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ORIGINAL SCIENTIFIC PAPER

Effects of a Short-Term Aquatic Training Program on In-Water Vertical Jump Performance and Neuromuscular Output in Water Polo Players

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Abstract

The dynamic nature of water polo imposes high physiological demands, requiring players to produce rapid, high-force lower limbs actions, while maintaining body control in a fluid medium. Vertical body elevation is essential for actions such as blocking and shooting, depends heavily on lower limb strength and coordination. Despite this, limited research exist on the effectiveness of aquatic-based strength intervention in enhancing such capabilities. This study aimed to evaluate the effects of a 21-day aquatic training program on vertical jump performance and neuromuscular output in competitive water polo players. Fourteen male athletes underwent targeted training focusing on explosive leg strength and maximal elevation of the body from the water. Employing a quasi-experimental, one-group pretest–posttest design, the study assessed performance using two portable systems: an adapted EasyForce dynamometer to measure, in water, peak force (PF), average force (AF), and time to peak force (TTPF); and a Kinect-based motion capture system to assess vertical displacement in water (H). The best of three vertical jump attempts was used for analysis. Due to non-normal data distribution, non-parametric statistical tests were applied. Within-group changes, assessed using the Wilcoxon signed-rank test, revealed significant improvements in H ($p=0.027$, $r=0.59$), TTPF ($p=0.004$, $r=0.77$), PF ($p=0.001$, $r=0.88$), and AF ($p=0.001$, $r=0.88$). These findings suggest that short-term aquatic training can improve neuromuscular coordination and explosive power in water polo athletes. Our study highlights the value of portable motion and force technologies in monitoring aquatic-specific performance changes. Future applications may consider extending such protocols for broader performance enhancement and integration into elite training routines.

Keywords: *water polo, vertical jump, training intervention, explosive power, EasyForce dynamometer, Kinect motion capture, aquatic performance assessment*

Introduction

Water polo is a high-intensity intermittent sport characterized by frequent explosive actions such as vertical jumps, rapid changes in direction, and overhead throwing, all performed in an aquatic environment (Kovačević et al., 2024; Spittler & Keeling, 2016; Uljević et al., 2013a). Performance in water polo relies on a complex interaction of multi-directional movements, including fast swimming with abrupt speed changes, transitions between horizontal and vertical positions, and high-intensity efforts like shooting, blocking, and grappling for position (Croteau et al., 2024; Melchiorri et al., 2010).

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One of the most critical abilities in these scenarios is the capacity to execute an effective in-water vertical jump, which allows athletes to perform technical actions such as shot blocking, pressured passing, or aerial contests with greater effectiveness (Perazzetti et al., 2023). This jump is typically initiated from a vertical floating position and involves a rapid upward propulsion using explosive leg strength.

Two main lower-limb techniques contribute to this movement: the eggbeater kick, which maintains vertical stability through a continuous alternating motion (Homma & Homma, 2005; Sanders, 1999; Melchiorri et al., 2015; Stirn et al., 2014), and the breaststroke kick, which is more commonly used for explosive upward elevation required during passes, shots, or goalkeeper saves (Tsunokawa et al., 2015). The latter requires high levels of muscular power and precise inter-limb coordination to achieve maximum vertical displacement under competitive conditions.

While vertical jump performance has been extensively studied in land-based sports (Cormie, McGuigan, & Newton, 2011; Komi, 2003), aquatic-specific training and testing methods remain relatively underdeveloped. In contrast to the broad body of literature addressing general conditioning in water polo (Botonis et al., 2015, 2018, 2019), few studies have explored the transfer of explosive strength training to water-based actions or assessed vertical jump ability under ecologically valid conditions. Some exceptions include research comparing dryland and in-water training modalities, which has shown that both can enhance water polo-specific performance, particularly when combined (de Villarreal et al., 2014, 2015).

Some recent efforts have validated sport-specific in-water jump tests (Uljević et al., 2013b; Uljević, Esco, & Sekulić, 2014) and investigated the force–velocity and power–velocity relationships involved in aquatic jumping (Annino et al., 2021). However, these approaches often rely on expensive laboratory equipment and lack accessibility for field implementation.

To address these limitations, the present study implemented a novel, portable dual-assessment protocol using a Kinect-based motion capture system to assess jump height and a customized EasyForce dynamometer to measure neuromuscular force parameters. These tools provide a practical, low-cost solution for field-based monitoring of aquatic performance.

