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The purpose of this study was to examine the effects of high volume aquatic-based plyometrics versus lower volume land and aquatic plyometric training on vertical jump (VJ), muscular peak power, and torque in the dominant knee. Thirty-nine adult participants were randomly assigned to 1 of 4 groups: aquatic group 1 (APT1), aquatic group 2 (APT2), land group (LPT1), and control group (CON). All groups performed a 6-week plyometric training program. The APT1 and LPT performed the same volume of training where APT2 doubled the volume. All participants were pre- and posttested on performance variables. A 4 (group) × 2 (time) ANOVA with repeated measures was used to determine differences between the performance variables. We found no significant differences between groups for all tested variables; however, APT2 showed the greatest increased average in the performance variables. The high volume aquatic plyometric protocol is useful to help increase performance and minimize muscle soreness.

Plyometrics are a form of physical conditioning that gained popularity in the early 1970s as athletes from the Eastern European countries began to dominate power-dependent events (Stemm & Jacobson, 2007). Due to the success that was experienced by these European athletes, plyometric training programs became more widely used. Plyometrics are now used in all types of sports and by different levels of athletes to increase strength and explosiveness.

Plyometrics are characterized into phases, beginning with an intense eccentric contraction of a muscle, an amortization phase, and followed immediately by a rapid concentric contraction (Baechle & Earle, 2000; Chu, 1998; Robinson, Devor, Merrick, & Buckworth, 2004). When a muscle is stretched, it stores elastic energy for a brief period of time. It is this stored elastic energy within the muscle that is used to assist the concentric contraction to produce more force than can be provided by simply performing a concentric action (Miller, Berry, Bullard, & Gilders,

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2002). During the amortization phase, Type Ia afferent nerves synapse with the alpha motor neurons in the ventral root of the spinal cord. The alpha motor neurons then transmit signals to the agonist muscle group (Baechle & Earle, 2000). The amortization phase is the most important phase in plyometric activity and is crucial in developing power production.

Research has shown that athletes who use land-based plyometric exercises are better able to increase acceleration and power than more traditional strength training (LaChance, 1995; Leubbers et al., 2003; Miller et al., 2002; Potteiger et al., 1999) and can contribute to improvements in vertical jump (VJ), leg strength, increased joint awareness, and overall proprioception (Fatouros et al., 2000; Martel, Harmer, Logan, & Parker, 2005; Miller et al., 2002; Myer, Ford, Brent & Hewett, 2006; Robinson et al., 2004). Land-based plyometric exercises are high intensity by nature, however, and may lead to muscle soreness and injury. The forces of impact can be potentially damaging to muscles and joints, which could lead to overuse injuries. The performance of plyometric training, specifically the eccentric phase, may also cause delayed onset muscle soreness (DOMS), which is generally experienced by individuals between 24–72 hr after normal to hard exercise (Baechle & Earle, 2000).

Aquatic-based plyometric training, while not a new concept, has become more popular within the last decade (Martel et al., 2005; Miller et al., 2002; Miller, Berry, Gilders, & Bullard, 2001; Miller, Cheatham, Porter, Ricard, Hennigar, & Berry, 2007; Robinson et al., 2004; Shaffer 2007; Stemm & Jacobson; 2007). Aquatic-based plyometrics have the potential to decrease impact forces as compared with land-based plyometric training. The decrease in distributed impact force is largely due to the properties of water in relation to fluid density and buoyancy (Miller et al., 2002). Water is approximately 800 times denser than air and provides buoyancy and resistance to movement (Dale, 2007; Pohl & McNaughton, 2003). Due to the principles of buoyancy, water acts as a counterforce to gravity, providing support for the athlete's body as it moves downward while resisting movement in the upward motion (Miller et al., 2001). Therefore, water buoyancy reduces forces on the musculoskeletal system during impact thereby decreasing the risk of injuries such as tendonitis, stress fractures, and other overuse injuries (Irvin & Johnson, 2000). Conversely, the resistance caused by the viscosity and drag increases the workload of muscles during the concentric phase, resulting in the potential for greater strength gains (Housle, 2006).

High volumes of plyometrics are discouraged due to the stress placed on joints and muscles (Chu, 1998; Miyama & Nosaka, 2004); however, the buoyant properties of the aquatic environment may limit overload stresses and allow for greater gains in strength and performance while potentially decreasing muscle soreness. Performing aquatic-based plyometrics in waist deep water lessens the load of impact, because approximately 50–54% percent of the body weight is supported due to buoyancy (Housle 2006). With the body being supported, the athlete can theoretically perform a higher volume of training in the water without applying significant stresses on the musculoskeletal system and potentially increase performance and explosiveness.

