokes). The second PJT session was completed 72 h after the first to allow a long enough recovery period between sessions. Each swimming training session lasted between 80 and 90 min. PJT drills were scheduled for 25–30 min. During that time, the CG followed their regular sport-specific swimming training (i.e., six sessions per week) throughout the intervention period. The average distance that was achieved in the pool was similar between groups for each training session (i.e., 2000 ± 300 m). Thus, both groups experienced similar training volumes in terms of training times and completed distances. No competitions were scheduled over the entire study period. At the beginning of the intervention, a focus was placed on proper exercise technique (e.g., landing mechanics). All jump exercises were performed on a stable surface 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 were gradually increased from 50 during the first week to 120 during the last week of training.¹⁹ A 90-s rest was provided between each set of exercises to allow sufficient recovery time.

Anthropometric measures

Anthropometrics (i.e., body-mass, height) were assessed by a

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), CMJs	4 × 6-7 4 × 6-7	50
2	Bilateral ankle hops (hurdle height: 20 cm), CMJs	4 × 7-8 4 × 7-8	60
3	Bilateral ankle hops (hurdle height: 20 cm), CMJs	4 × 8-9 4 × 9	70
4	Bilateral ankle hops (hurdle height: 20 cm), CMJs	4 × 10 4 × 10	80
5	Bilateral ankle hops (hurdle height: 20 cm), CMJs	4 × 10 6 × 8-9	90
6	Bilateral ankle hops (hurdle height: 20 cm), CMJs	6 × 8-9 6 × 8-9	100
7	Bilateral ankle hops (hurdle height: 20 cm), CMJs	6 × 8 6 × 10	110
8	Bilateral ankle hops (hurdle height: 20 cm), CMJs	6 × 10 6 × 10	120

Reps: repetitions; Notes: CMJ: countermovement jump.

Table 2
Characteristics of the study participants by group.

	PJT _G (n = 12)		CG (n = 10)	
	Pre-test	Post-test	Pre-test	Post-test
Age (years)	10.01 ± 0.57	10.22 ± 0.54	10.50 ± 0.28	10.71 ± 0.28
Body height (cm)	146.90 ± 7.62	146.29 ± 7.63	143.60 ± 5.05	144.00 ± 5.14
Body mass (kg)	36.39 ± 6.32	36.32 ± 5.49	38.41 ± 9.42	38.61 ± 8.74
Body mass Index (kg/m ²)	16.50 ± 1.73	16.67 ± 1.38	18.44 ± 3.77	18.49 ± 3.45
Maturity offset	-1.50 ± 0.50	-1.47 ± 0.5	-1.34 ± 0.51	-1.32 ± 0.50
Predicted APHV	11.50 ± 0.59	11.68 ± 0.58	11.85 ± 0.41	12.03 ± 0.41

Notes: Data are presented as means and standard deviations (SD); PJT: plyometric jump training group; CG: control group; APHV: Age at peak-height-velocity.

trained anthropometrist who was assisted by a co-worker. Standardized procedures were applied which were in accordance with the International Society for the Advancement of Kinanthropometry (ISAK)²⁶ (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.

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 hanging loosely 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 were not allowed to 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.

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. During the diving start tests (i.e., 15, 25, and 50-m), participants were not allowed to drift forward or backward before initiating the start. This was visually supervised by a qualified swimming coach. The average of the two recorded values was used for further statistical analyses. The start signal for the observer was the moment as the swimmer's feet left the block. For the water start without push-off, swimmer's 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 swimmer's hands touched the wall. The ICC for test-retest reliability ranged between 0.89 and 0.91 for all swimming tests.

Statistical analyses

Data were tested and confirmed for normal distribution using the Shapiro-Wilk's test. Baseline between-group differences were computed through independent t-tests. To establish the effect of the interventions on the dependent variables, a 2 (group: PJT_G and a CG) × 2 (time: pre, post) ANOVA with repeated measures on test was computed. When group × time interactions reached the level of significance (i.e., significant F value), group-specific repeated measure ANOVAs (time: pre, post) were used to determine within-

group pre-to-post performance changes. Additionally, effect sizes (ES) were determined by converting partial eta-squared from the ANOVA output to Cohen's *d*. According to Cohen,²⁷ ES can be classified as small ($0.00 \leq d \leq 0.49$), medium ($0.50 \leq d \leq 0.79$), and large ($d \geq 0.80$). Test-retest reliability was assessed using the intraclass correlation coefficient (ICC).²⁸ Data were presented as group mean values and standard deviation. The level of significance was established at $p \leq 0.05$. SPSS 26.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analyses.

