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Purpose: The purpose of the study was to compare effects of chest- and waist-deep-water aquatic plyometrics on average force, power, and vertical jump. ***Methods:*** Twenty-nine male and female participants were assigned to either a control group or 1 of 2 aquatic groups (waist deep and chest deep) and participated in a 6-wk, twice-per-wk plyometric-training program. Average force and power were measured on a force plate using 3 jumps: squat, countermovement, and drop jump. Vertical-jump heights were also recorded. A repeated-measures ANOVA was used to determine significant differences between testing and groups on average force, power, and vertical jump. ***Results:*** No significant differences were found with average force and power with the squat, countermovement, and vertical jumps. There were significant changes in drop-jump average in the control group from the pretest to posttest. ***Conclusions:*** With the water depths chosen and held constant, there appears to be no increased benefit in performance variables.

Key Words: performance variables, jump training, water

Plyometrics is considered a high-intensity conditioning program. It consists of explosive exercises that require muscles to adapt rapidly from eccentric to concentric contractions (Baechle, 1994; Chu, 1992; Holcomb, Kleiner, & Chu, 1998; Lundin & Berg, 1991; Martel, Harmer, Logan, & Parker, 2005; Potteiger et al., 1999; Robinson, Devor, Merrick, & Buckworth, 2004). Muscles, when stretched during an eccentric contraction, store elastic energy for a very brief period of time. The energy stored, followed quickly by a concentric contraction, produces greater force than a concentric contraction alone. Therefore, training muscles to adapt from an eccentric to a concentric contraction should enable them to increase the speed and force with which they perform.

Research has shown that athletes who use plyometric exercises are better able to increase acceleration, vertical-jump height, leg strength, joint awareness, and overall

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proprioception (Fatouros et al., 2000; Gehri, Ricard, Kleiner, & Kirkendall, 1998; Jensen & Ebben, 2003; Lundin & Berg, 1991; Martel et al., 2005; Miller, Berry, Bullard, & Gilders, 2002; Robinson et al., 2004; Vossen, Kramer, Burke, & Vossen, 2000). Plyometric programs have also been correlated to musculoskeletal injuries and delayed-onset muscle soreness because of the high-intensity and compression forces on the joints and muscles (Holcomb et al., 1998; Lees & Graham-Smith, 1996; Lundin & Berg; Miller et al., 2002; Radcliffe & Osternig, 1995).

Aquatic plyometric training is not a new concept, but it has recently become more popular, mostly because of the potential to decrease injuries compared with land plyometric contractions by decreasing impact forces on the joints (Miller et al., 2002; Robinson et al., 2004). Aquatic settings are beneficial not only for rehabilitation but also for conditioning because of the unique properties of water, specifically, buoyancy and resistance resulting from its viscosity (Gehlsen, Grigsby, & Winant, 1984; Miller et al., 2002; Prins & Cutner, 1999; Tovin, Wolf, Greenfield, & Woodfin, 1994).

Buoyancy is the force that water applies in an upward direction against gravity. The buoyant force provided by water decreases the patient's weight in relation to the degree of submersion and decreases the amount of force and joint compression during landing (Gehlsen et al., 1984; Prins & Cutner, 1999; Tovin et al., 1994). The buoyant properties of water reduce forces on the musculoskeletal system, thereby decreasing the risk of overuse injuries such as tendinitis and stress fractures (Gehlsen et al.; Prins & Cutner; Tovin et al.). Patients in an aquatic setting are also more likely to be relaxed and have a higher threshold of pain and therefore can begin functional exercise sooner (Miller et al., 2002; Nelson & Bandy, 2004; Prins & Cutner; Sova, 1988; Yacenda, 1988).

Water also provides resistance to movement that is used in training and conditioning programs. The resistance is equal to the amount of force exerted by the patient and varies by the velocity or speed at which the exercise is performed (Gehlsen et al., 1984; Prins & Cutner, 1999; Tovin et al., 1994). This occurs because of the increased viscosity and density associated with the water environment.

Previous studies comparing land-based and aquatic plyometric programs have been completed in varying depths of water (Gehlsen et al., 1984; Gregory, 1986; Martel et al., 2005; Miller et al., 2002; Prins & Cutner, 1999; Robinson et al., 2004; Tovin et al., 1994). These studies have shown that both shallow-water and deep-water training have benefits depending on the type and goal of training; however, previous studies have not used a predefined water depth to perform aquatic plyometric programs. In addition, training in water too deep might inhibit the stretch reflex and negate plyometric-training benefits. The purpose of this study was to compare chest- and waist-deep-water aquatic plyometrics and their effects on vertical-jump height and average force and power using the squat jump, countermovement jump, and drop jump.