The aim of this study was to examine the effects of a 21-day aquatic training program on in-water vertical jump performance and neuromuscular output in competitive water polo players. We hypothesized that athletes would demonstrate significant improvements in vertical jump height, time to peak force, and force output following the intervention.

Materials and Methods

Research Design

This study employed a quasi-experimental, one-group pretest–posttest design with repeated measures to investigate the effects of a targeted aquatic training program on vertical jump performance in competitive water polo athletes. Owing to logistical constraints and the structure of team-based participation, neither randomization nor a control group was implemented. Instead, a single cohort underwent a 21-day specialized aquatic intervention. All outcome variables were assessed under standardized testing conditions at both baseline and post-intervention time points. This design permitted the examination of within-subject changes over time attributable to the applied training protocol.

Participants

Fourteen male competitive water polo players voluntarily participated in the study. All athletes were medically cleared for unrestricted physical activity and had a minimum of three years of structured training experience. Participants completed a structured aquatic training program specifically designed to enhance vertical jump performance. All procedures were reviewed and approved by the institutional ethics committee (Protocol No.282/16.05.2025) and were conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to the start of the study.

Procedure and Assessments

Two primary aquatic performance parameters were evaluated before and after the intervention: vertical jump height and vertical force output. Vertical jump height was assessed using a Microsoft Xbox Kinect (Microsoft, Redmond, USA; Zhang, 2012) camera integrated with TouchDesigner software (Derivative, Vancouver, BC, Canada). The sensor system was calibrated to capture vertical displacement along the Y-axis by tracking a standardized anatomical landmark at the base of the neck. Each athlete performed maximal vertical jumps from a stationary position in water under two distinct arm conditions: both arms submerged and one arm raised above the water. Among the three attempts, the best performance regardless of arm position was selected for analysis, as no significant differences were observed between the two arm positions.

Vertical force output was measured using an EasyForce dynamometer (Meloq, Stockholm, Sweden; Meloq Devices, 2025), mounted on a custom-built telescopic rig positioned at the edge of the pool. Athletes were secured in a harness connected to a guiding pulley system that enabled vertical force application during simulated jump efforts. The device recorded peak force (PF), average force (AF), and time to peak force (TTPF). All testing procedures were standardized and supervised, and the best attempt from each condition was retained for subsequent analysis.

Pre- and post-intervention testing took place under standardized conditions using validated equipment: a Kinect video system for measuring maximal elevation of the body from the water and the EasyForce dynamometer for vertical force assessment. Testing protocols isolated lower limb contribution by instructing athletes to perform a vertical jump with submerged arms in a static position.

Intervention Protocol

The athletes underwent a 21-day specific aquatic training program aimed at enhancing vertical jump performance in water polo through targeted neuromuscular and biomechanical adaptations. Training sessions were conducted three times per week, each lasting approximately 60 minutes, and were supervised by a certified aquatic coach to ensure proper technique and adherence to the prescribed intensity.

Exercise selection focused on activating lower limb musculature under conditions of instability and resistance, employing tools such as elastic bands and medicine balls to simulate game-like scenarios. The protocol alternated between high-intensity efforts and short active rest intervals to stimulate neuromuscular adaptations while maintaining technical control. Asymmetrical exercises, such as holding a medicine ball with one arm, were included to enhance trunk musculature activation and dynamic balance. Forward and backward movements under load aimed to reproduce the demands of in-game maximal elevation of the body from the water. Training intensity was progressively adjusted based on athlete feedback and performance progression to ensure sustained neuromuscular overload without excessive fatigue.

Our intervention program was not directly adapted from a single published protocol. Its design was conceptually informed by a range of studies focusing on water polo-specific strength development, neuromuscular adaptation, and in water-vertical jump. Key findings from Annino et al. (2021) and Keiner et al. (2020) supported the use of force-velocity profiling in water while de Villareal et al. (2014) and Veliz et al. (2015) highlighted the efficacy of in season aquatic and resistance training in improving performance indicators such as jump height, throwing velocity, and sprint swim capacity. Additional evidence from Marrin and Bampouras (2008) and Platanou (2006) contributed to our exercise selection by emphasizing year-round physiological adaptation and sport-specific testing methods. Based on these insights, we created a novel, short-term intervention specifically tailored to the biomechanical and neuromotor requirements of vertical jump performance in water polo, while maintaining practical applicability under field conditions.

A detailed overview of the aquatic training protocol, including exercise descriptions, activity durations, rest intervals, and repetitions, is provided in Table 1.

