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Investigation of plyometric and endurance training on athletic performance in female elite rowers

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Abstract

Background: Plyometric training is defined as a quick, powerful movement involving a system of reactive exercises and an eccentric contraction, followed immediately by an explosive concentric contraction.

Aim: This study aimed to determine the effect of plyometric and aerobic training on peak power and performance in female elite rowers.

Materials and Methods: Sixteen female elite rowers with a minimum of 1 year's competitive rowing experience were recruited to perform six weeks of plyometric or cycling endurance training for 30 min before practice on the water three days per week. Rowing performance was assessed through a 500-m rowing time trial (TT), while peak rowing power (PR) was evaluated by over three maximal trials of 15 s on the rowing ergometer. The recorded value for peak power was the highest wattage observed during the 15-s period. All statistics were performed using commercially available software (SPSS v. 23, Armonk, NY). Pre-planned t-test comparisons were used to determine significance at baseline in changes within both groups.

Results: The results showed 500-m TT performance significantly improved for the plyometric group ($P< 0.05$) but not for the endurance group ($P> 0.05$). Moreover, PR was considerably higher in the plyometric group in post-test than endurance training.

Conclusion: These results suggest that plyometric can improve rowing performance in female elite rowers, and rowing coaches should continue using this form of training. Coaches can perform plyometrics in conjunction with other strength training methods or as a warm-up before beginning rowing-specific training.

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1. Introduction

Skeletal muscle is a highly adaptable and malleable tissue that participates in voluntary contraction according to command and responds to environmental and physiological challenges. These stimulations can improve muscle and athletic performance. Rowing is a high-intensity sport, requiring high strength, power, anaerobic, and aerobic capacity [1, 2]. Race times can range from 5.5 to 7 min in elite rowers (2-km rowing race), indicating a need for various training intensities [3]. It has been estimated that aerobic metabolism contributes 67–84% of the energy requirement during racing. In this regard, endurance training dominates the training programs of most rowers [3]. However, multiple factors affect rowing performance, indicating that a rower's training program must encompass aerobic and anaerobic training and training methods to develop peak power, such as strength or power training. Ingham et al. (2002) indicated that peak force and power over a maximal five-stroke test were two of the highest correlates to 2-km ergometer performance [1]. Therefore, training for power is a part of many rowers' training programs [2] which may consist of strength training [4] or heavy rowing [5], performed concurrently with aerobic training. While strength training has been shown to enhance rowing performance [6, 7], less is known about the effect of power training, such as plyometrics, on rowing performance.

Plyometrics is a type of training that develops the ability of muscles to produce force at high speeds in dynamic movements; these movements involve a stretch of the muscle immediately followed by an explosive contraction of the muscle. This pattern of muscle contraction is known as the stretch-shorten cycle. Plyometric exercises include vertical jumps, during which the athlete jumps as high as possible "on the spot", and bounds, during which the athlete leaps as high as and as far as possible, thus moving the body in the horizontal and vertical planes. It is generally accepted that the more specific a training exercise to a competitive movement, the greater the transfer of the training effect to performance [8, 9]. Plyometrics training improves power through an increased neural drive, muscle coordination changes, muscle tendon complex changes, and muscle size and architecture [10]. In addition to performance benefits, plyometric training also exerts healthogenic effects such as increased bone mineral density, improved neuromuscular function, body mass control, improved psychosocial well-being, improved cardiovascular risk profile, and decreased risk of injuries [10, 11, 12]. A twice-weekly plyometric training for 8 to 10 weeks with a 72 h rest period between training sessions improves high-intensity physical abilities (e.g., jump, sprint, agility) in the young soccer player population aged 10 to 17 y, in both sexes [13]. Monsef Cherif et al. (2012) showed that combined programs including sprint repetitions and high-intensity plyometric training in the same session positively influence handball players' jumping ability and sprint ability [14]. Moreover, adding combined plyometric and short sprints training to standard training improved jump performance, sprinting, change-of-direction ability, and balance in soccer players [15]. A recent systematic literature review shows that short-term plyometric training has a positive effect on endurance running performance or running economy [16].