Method

Participants

Twenty-nine participants (15 men and 14 women, age 25.3 ± 7.1 years, height 174.9 ± 8.7 cm, weight 77.5 ± 14.2 kg) free of lower extremity musculoskeletal injuries volunteered to participate in this study. The participants ranged from sedentary to recreationally active individuals who agreed not to modify their current exercise programs, if any, throughout the study. Participants were assigned to one of three groups: control or chest-deep or waist-deep water. Because we could not vary the water depths in the two pools used, participants were placed in the corresponding pool based on how high on the body the water level reached (chest or waist). Participants from 5 ft 4 in. to 5 ft 6 in. were assigned to the chest-deep group, and participants from 5 ft 7 in. to 6 ft were placed in the waist-deep group. Participants who were shorter than 5 ft 4 in. or taller than 6 ft were placed in the control group. The participants received a verbal and written explanation of the study's procedures before signing an informed consent in accordance with the institution's human-subject institutional review board. After signing the written consent, participants completed a medical-screening form. Participants completed two instructional sessions before pretesting to familiarize themselves with the pre- and posttesting procedures.

Instrumentation

Average force and power were determined using a Kistler 9421 A11 force plate and a Kistler 9861A eight-channel amplifier (Kistler Instruments, Amherst, NY) interfaced to a Gateway computer (Gateway Inc., Irvine, CA). The force data were sampled at 1,000 Hz using a Keithley-Metrabyte (Keithley Instruments, Taunton, MA) KPCI-3107 16-bit analog-to-digital converter. Average force and power were calculated by having the participants perform three jumps on the force plate: a squat jump, a countermovement jump, and a drop jump.

Average force for each jump was computed by summing the vertical force from the start of each jump to takeoff and then dividing by the number of points (Komi & Bosco, 1978). The vertical-force curves were interpolated using a quintic spline (Woltring, 1985). The spline coefficients were then mathematically integrated to obtain vertical acceleration and vertical position. Power was then computed by multiplying vertical force by vertical velocity (Dowling & Vamos, 1993). In the squat jump, average power was computed by summing the power from the start of the jump to takeoff and dividing by the number of points. In the drop jump and countermovement jump, average power was computed by summing the power from the start of the concentric phase of the jump to takeoff and dividing by the number of points.

Pre- and Posttest Measurements

Before data collection participants engaged in a warm-up session consisting of 5 min of general lower extremity stretching and 5 min of submaximal stationary-bike riding at a pace set by each individual. Participants were tested on the following variables: vertical-jump height, average force, and power. Participants were tested on all variables before and after the plyometric program.

Vertical-jump height was determined using a Ver-Tec jumping system (Columbus, OH). To measure vertical-jump height, we had participants stand and reach as high as possible, and the height obtained was recorded based on the base reach height. Participants were then instructed to jump up as high as possible off both feet and swat the inch markers on the Ver-Tec system. The difference between the base reach height and the highest vertical jump was recorded. Participants performed three jumps with 2 min of rest time between jumps.

The squat jump was performed by squatting down, holding the isometric contraction of the quadriceps, followed by jumping straight up from the squatting position and landing on the plate with both feet simultaneously. The countermovement jump was performed starting from an upright standing position. When given the command to jump, participants squatted down, jumped straight up, landing back on the plate with both feet. To perform a drop jump, participants stepped off a box 15 cm in height onto the force plate with both feet landing simultaneously and then immediately performed a countermovement jump. Participants completed three trials of each jump on the force plate.

Within 2 days of the completion of the 6-week plyometric-training program, participants were posttested. Participants were verbally encouraged to perform all jumps at maximal effort for both pre- and posttesting measures.

Plyometric-Training Program

A 6-week plyometric-training program was developed that included twice-per-week training sessions (Chimera, Swanik, Swanik, & Straub, 2004; Martel et al., 2005; Vossen et al., 2000). The training program was based on the recommendations of intensity and volume from previous literature (Miller, Berry, Gilders, & Bullard, 2001; Piper & Erdmann, 1998). Training programs were identical in drills, sets, repetitions, and volume for both the chest- and waist-deep aquatic-training groups (Table 1). Training volume ranged from 90 foot contacts to 140 foot contacts per session, and the intensity of the exercises increased throughout the course of the training program. Participants were instructed to perform exercises to their maximal ability. Participants were given a brief description and demonstration of each exercise before completing each training session. All participants were supervised by the researchers and verbally encouraged to perform with maximal effort.