Results

All subjects received treatment conditions as allocated. Two participants in the active CG dropped out because they left the club for personal reasons. Thus, 22 swimmers completed the training program. Adherence rate to training was 97%, for both groups. None of the subjects reported any training- or test-related injuries. There were no statistically significant between-group baseline differences for chronological age, body height, body-mass, maturity-offset or swimming expertise (Table 1). Additionally, no significant between-group differences were recorded at baseline regarding proxies of muscle power and sport-specific swimming performances (Table 3).

Muscle power

A significant main effect of time was found for both the CMJ ($d = 0.78$, $p < 0.01$) and the SLJ ($d = 0.91$, $p < 0.05$) tests. Likewise, the same tests displayed significant time \times group interactions (CMJ [$d = 1.24$, $p < 0.01$], SLJ [$d = 0.97$, $p < 0.05$]). Post-hoc analysis showed significant increases in CMJ and SLJ performances from pretest to posttest in the PJTG only (CMJ [$p < 0.01$, $d = 2.5$]; SLJ [$p < 0.01$, $d = 2.7$]).

Specific swimming test

25-m and 50-m front crawl test. A significant main effect of time ($d = 2.5$, $p < 0.01$) and a significant group \times time interaction ($d = 1.63$, $p < 0.01$) was found for the 25-m front crawl test. The post-hoc analysis showed a significant increase in 25-m front crawl test performance from pretest to posttest for the PJTG only ($p < 0.01$, $d = 3.5$). For the 50-m front crawl test, a trend towards a significant main effect of time was found ($p = 0.07$, $d = 0.83$). The respective group \times time interaction ($p < 0.05$, $d = 1.04$) turned out to be significant. The post-hoc analysis showed a significant increase from pre-to-posttest in the 50-m front crawl test in PJTG ($d = 1.8$, $p < 0.01$) (Figs. 1 and 2).

25-m kick without push test. Our statistical analysis showed a significant main effect of time in the 25-m kick without push test

($d = 1.38$, $p < 0.01$) and a significant group \times time interaction ($d = 1.31$, $p < 0.01$). The post-hoc analysis revealed a significant increase in the performance of the 25-m kick without push in PJTG ($d = 2.18$, $p < 0.01$) (Fig. 3).

25-m front crawl without push test. Results showed a non significant main effect of time in the 25-m front crawl without push test ($d = 0.6$, $p > 0.05$). However a significant group \times time interaction was found for the same parameter ($d = 0.89$, $p < 0.05$). Post-hoc tests revealed a significant improvement in favor of the PJTG ($d = 1.34$, $p < 0.05$) (Fig. 4).

Discussion

To the authors' knowledge, this is the first study 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 specific performances in prepubertal female swimmers. The main findings of this study showed that PJT is effective in improving jump and swimming performance in prepubertal female swimmers. Regular swimming training without PJT did not induce any significant effects on these outcome parameters.

Muscle power

Jump performance is a key performance determinant in swimming. In addition, performances during jumping have been shown to be valid talent-identification markers that have the potential to discriminate between elite and non-elite athletes.²⁹ According to Sanders,³⁰ the flip turn may be likened to a CMJ based on the period of flexion after the initial contact in which the major muscle extensors of the hip, knee, and ankle muscles are working eccentrically. This eccentric phase is followed by concentric work of muscles to extend the hip, knee, and ankle to accelerate and propel from the wall.

In this study, PJT induced significant improvements on measures of vertical (i.e., CMJ) and horizontal (i.e., SLJ) jump performances in prepubertal female swimmers. These outcomes were expected considering the extensive amount of studies that support the effectiveness of this type of training in youth female populations.²⁰ Our results are in line with those established by Potdevin et al.⁹ who revealed significant improvements in CMJ and squat jump height (ES = 1.73, and 0.73, respectively) after 6 weeks of PJT in adolescent male and female swimmers aged 13–15 years. Likewise, de Villarreal et al.⁸ showed a significant improvement in CMJ height (ES = 0.66) after 6 weeks of PJT in adolescent male water-polo players (23 years). More recently, Sammoud et al.¹⁹ observed small (ES = 0.53) and moderate (ES = 0.95) improvements in CMJ height and SLJ performance, respectively, in prepubertal male

Table 3
Group-specific baseline and post-test performances after eight weeks of an in-season plyometric jump training on jumping and sport-specific performance in prepubertal female swimmers.