Table 1. Aquatic Training Program Protocol Over 21 Days

Phase	Exercise Description	Activity Duration	Rest Period	Repetitions
Warm-up	General lower limb warm-up performed in water	5 minutes	–	–
Exercise 1	Athlete treads water while extending an elastic band to 70% of maximal length for 20 seconds, followed by a 10-second maximal stretch on coach's whistle	30 seconds	60 seconds	4
Active Rest	Short active rest	–	2 minutes	–
Exercise 2	Athlete holds a 5 kg medicine ball above the forehead with shoulders out of the water for 20 seconds, followed by 10 seconds of vertical breaststroke kicks	30 seconds	60 seconds	4
Active Rest	Short active rest	–	2 minutes	–
Exercise 3	Athlete treads water while holding a 2 kg ball above the head with one arm for 40 seconds; after 20 seconds of rest, the movement is repeated with the other arm	40 seconds × 2 arms	20 seconds between arms	4
Active Rest	Short active rest	-	2 minutes	–
Exercise 4	Athlete holds a 2 kg medicine ball overhead while moving forward for 40 seconds, then backward on the coach's whistle using eggbeater kicking	40 seconds × 2 (forward/back)	40 seconds	6
Recovery	Four 25 m low-intensity front crawl kick laps using a kickboard	5 minutes	-	4

Note. The training protocol was applied across a 21-day intervention period. All sessions were supervised by a certified aquatic coach. Exercise intensity was progressively adjusted to ensure neuromuscular overload while maintaining technical control.

Statistical Analysis

Descriptive statistics were used to characterize the sample and summarize baseline demographic and performance variables. The Shapiro–Wilk test was performed to assess the normality of the data distribution. As the assumptions for parametric analysis were not met, the Wilcoxon signed-rank test was applied to assess within-group changes from pre- to post-intervention. Effect sizes for non-parametric tests were calculated using the formula $r=Z/\sqrt{N}$ and interpreted according to Cohen's (2013) guidelines as small (≥0.10), medium (≥0.30), or large (≥0.50). All statistical analyses were conducted using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $p<0.05$.

Results

Descriptive statistics were calculated for all measured variables at both the pretest and posttest stages for the experimental group (see Table 2 and Table 3).

According to Table 2, at baseline, the experimental group demonstrated a mean vertical jump height (Hi) of 0.24 m (SD=0.09), peak force (pre_PF) of 290.14 N (SD=56.81), average force (pre_AF) of 127.21 N (SD=17.83), and time to peak force (pre_TTPF) of 0.52 s (SD=0.11).

Table 2. Pretest Descriptive Statistics for Experimental Group

Group	Variable	Mean	SD
Experimental group	H_i (m)	0.24	0.09
	pre_TTPF (s)	0.55	0.08
	pre_PF (N)	290.14	56.81
	pre_AF (N)	127.21	17.83

Note. H_i=initial stage height; pre_TTPF=time to peak force (pre-test); pre_PF=peak force (pre-test); pre_AF=average force (pre-test); SD=standard deviation. Measurements for force are expressed in Newtons (N), height in meters (m), and time in seconds (s).

Following the 21-day aquatic training protocol, the experimental group showed improvements across all performance metrics (Table 3). Final height (Hf) increased to 0.29 m (SD=0.08), post_TTPF decreased to 0.44 s (SD=0.10), and both post_PF and post_AF increased to 348.14 N (SD=55.48) and 145.00 N (SD=22.58), respectively.

Table 3. Posttest Descriptive Statistics for Experimental Group

Group	Variable	Mean	SD
Experimental group	H_i (m)	0.29	0.08
	post_TTPF (s)	0.44	0.10
	post_PF (N)	348.14	55.48
	post_AF (N)	145.00	22.58

Note. H_f=final stage height; post_TTPF=time to peak force (post-test); post_PF=peak force (post-test); post_AF=average force (post-test); SD=standard deviation. Measurements for force are expressed in Newtons (N), height in meters (m), and time in seconds (s).

The observed differences in neuromuscular performance between the initial and final assessments in the experimental group are presented in Figure 1.

Subsequently, a Wilcoxon signed-rank test was applied to examine within-group changes in the experimental group, assessing whether the intervention led to significant improvements in the measured parameters (see Table 4).