Thus, as plyometrics can improve endurance performance and power, with no chronic detriment when performed concurrently [17], plyometrics has the potential to be an effective means to improve performance in rowers, where the legs contribute significantly to generating stroke power. Coaches that do use plyometrics often perform other strength training methods in addition, as concurrent training has been shown to increase rowing performance [18]. However, it remains to be seen whether plyometrics alone can improve rowing performance and thus validate their use by rowing coaches [5]. Furthermore, a recent systematic review reported that there is no more risk of injury with the plyometric training programs than any other physical or recreational activity in which children and adolescents usually participate [13]. Recent studies have reported significant improvements in athletic performance in young and adult athletes following the sprint training protocol, but no injuries have been observed after this type of training [19, 20]. Therefore, this study's objective was to determine the effect of plyometric and aerobic training on peak power and performance in female elite rowers. It was hypothesized that plyometric training would induce significant changes in rowers' performance in competitive female elite rowers.

2. Materials and Methods

2.1. Participants

Sixteen female elite rowers with a minimum of 1 year's competitive rowing experience were recruited to this study and divided into experimental plyometric (PLYO) and the aerobic training (AT) group, consisting of eight subjects. The groups were matched with regard to pre-training 500-m times. Subjects were not involved in lower body musculoskeletal conditions for at least six months before beginning the study. Moreover, the participants had no previous experience with plyometric training. All procedures were approved by the University of Tehran ethical committee and performed following the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All subjects were given written and oral explanations about procedures and then informed consent.

2.2. Training protocols

The intervention was performed for six weeks, long enough to elicit significant physiological and/or performance changes [21]. These six weeks of training were selected to complete before the major competitions for the rowers. Both groups performed 30 min of cross-training before on-the-water practice, three days/week, with 48 h in between sessions. The PLYO group performed 30 min of plyometric exercise, while AT performed steady-state cycling. All plyometric sessions contained exercises focusing on vertical explosiveness, such as box jumps, depth jumps, multiple box-to-box jumps, and double leg hops.

Furthermore, as the rowing stroke involves opening the trunk, backward and overhead throws of medicine balls (10 lbs) were included to train explosive triple extensions. Sessions ranged from 100- to 150-ft contacts in week 1 to 125- to 170-ft contacts in week 6. Medicine ball exercise repetitions were periodized to progressive overload. The volume (number of foot contacts) conforms to recommended guidelines [22]. The full training program can be found in Table 2.

The AT group performed 30 min of steady-state cycling at the ventilatory threshold simultaneously as the experimental group.

Table 1. The participant characteristics at baseline and following the 6-week intervention

	Experimental plyometric		**Aerobic training**	
	Pre	**Post**	**Pre**	**Post**
Age (yrs)	17±0.8	17±0.8	17±0.4	17±0.4
Height (cm)	163±3	16±3	165±4	165±4
Weight (kg)	62±1.7	62±0.98	63±1.5	63±1.1
Body fat (%)	21±1.9	20±1.2	20±1	19±0.98

Table 2. The plyometric program performed for 30 min, three days a week, for six weeks

	Week 1	**Week 2**	**Week 3**	**Week 4-6**
Day 1				
Single leg push-off	3×8	3×10	3×10	3×10
Box jump	3×5	3×6	3×6	3×6
Depth jump	3×5	3×5	3×5	3×5
Squat jump	3×15	3×20	3×10	3×10
Backward throw	3×6	3×6	3×6	3×6
Overhead throw	3×5	3×6	3×6	3×6
Trunk rotation	3×5	3×6	3×6	3×6
Foot contacts	100	125	125	125
Day 2				
Double leg hops	3×5	4×5	4×5	4×5
5-5-5 squat	3 times	4 times	4 times	4 times
Front cone hops Squat jump	4 cones, 5 times	4 cones, 5 times	4 cones, 5 times	4 cones, 5 times
Multiple box-to-box jumps	5 times	5 times	5 times	5 times
Wave squat	2×5	10 reps	10 reps	10 reps
Box jump	3×5	4×5	4×5	4×5
Foot contacts	150	170	170	170
Day 3				
Standing jump over barrier	3×5	4×5	4×5	4×5
Lateral jump over barrier	3×5	4×5	4×5	4×5
Single leg push-off	3×8	3×8	3×8	3×8
Depth jump	3×5	4×5	4×5	4×5
Pyramiding box hops	3 rounds	5 rounds	5 rounds	5 rounds
Backward throw	3×6	3×6	3×6	3×6
Overhead throw	3×5	3×5	3×5	3×5
Foot contacts	120	150	150	150

The athletes were also familiar with this method, which was used at their club to prescribe low-intensity aerobic workouts. Cycling was used so that one group was not provided with a higher volume of rowing-specific training than the other and is also a standard cross-training method for rowers. After each group completed the 30 min training, they proceeded to their on-the-water rowing practice. All subjects completed the same on-the-water workouts, and members from the PLYO and AT groups rowed together in mixed boats.