	PJTG				CG				ANOVA		
	Pretest		Posttest		Pretest		Posttest		<i>p</i> -value (ES)		
	M	SD	M	SD	M	SD	M	SD	Time	Group	Group \times Time
CMJ (cm)	15.84	3.52	19.72	0.63	16.97	4.24	16.40	0.72	0.001 (0.78)	0.98 (0.00)	0.01 (0.29)
SLJ (cm)	119.75	11.85	132.81	3.80	121.70	18.21	118.52	4.33	0.04 (0.97)	0.55 (0.27)	0.04 (0.97)
25-m kick WP (s)	29.52	2.00	27.68	0.45	28.01	4.15	28.03	0.51	0.01 (1.38)	0.63 (0.22)	0.01 (1.31)
25-m front crawl WP (s)	22.23	1.14	20.97	0.32	20.11	1.78	20.70	0.36	0.19 (0.60)	0.02 (1.17)	0.05 (0.89)
25-m front crawl (s)	19.27	1.13	18.05	0.15	18.35	1.19	18.50	0.17	0.001 (2.50)	0.31 (0.46)	0.001 (1.63)
50-m front crawl (s)	42.79	2.65	41.08	0.52	40.51	3.10	40.94	0.59	0.08 (0.83)	0.27 (0.50)	0.03 (1.04)

Notes: M: mean; SD: standard deviation; *d*: Cohen's *d* (effect size); CMJ: countermovement jump; SLJ: standing long jump; 25-m kick WP: 25-m kick without push; 25-m front crawl WP; 25-m front crawl without push.

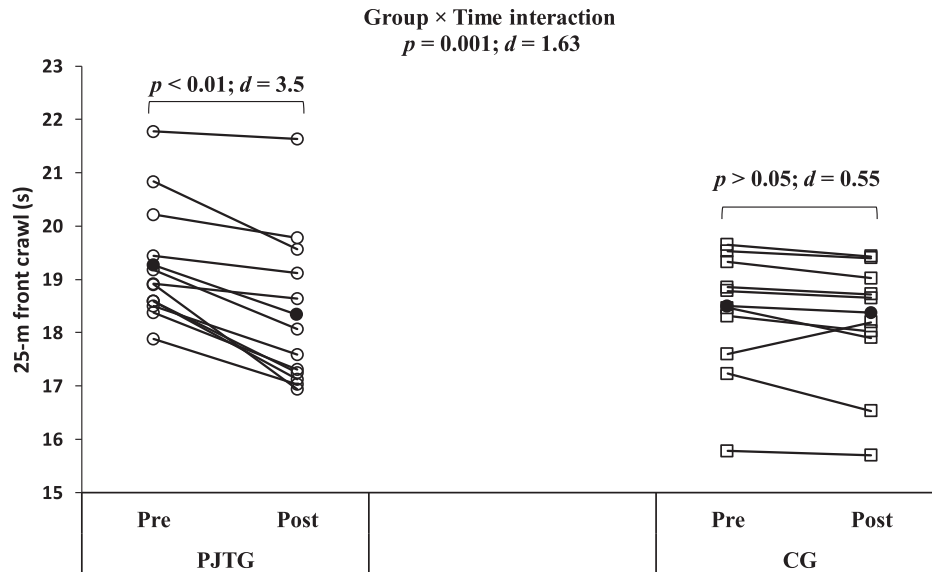


Fig. 1. Pre-to-post individual and mean performance for the 25-m front crawl test in both groups. Unfilled circles indicate individual data and filled circles indicate mean data for the plyometric jump training group. Unfilled squares indicate individual data and filled squares indicate mean data for the control group.