As shown in Table 4, the Wilcoxon signed-rank test was conducted to assess within-subject changes in the experimental group (N = 14) before and after the 21-day aquatic training program. The results revealed statistically significant improvements across all measured variables: final height (Z=-2.21, p=0.027, r=0.59), time to peak force (TTPF; Z=-2.89, p=0.004, r=0.77), peak force (PF; Z=-3.30,

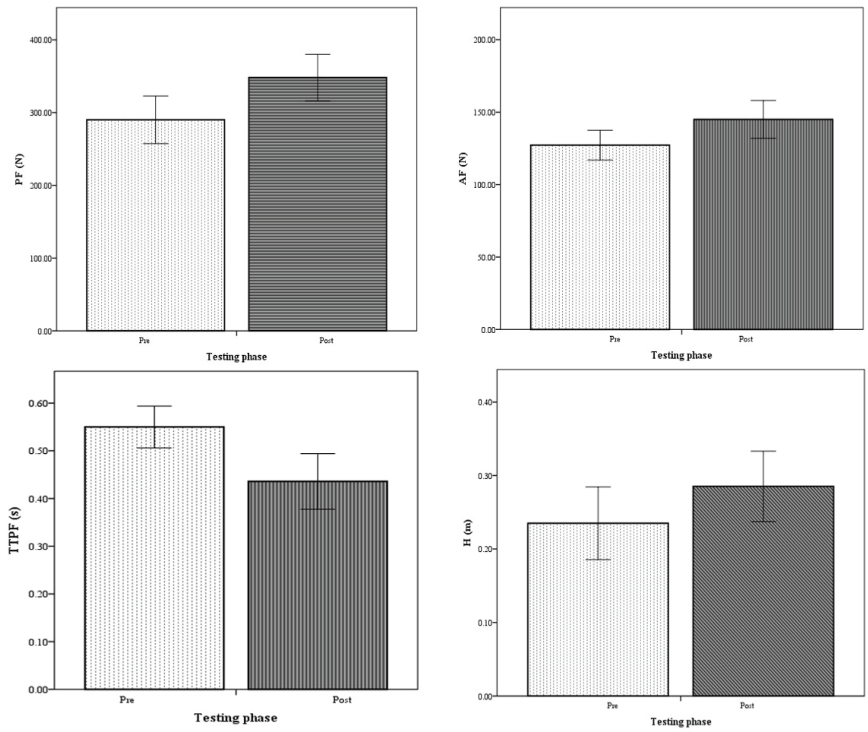

FIGURE 1. Changes in neuromuscular performance variables between pre- and post-training assessments in the experimental group
Note. Values are presented as means ± standard errors for peak force (PF), average force (AF), time to peak force (TTPF), and vertical displacement (H) during in-water vertical jump tests. All comparisons reflect within-subject differences across testing phases (Pre vs. Post).

Table 4. Wilcoxon Signed-Rank Test Results for Within Experimental Group Differences

Variable	Z	P	r
Height (m)	-2.21	0.027	0.59
TTPF (s)	-2.89	0.004	0.77
PF (N)	-3.30	0.001	0.88
AF (N)	-3.30	0.001	0.88

Note. Z=standardized test statistic; p=exact significance (2-tailed); r=effect size, calculated as Z/√N. Differences were considered statistically significant at p<0.05.

p=0.001, r=0.88), and average force (AF; Z=-3.30, p=0.001, r=0.88). These large effect sizes indicate that the aquatic training program had a substantial impact on both neuromuscular coordination and strength development, effectively enhancing explosive and maximal force capabilities in the participants.

Discussion

The aim of the study was to examine the effects of a 21-day aquatic training program on in-water vertical jump performance and neuromuscular parameters in competitive water polo athletes. The results demonstrated significant within-group improvements in all measured variables: jump height (H), time to peak force (TTPF), peak force (PF), and average force (AF), with large effect sizes. This indicates that even a short-term, water based intervention can trigger meaningful neuromuscular adaptations in competitive athletes.

Such outcomes highlight the value of biomechanically relevant training stimuli tailored to the aquatic environment, aligning with prior literature that emphasizes specificity and contextual relevance in conditioning programs (Botonis et al., 2018; de Villareal et al., 2015). Our observed increase in jump height (from 0.24 m to 0.29 m; M=0.05 m, or +20.8%) aligns with the findings of de Villarreal et al. (2014), who reported significant CMJ improvements (2.6 cm; +7.6%) in their in-water strength group (WSG) following a six-week training period. Although their intervention was longer in duration, our aquatic-only protocol yielded comparable or superior relative gains, particularly in PF and H, reinforcing the efficacy of water-based strength training conducted independently of dry-land components. In contrast, Heywood et al. (2022), in their systematic review, noted that several studies employing aquatic-only plyometric interventions reported more modest performance gains, likely due to lower training intensity, shorter protocol durations, or suboptimal specificity. Our findings contrast with these limitations, likely because our protocol emphasized high-effort, game-relevant movements such as resistance vertical thrust and asymmetrical loads, enhancing both neuromuscular activation and specificity.