Statistical Analysis

Means and standard deviations were calculated for vertical jump, force, and power for each training group. A factorial repeated-measures ANOVA was used to examine significance between the independent variables of testing (pre- and post-) and groups (control and chest and waist deep) on the dependent variables of average force and power with the squat, countermovement, and drop jumps and vertical-jump height. Statistical significance was set a priori at $p < .05$. All statistical tests were calculated using the Statistical Package for the Social Sciences (SPSS) for Windows (version 11.0, Chicago).

Results

The means and standard deviations for average force, power, and vertical jump are provided in Tables 2–4. With respect to force, all groups showed a decrease from pre- to posttest except for the chest-deep group in the squat jump (+22.3 N), the control group in the countermovement jump (+25.4 N), and the chest-deep group in the drop jump (+48.1 N). With respect to power, all groups decreased pre- to

Table 1 Six-Week Plyometric-Training-Program Drills and Intensity

Training week	Training volume	Plyometric drill	Sets × Repetitions	Training intensity
1	90	Side-to-side ankle hops	2 × 15	low
		Standing jump-and-reach	2 × 15	low
		Front cone hops	6 × 5	low
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
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
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
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
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
		Single-leg lateral jump	2 × 10	high

posttest except for the chest-deep group in the squat jump (+38.6 W), the chest-deep group in the countermovement jump (+29.3 W), and the control group in the drop jump (+65.6 W). With respect to vertical-jump height, both the chest- (+1 cm) and waist-deep (+2.5 cm) groups increased slightly, whereas the control group decreased slightly (–2.1 cm). The factorial repeated-measures ANOVA revealed no significant differences among the three groups with respect to average force and power with the squat jump and countermovement jump and no significant difference between the groups with the vertical jump from pre- to posttesting. Significance between

Table 2 Average Vertical Force (N), *M* ± *SD*

Condition	Squat Jump		Countermovement		Drop Jump	
	Pretesting	Posttesting	Pretesting	Posttesting	Pretesting	Posttesting
Chest deep	1,111.4 ± 211.9	1,133.7 ± 228.9	1,231.1 ± 248.6	1,195.3 ± 311.9	1,332.7 ± 287.7	1,380.8 ± 323.0
Waist deep	1,239.0 ± 317.5	1,205.6 ± 317.2	1,265.8 ± 246.4	1,197.1 ± 222.3	1,512.4 ± 356.3	1,481.7 ± 337.9
Control	1,206.8 ± 188.1	1,142.1 ± 164.2	1,249.5 ± 253.9	1,274.9 ± 227.6	1,555.9 ± 286.1	1,427.7 ± 189.9

Table 3 Average Power (W), *M* ± *SD*

Condition	Squat Jump		Countermovement		Drop Jump	
	Pretesting	Posttesting	Pretesting	Posttesting	Pretesting	Posttesting
Chest deep	930.8 ± 260.5	969.4 ± 252.6	1,335.8 ± 580.5	1,365.1 ± 424.7	1,325.0 ± 841.4	1,304.6 ± 871.8
Waist deep	1,124.8 ± 493.2	1,034.3 ± 365.9	1,546.3 ± 576.6	1,450.8 ± 594.1	1,321.0 ± 706.2	1,113.4 ± 681.2
Control	1,257.6 ± 357.2	1,095.2 ± 304.3	1,844.8 ± 633.3	1,661.1 ± 462.1	1,239.0 ± 841.4	1,304.6 ± 871.7

Table 4 Average Peak Vertical-Jump Height (cm), *M* ± *SD*

Time	Chest deep	Waist deep	Control
Pretesting	40.9 ± 10.7	46.5 ± 13.2	54.9 ± 13.7
Posttesting	41.9 ± 7.4	49.0 ± 14.5	52.8 ± 12.4

the groups was found in average power with the drop jump, $F(2, 21) = 5.087$, $p = .016$, with the control group increasing power from pre- to post-testing.

Discussion

Our study was performed to determine whether there were differences in vertical-jump height, power, and force as a result of participating in an aquatic plyometric-training program in three different environments. We found that after 6 weeks of plyometric training in the aquatic environment, there were no significant differences in force production for the selected jumps. In addition, there were no significant differences in vertical-jump height for any of the three groups. What was interesting to note is that the chest-deep group had slight increases, although not significant, in force and power from pre- to posttest for two of the three plyometric jumps; however, the waist-deep group descriptively had slightly better vertical-jump heights than the chest-deep group, although these were not statistically significant differences and therefore need to be interpreted as being the same. Even the control group showed increases in force with the countermovement jump and power with the drop jump. This increase occurred despite the researchers' asking the control group to refrain from adding to or otherwise altering their current exercise regimen. The control group, however, might have increased their activity or training levels because of the changing seasonal weather (winter to spring) or personal training objectives over the course of the study. In addition, the variations in height, especially for participants over 6 ft tall, over the experimental groups might have contributed to the differences because of longer legs and lower extremity muscles, which have the potential to produce more force during jumping.