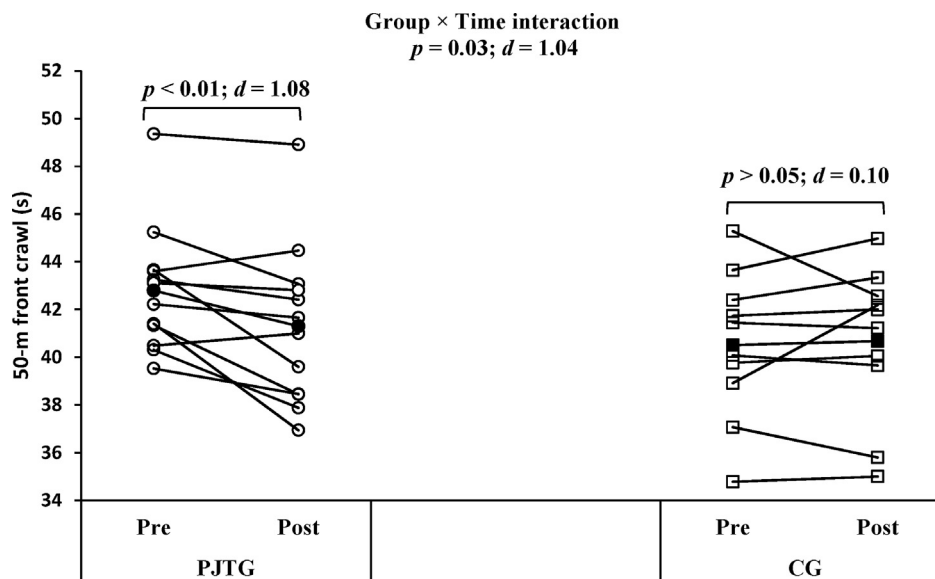


Fig. 2. Pre-to-post individual and mean performance for the 50-m front crawl test in both groups. Unfilled circles indicate individual data and filled circles indicate mean data for the plyometric jump training group. Unfilled squares indicate individual data and filled squares indicate mean data for the control group.

swimmers following PJT combined with regular swimming training. According to Behrens et al.³¹, the noted improvement in jump height is most likely due to the velocity at takeoff. Shorter time intervals between eccentric and concentric actions during plyometric training allow an athlete to become more powerful through improvements in muscle, tendon, and nerve function. In the same context, Asadi et al.³² explained that the improvement in vertical jump performance after PJT may be attributed to increased fiber length. In fact, it has been shown that PJT contribute to adding sarcomeres in series. This could result an increase in shortening velocity at the expense of force production because the sarcomeres in series pull against each other.³³ However, plyometric training is also likely to improve coordinative aspects during jumping. This is most likely caused by neuromuscular adaptations that enhance power production. In addition, the better ability of participants to

use neural and elastic benefits of the SSC could explain the improvement in jump performance after the PJT program.^{34–36}

Sport-specific swimming performances

Based on our findings, PJT has the potential to improve specific swimming performances in prepubertal female swimmers. Results from a previous study⁹ revealed a significant increase in 50-m, and 400-m average swimming time ($ES = 0.1$, and 0.15 for 50-m, and 400-m, respectively) after a 6-week PJT program in adolescent male and female swimmers. Likewise, Veliz et al.³⁷ showed an improvement in 20-m sprint swim time ($ES = 0.56$) after 16 weeks of combined lower-body resistance and PJT training in elite female water-polo players. Girolid et al.³ showed a significant enhancement ($\Delta 2.8\%$) in 50-m front crawl performance after 12 weeks of dry-land

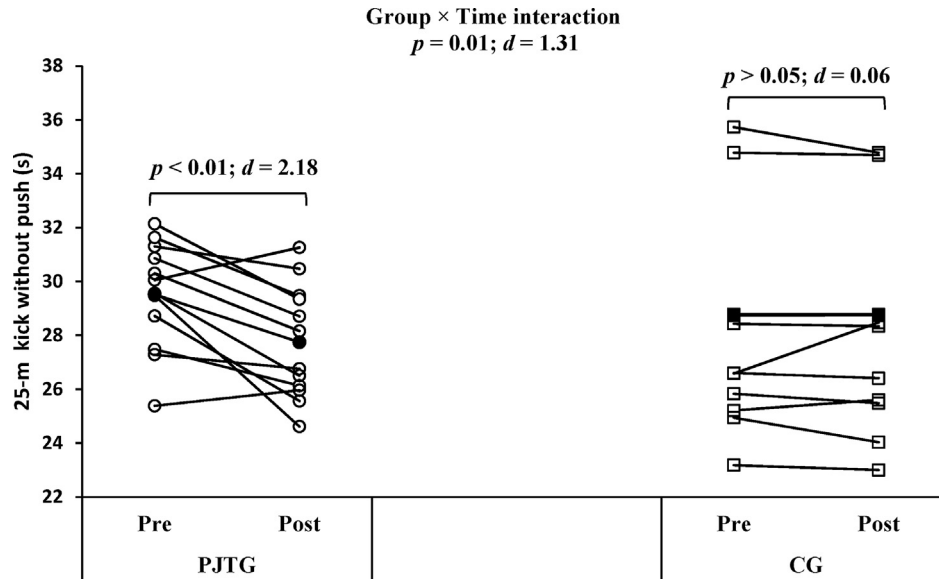


Fig. 3. Pre-to-post individual and mean performance for the 25-m kick without push test in both groups. Unfilled circles indicate individual data and filled circles indicate mean data for the plyometric jump training group. Unfilled squares indicate individual data and filled squares indicate mean data for the control group.