Water-based propulsion requires distinct neuromuscular coordination strategies compared to dry-land movements due to water resistance and buoyancy forces (Sanders, 1999; Stirn et al., 2014). The significant decrease in TTPF suggests improved neuromuscular efficiency, a critical factor in the rapid execution of explosive actions in water polo, such as shot blocking or aerial ball contests (Perazzetti et al., 2023).

Mechanistically, early-phase neuromuscular adaptations likely underpin the observed performance improvements. These include enhanced motor unit synchronization, increased recruitment of high-threshold units, and better intermuscular coordination, as supported by prior findings (Aagaard et al., 2022; Bobbert & van Ingen Schenau, 1988). Moreover, the repeated exposure to resisted aquatic movement patterns may promote a faster rate of force development and proprioceptive refinement, crucial aspects for vertical elevation under unstable water dynamics. A comprehensive understanding of aquatic sport-specific motor actions requires the examination of the entire integrated psycho–neuro–motor continuum ranging from cortical command initiation to peripheral muscular execution and the reciprocal feedback mechanisms involved in movement regulation and neuromuscular adaptation (Geantă & de Hillerin, 2023). This integrated framework highlights the importance of assessing not only mechanical outputs but also the neuromotor coordination strategies that underpin explosive actions in water polo and potentially other aquatic sports.

The consistent within-group gains in strength metrics observed in this study suggest positive neuromuscular adaptations, consistent with early-phase training responses described in the literature (Aagaard et al., 2002; Bobbert & van Ingen Schenau, 1988). It is also worth noting that improvements in coordination and speed of force development may precede increases in absolute strength, particularly in aquatic contexts where technical execution plays a dominant role.

A methodological strength of the study lies in the use of portable, field-based technologies namely the EasyForce Dynamometer and Xbox Kinect which enabled ecologically valid testing in sport-specific settings. Prior validation studies (Bonnechère et al., 2014; Gray et al., 2017; Karl et al., 2024; Pfister et al., 2014) support the reliability and applied value of these tools in sport science. Importantly, all performance assessments and training were conducted exclusively in the aquatic environment, enhancing transferability to actual competitive contexts. To the best of our knowledge, this is the first investigation conducted in Romania involving competitive water polo players and employing such portable neuromuscular assessment technologies representing a novel methodological contribution to the national context of aquatic performance research. This study's strengths also include the ecological validity of the intervention, the use of sport-specific movements, and the deployment of accessible measurement tools. Limitations include the absence of a control group, small sample size, and lack of biomechanical markers such as electromyography.

From an applied standpoint, the intervention demonstrates high practical scalability, requiring minimal equipment and allowing for seamless integration into existing training framework. The training components including asymmetrical loading, maximal elevation overload, and active rest alternation, proved effective in eliciting targeted neuromuscular adaptations aligned with the physiological and tactical demands of competitive water polo. This make the protocol particularly useful in settings where dry-land training may be limited or contraindicated (e.g. injury, rehabilitation, or in-season management). The approach has attracted institutional interest, with formal discussions in progress to incorporate the findings into national performance monitoring protocols under the guidance of the Romanian Water Polo Federation. This highlights the translational value of the research and its relevance in shaping evidence-based, sport-specific conditioning strategies.

Future studies should incorporate longer intervention periods, female athletes, and transfer assessments to in-game performance. Despite these limitations, the 21-day aquatic program proved scalable and effective, with strong translational relevance. Our results align with recent systematic reviews confirming the utility of aquatic plyometric in enhancing strength, power, and jump ability (Heywood et al., 2022; Ramirez-Campillo et al., 2022).

Conclusion

The 21-day aquatic training intervention led to significant improvements in vertical jump height and neuromuscular performance in competitive water polo athletes. These findings highlight the effectiveness of targeted, sport-specific training conducted in water and support the integration of aquatic-based strength and power exercises in elite water polo preparation. The use of portable and accessible tools highlights the feasibility of monitoring performance in real-world, sport-specific environments.

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Conflict of Interest
The authors declare no conflict of interest related to this study. The research was conducted independently, and no financial or personal relationships influenced the design, execution, or reporting of the findings.

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