The purpose of this study was to examine the effects of high volume aquatic-based plyometrics on VJ, muscular peak power, and torque. We hypothesized that all training groups would have increases in the performance variables; however, the high volume aquatic-based plyometric training would demonstrate increased performance measures in comparison with the traditional water or land groups.

Method

Participants

Forty-seven healthy individuals started the training, but only 39 ($n = 39$) completed the protocol due to noncompliancy issues and injuries that occurred outside of the training protocol (16 males: age 21.8 ± 2.3, height 181.9 ± 6.9cm, weight 80.7 ± 9.2kg; 23 females: age 22.4 ± 3.5, height 166.5 ± 5.8cm, weight 65.7 ± 10.0kg). All participants were untrained individuals, meaning inexperienced or not involved in any form of organized physical fitness. Participants were from the institution where the study was conducted and were free of lower leg injuries for a period of at least one month before the start of the study. All participants were at least 18 years of age and provided their own informed consent.

The participants were randomly assigned to 1 of 4 groups before the data collection process: aquatic group 1 (APT1, 10 participants), aquatic group 2 (APT2, 11 participants), land group (LPT1, 8 participants), and control group (CON, 10 participants). Before participants agreed to participate in the study, they attended an informational meeting regarding the training. Participants who were interested signed an institutional approved informed consent and went through a health screening. Participants were instructed not to change their current exercise habits for the duration of the research study.

Instrumentation and Measurements

Data to determine VJ height, muscular peak power, and torque values were collected for all participants before and at the conclusion of the training program. For the purpose of the study, VJ height was defined as the difference between standing reach height and the maximal jump height and was measured to the nearest 1.28cm. Initial reach height was determined by having the subject stand with feet flat and positioned directly below the Vertec (Sports Imports, Columbus, OH). Each individual was then instructed to reach as high as possible with their dominant arm and hit the highest rung possible on the Vertec. The Vertec was adjusted to accommodate for height and potential jumping ability.

Proper jump technique consisted of a counter-movement jump (CMJ) where only an arm swing was allowed. No rocker steps were permitted. Three total jumps were performed by each participant with a 1-min recovery period between jumps. To insure reliability, each test participant was pre- and posttest measured by the same investigator. An instructional session was given immediately before the baseline testing process.

The peak power and torque testing was performed on a KinCom isokinetic dynamometer (Chattanooga Group, Inc., Hixon TN). Participants were required to use their dominant knee for the testing procedures, which was the leg they would use to kick a ball. Concentric peak torque was measured in the dominant knee of all subjects during knee extension and flexion at 60 deg/s by the same investigator before and after the study. The subjects were seated on the KinCom in a comfortable position with the hip and knee flexed to 90 degrees. The knee was aligned with the axis of rotation of the dynamometer. The load cell was aligned with the lateral malleolus. All participants were securely strapped to the seat using chest, lap, and leg belts. Each participant then performed a familiarization test where they performed 1 set of knee extension and flexion. Following a 2-min rest period each subject performed 3 separate sets of 1 knee extension and flexion at maximal effort. Each set was separated by 2-min of rest. Peak torque values were determined to be the highest values recorded by each participant in extension and flexion.

Plyometric Training Program

The study adopted a 6-week plyometric training program that had been used in previous studies (Chimera, Swanik, Swanik, & Straub, 2004; Martel et al., 2005; Miller et al., 2007; Table 1). When developing the protocol, Piper and Erdmann (1998) and Miller et al. (2001) recommended a gradual approach to aquatic plyometric training. The training program began with low volume plyometric drills and progressively increased in volume and intensity until the completion of the study.

Table 1 6-Week Plyometric Training Program Protocol Developed by Miller and Colleagues

Training Week	Training Volume	Plyometric Drill	Sets × Repetitions	Training Intensity
Week 1	90	Side to side ankle hops	2 × 15	Low
		Standing jump and reach	2 × 15	Low
		Front cone hops	6 × 5	Low
Week 2	120	Side to side ankle hops	2 × 15	Low
		Standing long jump	2 × 15	Low
		Lateral jump over barrier	6 ×5	Medium
		Double leg hops	10 × 3	Medium
Week 3	120	Side to side ankle hops	2 × 12	Low
		Standing long jump	2 ×12	Low
		Lateral jump over barrier	6 × 4	Medium
		Double leg hops	8 × 3	Medium
		Lateral cone hops	2 × 12	Medium
Week 4	140	Single leg bounding	2 × 12	High
		Standing long jump	3 × 10	Low
		Lateral jump over barrier	8 ×4	Medium
		Lateral cone hops	3 × 10	Medium
		Tuck jump with knees up	4 × 6	Medium
Week 5	140	Single leg bounding	2 × 10	High
		Jump to box	2 × 10	Low
		Double leg hops	6 × 3	Medium
		Lateral cone hops	2 × 12	Medium
		Tuck jump with knees up	6 × 5	High
		Lateral jump over barrier	3 × 10	High
Week 6	120	Jump to box	2 × 10	Low
		Depth jump to prescribed height	4 × 5	Medium
		Double leg hops	6 × 3	Medium
		Lateral cone hops	2 × 10	Medium
		Tuck jump with knees up	4 × 5	High
		Lateral jump single leg	2 × 10	High