2.3. Outcomes

The 500-m TT and peak rowing power (PR) were taken during a single testing session before and after the six weeks of training. The post-testing was performed at least 48 h after the last training session, allowing adequate recovery. Participants completed a maximal 500-m TT on the rowing ergometer. All participants were familiar with performing maximal 500-m trials as these were performed frequently as part of their normal training and/or performance assessments before enrollment in the study, but none were performed during the intervention period. A 2-min warm-up and cooldown were completed before and after the TT, with participants asked to rest for 30 min following the TT. Peak rowing power (PR) was then measured over three maximal trials of 15 s on the rowing ergometer. The recorded value for peak power was the highest wattage observed during the 15-s period. For the TT, the participants were instructed to self-select the ergometer resistance, which had to be the same for both the pre-and post-testing. For the PR test, the resistance was set to the highest value on the rowing ergometer [22].

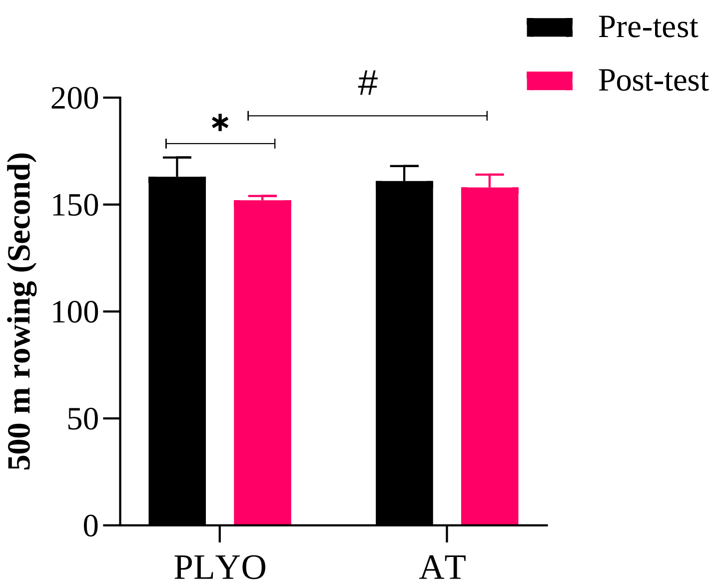
2.4. Statistical analysis

Statistical analysis was conducted using SPSS software (version 21; IBM, Chicago, IL) and reported as mean ± SD. The normality of the data and equality of variances was tested using the Shapiro–Wilk, and Levine test, respectively. A pre-planned T-test was run to analyses differences across time (baseline vs. follow-up) and groups in all variables. An alpha of $P \leq 0.05$ was considered statistically significant for all comparisons for all statistical analyses.

3. Result

There was no difference in the 500-m times between the groups before training ($P=0.32$). TT performance did not change for AT after training ($P=0.175$); however, the TT performance was significantly improved in PLYO ($P<0.05$). Furthermore, the difference in TT performance was statistically different between the groups at post-testing ($P<0.05$).

Moreover, there was no difference in PR between the groups before training ($P=0.234$). After training, there was no change in PR in PLYO or AT ($P=0.135$, $P=0.154$). Furthermore, the difference in PR was not statistically significant between the groups at post-testing ($P \geq 0.05$).



* significance within-group compared to pre ($P \leq 0.05$)
# significance between groups in post-test ($P \leq 0.05$).

Figure 1. The 500-m rowing ergometer time trial performance of the experimental (PLYO) and aerobic training (AT) groups was recorded before (n=8/group) and after six weeks of training. Data are expressed as means ± SD.