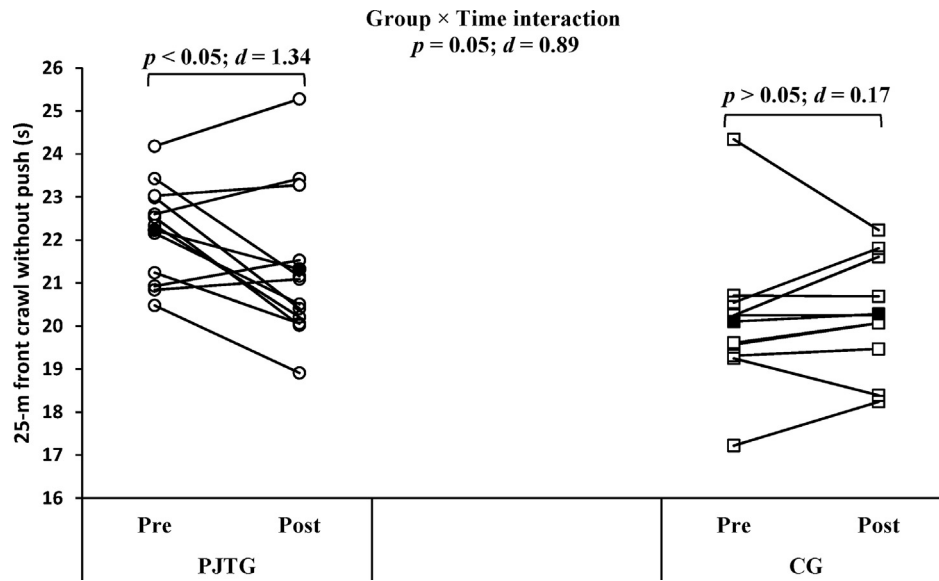


Fig. 4. Pre-to-post individual and mean performance for the 25-m front crawl without push test in both groups. Unfilled circles indicate individual data and filled circles indicate mean data for the plyometric jump training group. Unfilled squares indicate individual data and filled square indicate mean data for the control group.

strength training in male and female adolescent swimmers. More recently, Sammoud et al.¹⁹ revealed small-to-moderate improvements in the 50-m front crawl test (ES = 0.56), and the 15-m (ES = 0.99) as well as the 25-m front crawl tests (ES = 0.85) following 8-weeks of PJT in prepubertal male swimmers. The same authors showed small (ES = 0.25) and moderate (ES = 0.60) performance improvements for the 25-m KWP, and 25-m WP, respectively. The observed increases in swimming performances following PJT are most likely caused by increases in neuromuscular activation of the trained muscles. More specifically, increases in the number and/or firing frequencies of active motor units and/or changes in the recruitment pattern of the motor units, primarily of fast-twitch muscle fibers might account for the observed results.^{34,35} More research is needed however to elucidate the underlying mechanisms following PJT in female young athletes.

This study has some methodological limitations that warrant discussion. First, the number of participants was limited. However, we did not draw our sample from the overall population but from an a priori limited cohort which is young athletes. In addition, we computed an a priori power analysis and showed that the included number of participants is sufficient to reach 80% statistical power at a significance level of $p < 0.05$. Second, the testing of swimming performance using a stopwatch represents a limitation in terms of test accuracy. However, we computed ICCs and showed that all swimming tests displayed high test-retest reliability (ICC = 0.89 to 0.91). Future studies should use electronic timing systems (e.g., Omega system). Third, the underlying physiological mechanisms responsible for the observed training-induced performance improvements were not tested using for instance surface electromyography (neuromuscular mechanisms) or hormonal status (e.g.,

testosterone/insulin-like growth factor-I levels). This has to be considered in future research.

Conclusion

The outcomes of this study suggest that PJT is safe (i.e., no injuries occurred), and feasible (2 training sessions per week) in prepubertal female swimmers. In addition, our findings imply that prepubertal female swimmers benefit from an in-season PJT program that is conducted in replacement of some swimming specific drills by increasing muscle power and specific swimming performances. Our findings suggest that pediatric strength and conditioning coaches should consider including PJT as a regular part of their training regime in young female swimmers to promote physical fitness and sport-specific performance.

Declaration of competing interest

The authors declare no conflict of interest.

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