The plyometric training program was conducted two times per week on Tuesday and Friday mornings. The groups were divided into separate training sessions on the same day to accommodate for appropriate supervision and time constraints for the participants. Participants were supervised and instructed by the research investigators during each training session. The participants were requested to provide maximal effort for each session throughout the 6-week period.

The APT2 group doubled the same protocol that was performed by the participants in the other plyometric training groups. All aquatic plyometrics were performed in the same pool which had a depth of 106.7cm and a maintained water temperature of 30–31 °C. Due to space restrictions, the LPT group performed the original protocol on a hardwood gym floor. Although firm surfaces are not recommended for plyometric training (Miyama & Nosaka 2004), there were no alternative testing sites with appropriate flooring.

Plyometric platforms were used by all training groups during the program for certain exercises. Participants were instructed to jump onto, over, or off of the platforms as designated for specific exercises. These platforms were submersible and designed for water usage, but could also be used on land (Figure 1). The platforms measured 14cm in height, with each additional lift measuring 4.5cm (Figure 2). The base height at week 1 was 18.5cm. Every 2 weeks another lift was added to increase the height until a final height of 27.5cm was reached. Submersible cones were also used in the study, which were 23cm in height, and were used by asking the participants to jump over the cones.

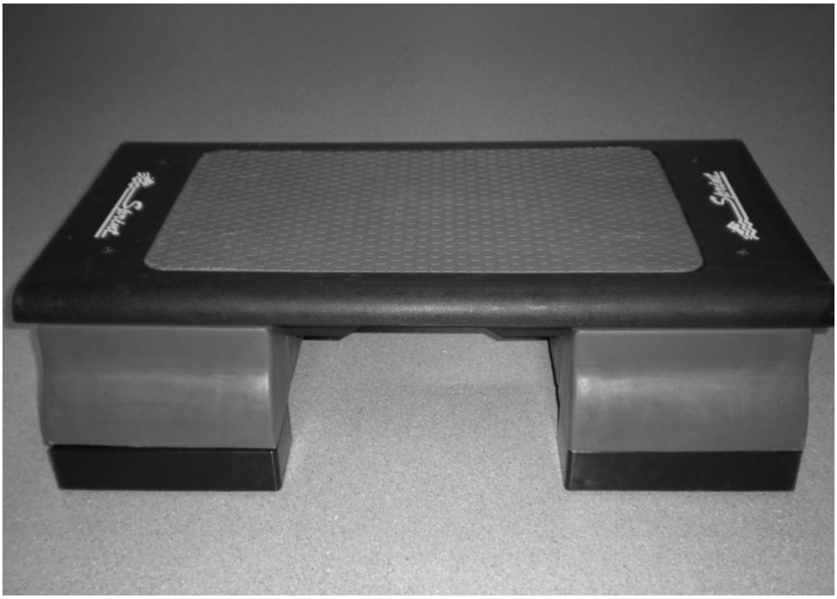

Figure 1 — Aquatic plyometric box with lift attached (18.5cm).

Figure 2 — Aquatic plyometric box (14cm) with lift (4.5cm) shown on the left.

Statistical Analysis

We used 4 (group) × 2 (time) factorial analyses of variance (ANOVA) with repeated measures on the last factor to examine changes in the dependent variables of VJ, peak power, and torque in the dominant knee. Means and standard deviations (± SDs) with a confidence interval (CI) of 95% were calculated for each group with each of the associated dependent variables. The α was set a priori at ≤ 0.05 for all tests. Data were analyzed with the Statistical Package for the Social Sciences for analysis (SPSS Version 15.0, SPSS Inc., Chicago, IL).