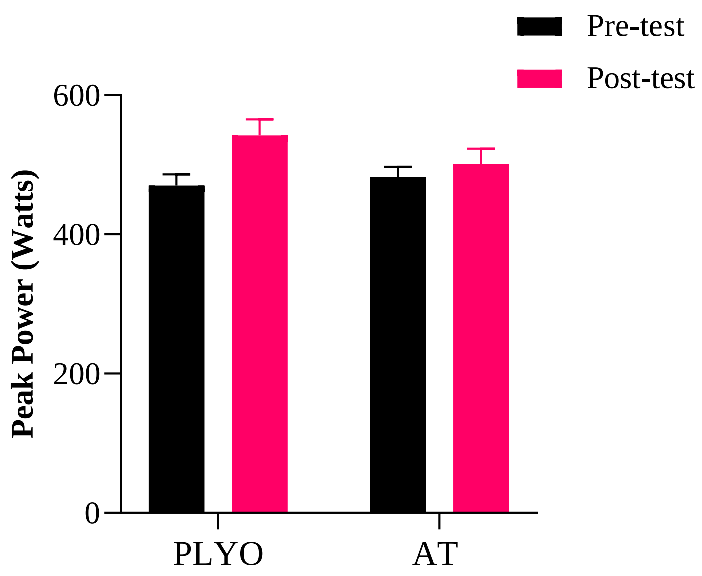


Figure 2. Peak rowing power was observed during three trials of 15-s maximal rowing ergometer tests in the experimental (PLYO) and aerobic training (AT) groups recorded before (n=8/group) and after six weeks of training. Data are expressed as means ± SD.

4. Discussion and Results

This study investigates the effect of plyometric and aerobic training on peak power and performance in female elite rowers. The results showed that compared to the AT group, TT performance was significantly improved in the PLYO group ($P \leq 0.05$). Moreover, a significant difference in TT performance was observed at the follow-up values between AT and PLYO groups ($P \leq 0.05$). Moreover, there was no change in RP after training in PLYO or AT ($P=0.135$, $P=0.154$). Furthermore, the difference in RP was not statistically significant between the groups at post-testing ($P \geq 0.05$). However, peak rowing power was moderately changed as there was a tendency for the difference between groups post-training with higher peak power in the plyometric group in response to this relatively short intervention.

Results from the current study indicate that plyometric training in female rowers may elicit a moderate increase in rowing power for this length of time (6 weeks). This agrees with previous research as plyometrics are typically used to improve power [2, 10]. Egan-Shuttler et al. (2017) showed four weeks of plyometric training moderately improved peak rowing power [22]. Cherif et al. (2012) showed that a combined program including sprint repetitions and high-intensity plyometric training in the same session positively influenced handball players' jumping and sprint ability [14]. Aloui et al. (2021) reported replacing part of the regular in-season training with eight weeks of biweekly combined plyometric with short sprints training would improve horizontal and vertical jump performance and the sprint performance of male soccer players [15]. Moreover, it has been shown that the combination of high-intensity plyometric exercises and running endurance training induces significant increases in explosive strength and running endurance performance after six weeks of moderate volume plyometric training in the competitive middle- and long-distance runners [23].

This corroborated Hammami et al.

(2020) findings, who studied the effects of the combination of 10-week plyometric training and short sprint exercises in male soccer players and noted improvement in vertical and horizontal jump performance [24]. Moreover, de Villarreal et al. (2015) observed significant increases in horizontal jump performance following combined plyometric and short sprints training in male soccer players under 15 [25]. The improvement in jump performance following plyometric training may be partially attributable to a change in the level of neuromuscular activation, motor intermuscular and intramuscular coordination, and elastic advantages of SSC and/or changes in muscle typology [10, 15].

On the other hand, it seems that the moderate improvement in rowing power may be attributed to a number of potential factors. The training period was relatively short compared to other studies in the field of plyometrics, so with further training, there could have been a greater and/or significant change in rowing power. The sample size was also relatively small, possibly lacking the statistical power necessary to observe an increase in rowing power. Changes in PR also varied within the groups, suggesting that some individuals may have been better at performing the 15-s peak power ergometer test or possess the innate physiological traits or training understanding to achieve high rowing powers. Also, the motor coordination trained using plyometrics (jumping) is vastly different from the patterns used during the maximal peak power test, with a high rowing resistance.