Previous studies that showed significant increases in force and power as a result of plyometric training had been conducted over an 8- to 12-week training period (Fatouros et al., 2000; Luebbers et al., 2003; Miller et al., 2002; Robinson et al., 2004). Still other studies showed that 6 weeks of plyometric training were effective in producing significant changes (Chimera et al., 2004; Martel et al., 2005; Vossen et al., 2000). Most of these studies found significant increases between groups, but for participants who also were strength training during the plyometric-training period (Chimera et al.; Martel et al.). Martel et al. found significant increases in vertical-jump performance during a 6-week training period, but their aquatic plyometric program was completed in conjunction with the team's regular preseason training. Participants in the current study were supposed to refrain from any strength-training regimen and were not participating in organized athletics, which decreased the overall volume of training and might explain the findings of no significant increases in vertical-jump height similar to what Martel et al. discovered.

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Previous research has also shown that for increases in vertical jump to be induced, the participants should perform depth jumps from heights ranging from 0.8 to 1.1 m (Holcomb et al., 1998; Lees & Graham-Smith, 1996; Lundin & Berg, 1991; Radcliffe & Osternig, 1995). Depth jumps are considered very high-intensity exercises that require appropriate training and careful progressions for safe completion of the program (Holcomb et al.; Lees & Graham-Smith; Lundin & Berg; Radcliffe & Osternig). Our participants performed depth jumps from 0.19 m, which is lower than the recommended range because our participants did not have previous plyometric-training experience. In addition, aquatic boxes used for the depth jumps in the pool are manufactured differently to be lower in height and prevent floating and slipping. The aquatic boxes are lower in height because of the difficulty of jumping onto subsequent boxes caused by the water's resistance.

Our plyometric program's intensity of was low based on using untrained participants in order to allow them to become familiarized with the type of exercises. As a result, the lower intensity might explain why we found only slight increases in the performance variables from pre- to posttesting. Other studies used participants with higher fitness levels (athletes) who therefore could sustain a higher intensity program (Chimera et al., 2004; Gehri et al., 1998; Jensen & Ebben, 2003; Luebbers et al., 2003; Potteiger et al., 1999; Stemm, 1993). Future studies should investigate using untrained versus trained participants in the aquatic setting while also using a 6- to 10-week plyometric program to determine which training period is more effective and to determine whether concurrent strength-training regimens of trained athletes promote better outcomes.

Plyometric training should follow the same guidelines as other weight-training programs and should only be performed two or three times per week (Lees & Graham-Smith, 1996). Aquatic plyometric programs, because of the buoyant and viscous properties of water, might need the number of sessions per week adjusted. Conducting plyometrics in an aquatic setting can decrease the speed of the stretch-shortening cycle of the lower extremity, especially at the knee, compared with land plyometrics, affecting the elastic-recoil properties of the muscles. The relationship between the stretch-shortening cycle performed on land and in the water has yet to be determined. The eccentric and concentric muscle actions of the lower extremity might be delayed in an aquatic setting because of the resistance of the water, which slows the overall movement. Further studies should examine whether there is a longer delay period from the initial lengthening of the muscle to the concentric contraction by videotaping participants performing plyometrics in water. Additional investigation should also examine the appropriate frequency and volume of training in the aquatic environment to determine what is most effective.

Most previous studies had at least 30 participants, which provided greater statistical power to identify meaningful differences that did occur (Fatouros et al., 2000; Gehri et al., 1998; Luebbers et al., 2003; Miller et al., 2002; Robinson et al., 2004). Our study began with 29 participants, but only 24 completed the study. In addition, several participants reported slight slipping while performing the aquatic plyometric exercises. Slipping during the movement can alter the mechanics of the movements and prevent the stretch-shortening cycle from working properly. Further research should investigate the use of aquatic footwear that might reduce the likelihood of slipping while performing plyometrics in the aquatic setting.

Conclusion

The present study demonstrated that after 6 weeks of plyometric training in an aquatic environment, there were only slight changes in force and power production in the chest-deep group and only slight, nonsignificant differences in vertical jump in the waist-deep group. In addition, aquatic plyometrics, because of the resistive and buoyant properties of water, might decrease forces on the joints compared with land plyometrics and limit the extent of joint and muscle injuries. The speed of movement is definitely slowed in the water. Finally, despite the lack of significant results associated with aquatic plyometrics, we still think that the aquatic setting can be a unique environment in which to motivate and train individuals and serve as a rehabilitative tool while patients are recuperating from injury or surgery.

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