Results

Means and standard deviations for the VJ, power, and torque are shown in Tables 2–4. The repeated-measures ANOVA found no group × time interaction in VJ, $F(3, 35) = 1.637$, $p = 0.198$; no main effect for group, $F(3, 35) = 0.559$, $p = 0.645$; no main effect for time, $F(3, 35) = 1.552$, $p = 0.221$. Peak knee extension power resulted in no group × time interaction, $F(3, 35) = 0.109$, $p = 0.954$; no main effect for group, $F(3, 35) = 0.601$, $p = 0.619$; no main effect for time, $F(3, 35) = 0.136$, $p = 0.714$. Peak knee flexion power resulted in no group × time interaction, $F = 1.449$, $p = 0.245$; no main effect for group, $F(3, 35) = 0.256$, $p = 0.857$; no main effect for time, $F(3, 35) = 3.572$, $p = 0.067$. Peak knee extension torque resulted in no group × time interaction, $F(3, 35) = 0.453$, $p = 0.717$; no main effect for group, $F(3, 35) = 0.382$, $p = 0.766$; no main effect for time, $F(3, 35) = 0.019$, $p = 0.890$. Peak knee flexion torque resulted in no group × time interaction, $F(3, 35) = 0.225$, $p = 0.878$; no main effect for group, $F(3, 35) = 0.140$, $p = 0.935$; no main effect for time, $F(3, 35) = 0.002$, $p = 0.966$.

Table 2 Average Vertical Jump, M ± SD (cm)

Groups	Pretest	Posttest
APT1	45.7 ± 11.3	46.0 ± 12.8
APT2	41.8 ± 9.8	43.1 ± 7.1
LPT	49.4 ± 13.2	48.1 ± 13.9
CON	43.9 ± 9.2	46.5 ± 8.5

Table 3 Average Power, (Watts), M ± SD

Groups	Pretest Flexion	Posttest Flexion	Pretest Extension	Posttest Extension
APT1	61.4 ± 24.0	59.3 ± 25.6	126.1 ± 39.4	123.9 ± 42.2
APT2	55.0 ± 20.0	69.8 ± 37.8	119.0 ± 34.8	120.2 ± 35.4
LPT	55.8 ± 15.3	60.1 ± 19.0	130.6 ± 24.4	129.6 ± 24.2
CON	50.8 ± 25.4	56.8 ± 24.4	109.3 ± 43.9	107.9 ± 40.9

Table 4 Average Torque Values (ft·lbs), M ± SD

Groups	Pretest Flexion	Posttest Flexion	Pretest Extension	Posttest Extension
APT1	66.9 ± 21.9	68.1 ± 26.5	119.4 ± 37.7	117.1 ± 39.9
APT2	75.4 ± 31.5	73.5 ± 33.0	115.0 ± 37.2	118.2 ± 37.6
LPT	71.3 ± 21.0	69.2 ± 20.4	123.5 ± 24.2	124.0 ± 24.3
CON	67.0 ± 30.5	70.2 ± 30.9	107.2 ± 46.2	104.6 ± 41.2

Discussion

Our study was performed to determine whether there were differences in VJ height, muscular peak power, and torque in the dominant knee when comparing high volume aquatic-based plyometric training to lower volume aquatic and land-based training. At the conclusion of the 6-week training programs, we found no significant differences between groups for any tested variables. Contrary to our hypotheses, our data showed no differences from pre- to posttesting when evaluating VJ for all groups tested. The recorded differences of approximately 1.5 cm were simply too small compared with the observed variability. Strangely, of all the groups, the CON group recorded the greatest descriptive increase in VJ at 2.6 cm, while the LPT actually recorded a slight descriptive decrease. The minimal differences in vertical jump in relation to group variability may have occurred for various reasons such as training duration, use of untrained individuals, and time of day the training took place. Because even the land-based training failed to show any differences suggests that the intensities, time, and duration were likely the primary reasons for the failure to observe any effects from plyometric training.

Our results also showed no significant changes in regard to muscle power and torque. Recent studies have investigated power and torque values during aquatic-based plyometric training. Martel et al. (2005) measured torque values and found significant gains after 6 weeks of training in both flexion and extension at 60 deg/s and 180 deg/s. Miller et al. (2002) measured muscle and found significant gains from pre- to posttesting after 8 weeks of training. In addition, Robinson et al. (2004) found significant gains in both power and torque values using isokinetic strength testing after 8 weeks of training. The results from our study demonstrated no significant improvements despite using the same or similar parameters in the testing and training procedures, which was indeed perplexing.

During the pretesting process, it was noted that some participants would have benefited from more than one familiarization session with the KinCom dynamometer, where participants could practice maximal effort in flexion and extension. Previous research used a minimum of two instructional or familiarization sessions to accustom the participants to the testing procedures thus allowing them to become acquainted with the equipment that would be used (Miller et al., 2007; Robinson et al., 2004; Shaffer, 2007). Future studies should make an effort to have an extra familiarization session to accustom the subjects to the procedures of the protocol.