Furthermore, muscle coordination could have significantly differed between individuals due to the athletes being at varying stages of athletic maturity. However, it should be noted that a significant difference in peak rowing power could be observed with greater sample size and/or a longer training period. Moreover, the athletes' younger age and relatively lower training history utilized in the current study may explain the moderate improvement in rowing power. Specifically, these athletes may not have completed the physical and technical development to achieve maximum power truly, thus perhaps underestimating the possible changes with the training [22].

Additionally, plyometric training has been shown to improve short running sprint performance. Results from the current study indicate that plyometric training can improve rowing sprint performance [9]. Kargarfard et al. (2020) studied the effects of the combination of 6-week plyometric and short sprints exercises in male soccer players, reporting improved sprint performance over 30 m [26]. Moreover, in male soccer players, Hammami et al. (2020) observed significant increases in 5, 10, 20, 30, and 40 m sprint times following combined loaded and unloaded plyometric and short sprints training [24]. Indeed, gains in sprint performance due to combined plyometric and short sprints training in male soccer players have been observed [25]. Aloui et al. (2021) reported rep plyometric with short sprints training would improve sprint performance of male soccer players [15]. Another study showed sprint repetitions and high-intensity plyometric training positively influence the sprint ability of handball players [14].

Moreover, it has been shown that the combination of high-intensity plyometric exercises and running endurance training induces significant increases in explosive strength and running endurance performance after 6 weeks of moderate volume plyometric training in the competitive middle- and long-distance runners [23]. On the other hand, these findings contrast a study performed by Kramer et al. (1993), in which 20 min of simple double leg plyometric exercises were added at the end of the strength training sessions completed by female collegiate rowers [27]. Their rowing measures were a 2.5-km ergometer test, and the distance in meters was achieved in 90 s. Compared with the current investigation, the 90-s rowing test is very similar to the 500-m TT. The average time for the plyometric group to perform the 500-m TT after training was ~95 s. Kramer et al. (1993) found no changes in the 90-s test after 9 weeks of training [27], whereas we observed a significant improvement in 500-m performance. Improvements in sprint performance occur mainly due to neural factors such as improved intermuscular coordination, increased excitability of the Hoffman reflex (H-reflex), and enhanced motor unit recruitment strategy [10, 28]. Moreover, it seems that improved sprint performance after combined plyometric and short sprints training may be related to the effect of a positive number of exercises to ensure sufficient performance of neuromuscular and metabolic systems of participants [25]. Therefore, these results suggest that a plyometric training program should be added to their regular training program to optimize rowing performance and explosive adaptations in female rowers.

There have been some possible limitations in this research, which must be considered in the following studies. The sample limitation might have a tangible effect on results. This possibility can be discussed for future research by thought increasing sample research. The 500-m TT measure used here is not the gold standard rowing performance test used by rowing coaches. The 2-km ergometer time trial is the most common rowing performance measure. This test measures rowing ability, fitness, technique, and mental fortitude. For this last reason, the 2-km test was not used to evaluate the rowing performance of the young athletes in the current study. As the 2- km test was not performed in the present study, further research is needed to definitively demonstrate whether improvements in 500-m performance due to plyometrics can be translated into the full 2-km test.

Furthermore, future studies should extend these observations to other disciplines, age groups, gender, and other competitive levels. It is also necessary to compare the gains in test performance with performance analysis during competitions. Furthermore, neuromuscular mechanisms that underlie the improvements reported here can also be an area of future research.

5. Conclusion

The purpose of this study was to determine whether plyometrics, a form of power training already used by rowing coaches, could improve rowing performance and rowing power. Plyometrics significantly improved the 500-m TT rowing performance and moderately improved peak rowing power, suggesting that improved rowing power and other factors could be responsible for the observed increased performance. These results suggest that plyometrics can improve rowing performance in young female rowers and that rowing coaches should continue using this form of training. Coaches can perform plyometrics in conjunction with other strength training methods or as a warm-up before beginning rowing-specific training. However, further research is needed to determine whether plyometrics can improve the 2-km rowing performance and performance of other populations.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design.

Ethical considerations

The author has completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc.

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

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