Plyometric activity by nature is a high intensity and high impact exercise. Researchers using this form of activity should be aware of the effects of impact on muscles, specifically delayed onset muscle soreness. Previous studies reported differences between land-based and aquatic-based plyometric training with aquatic groups reporting significantly less muscle soreness (Martel et al., 2005; Miller et al., 2002; Robinson et al., 2004; Shaffer 2007). Robinson et al. (2004) showed muscle soreness increases in the land-based group in compared with aquatic groups at 0, 48, and 96 hr after protocol intensity increases. Although we did not purposely measure muscle soreness as a variable, informal observations for multiple subjects using the visual analog scale (VAS) were collected every 72 hr to fall within the time frames of Robinson et al. (2004). The most notable difference in muscle soreness occurred in the first week of training. The land-based plyometric group reported a VAS average of 3.1, where the APT groups were 1.2 (APT1) and 2.4 (APT2), respectively. Differences after the first week of the study were very minimal and statistically insignificant thus were not recorded in our study.

Our inconsistent results may have occurred for various reasons. One suggestion could be proper training duration. There have been recent studies that have investigated the concept of training duration, comparing land-based training against aquatic-based training (Martel, et al., 2005; Miller et al., 2002; Robinson et al., 2004). The studies focused on peak torque values, speed, agility, muscle soreness, muscle strength, and VJ. These studies were conducted over an 8–12 week training period where increases in force and power were found (Fatouros et al., 2000; Luebbers et al., 2003; Miller et al., 2002; Robinson et al., 2004). Another study performed by Martel et al. (2005) presented significant increases in VJ after the 6-week time frame while using trained and conditioned high school volleyball players. In addition, Miller et al. (2007) also reported significant gains in VJ after 6 weeks of training while comparing land and aquatic groups. A recent study by Stemm and Jacobson (2007) that resulted in no significant differences in VJ, however, compared aquatic and land-based training sessions for the 6-week time frame. Research has shown inconsistent results and a longer time frame in the current study may have produced significant results. We were forced to perform our study in 6 weeks due to the academic calendar of the university and availability of our participants.

Another possibility for the inconsistent results could have been our use of untrained individuals. Due to the volume of participants needed, we were unable to recruit trained individuals. Martel et al. (2005) used trained subjects and found that trained individuals can potentially bring about greater gains with less within group variability. These findings may have been due to intrinsic motivation and the need to improve physical condition and athletic ability. Fatouros et al. (2000) used untrained participants and found significant results in regard to VJ and explosive performance when using plyometric land-based training combined with Olympic-style weight lifting exercises. Robinson et al. (2004) used participants who were exercising regularly (≥ 30 min, ≥ 3 days per week) for at least 6 months and also involved in sports, and found that the aquatic-based plyometrics provided the same performance enhancement benefits as land-based plyometrics with significantly less muscle soreness. Based on the previous research, both trained and untrained individuals have shown significant recorded results in various tested variables, but these results have been found with land training only. Future studies should compare the performance and motivation of trained versus untrained subjects in an attempt to determine which groups will record greater increases in a variety of variables including VJ and peak power and torque in the aquatic setting.

Another factor that may have contributed to a lack of significant differences between groups may have been the time of the training. Our study was performed in the morning due to availability of participants. Cappaert (1999) suggested that performance of short-term, high-intensity exercise should be scheduled in the afternoon to reach maximum performance results. When exercising in the afternoon, blood flow and body temperature are higher because the body has had time to warm up naturally throughout the day (Cappaert, 1999). Participants in our study were unable to participate in afternoon sessions due to scheduling conflicts.

Even though the high volume aquatic training program did not produce statistically significant increases in performance variables, plyometrics can still be a beneficial method of training. The aquatic environment is ideal for plyometric training as forces on muscles and joints are minimized while the body still receives the benefits of land-based plyometric training. The training protocol was successful in increasing performance variables; however, more research should be conducted to determine the optimal training duration, intensity, and time of day.

Conclusion

The results of the current study showed no significant improvements over the course of the 6-week plyometric training program, although all groups presented minimal increases in performance. High volume aquatic plyometrics can be used by health care professionals to help increase performance while minimizing muscle soreness. The aquatic setting provides an excellent training medium for enhancing performance due to the buoyant properties of water. High volumes of plyometric training should increase athletic performance. Due to the physical stress placed on the body, however, the optimal duration of an aquatic plyometric program along with the progression of intensity should be investigated further.

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