Original Research

A Comparison of Aquatic- vs. Land-Based Plyometrics on Various Performance Variables

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ABSTRACT

International Journal of Exercise Science 8(2) : 134-144, 2015. The purpose of this study was to compare the effects of an aquatic- (W) and land-based (L) plyometric program on balance, vertical jump height, and isokinetic quadriceps and hamstring strength. Thirty-four participants were randomized into three groups, W (n = 12), L (n = 11), and control (n = 11). The W and L groups completed an eight-week plyometric program. A two-way repeated measures ANOVA revealed a significant main effect of condition (F = 346.95, $p < 0.001$) and interaction between condition by time (F = 1.88, $p = 0.01$). Paired samples t-tests revealed statistically significant improvements from pre- to post-testing in the L group for isokinetic quadriceps strength at 60 degrees per second ($p = 0.02$) and hamstring strength at 120 degrees per second ($p = 0.02$). Statistically significant improvements were observed from pre- to post-testing in the W group for balance ($p = 0.003$), vertical jump height ($p = 0.008$), isokinetic quadriceps strength at 60 and 120 degrees per second ($p \leq 0.001$), and hamstring strength at 120 degrees per second ($p = 0.03$). Results demonstrate that aquatic-based plyometric training can be a valid form of training by producing improvements in balance, force output, and isokinetic strength while concurrently decreasing ground impact forces.

KEY WORDS: Aquatic training, low impact exercise, balance, vertical jump, isokinetic strength, amortization phase

INTRODUCTION

Plyometric training enables a muscle to reach maximal force in the shortest time possible, therefore being a beneficial method of training for those activities that require explosive and powerful movements in a short duration of time. Plyometric exercise is defined as a quick, powerful movement using a prestretch, or countermovement, that incorporates the stretch-shortening cycle (SSC) (1). The SSC consists of three phases: eccentric, amortization, and concentric. The amortization phase, the time between the eccentric and concentric phases, is considered the time when the feet make contact with the ground and is also the most crucial phase in allowing for maximal force production (1). The duration of the amortization phase must be kept short, and if not, the energy that is stored during the eccentric phase will dissipate as heat, therefore not allowing the stretch reflex to increase muscle activity during the subsequent concentric phase (1). Research has demonstrated the beneficial effects of land-based plyometric training at improving many performance variables such as explosive strength, power, vertical jump height, etc. (9, 13, 14, 19).

Although plyometric training has been proven to have many performance related benefits it can also be associated with muscle soreness and chronic injuries such as tendonitis, as a result of repetitive, high ground impact forces (2, 5, 6, 11, 12, 20). Recent research has examined the effectiveness of an aquatic environment for plyometric training (2, 5, 12, 15, 20). More specifically, buoyancy has been associated with decreasing ground impact forces, placing less stress on the lower extremity musculature, and reducing the risk of chronic injuries (3, 5, 12, 18). While performing plyometrics in an aquatic environment the amount of forces transmitted throughout the body are reduced while concurrently the resistance of movement is increased, therefore decreasing ground impact forces while at the same time creating a strong enough stimulus to elicit physiological improvements (12).

Miller and colleagues (11, 13) conducted a six-week aquatic plyometric training program at various water depths, and their findings demonstrated no improvements in average force, power, and vertical jump height. Their plyometric training program consisted of meeting two times per week, 90-140 foot contacts, and the intensity of all exercises (side-to-side ankle hops, front cone hops, standing long jump, lateral jump over barrier, tuck jump, jump to box, etc.) increased throughout the course of the training program (11, 13). Miller and colleagues (11, 13) suggested that they did not observe improvements possibly due to the low training volume, which was enforced because their participants were untrained and were not familiar with plyometric training. In another study conducted by Colado and colleagues (2), when comparing squat jumps in both land and in water peak ground impact forces were lower while peak concentric forces were higher in the aquatic group, suggesting that an aquatic environment is favorable for enhancing vertical jump height without increasing ground impact forces. Colado and colleagues (2) recruited trained individuals with prior plyometric training experience, which allowed them to create a higher-intensity plyometric program (2).

Studies conducted by Miller and colleagues (14) and Robinson et al. (16) found equivocal findings within an aquatic-based plyometric group in performance variables such as power, torque, velocity, and decreased muscle soreness. The lack of significant results in Miller and colleague's study (14) was suggested to be due to the duration of the study (six-weeks). According to Baechle and Earle (1), eight-weeks is considered the low end of the spectrum when individuals begin to see physiological benefits from training. On the other hand, the significant improvements seen in Robinson et al. study (16) was suggested to be contributed to both the duration of the study (eight-weeks) and the high-intensity plyometric training program. These findings from Robinson et al. (16) are beneficial because they suggest that when performing aquatic plyometrics individuals can have improvements in performance variables while subsequently decreasing muscle soreness after participating in high-intensity plyometric training sessions, potentially decreasing recovery time from training sessions and also decreasing strain in the lower extremity musculature from ground impact forces.

An aquatic-based plyometric training program has demonstrated potential at improving performance variables (9, 13, 14, 19), but can also contribute to injury prevention by decreasing ground impact forces (16). Since previous studies have yielded equivocal findings (14, 16), it is necessary to investigate aquatic-based plyometrics in further detail. Therefore, the purpose of this study was to compare the effects of an aquatic- (W) and land-based (L) plyometric program on balance, vertical jump height, and isokinetic quadriceps and hamstring strength. It was hypothesized that the aquatic-based plyometric group (W) would have significant improvements in all performance variables when compared to the land-based plyometric (L) and control (C) groups.

METHODS

Participants

Thirty-four total, males (*n* = 21) and females (*n* =13), between the ages of 19-24 (22.5 ± 1.41), participated in this 10-week study that received approval by the Institutional Review Board from The University of Akron. Participants were recruited from Exercise Physiology classes at The University of Akron. Inclusion criteria consisted of no injuries to the lower-body (hips, knees, ankles, feet), no contraindications to exercise, and within the past three-months prior to the study participated in regular exercise as defined by the American College of Sports Medicine (ACSM) (10) that included cardiovascular and resistance training, and with the addition of lower-body plyometrics to ensure that all participants had some level of baseline fitness and would not be affected significantly by the effects of delayed-onset muscle soreness. Exclusion criteria consisted of orthopedic injuries to the lower-body and/or sprains or strains in the three-months preceding the study that would affect performance. Participants who were currently using performance-enhancing supplements such as creatine, caffeine (over 400 mg per day), steroids, ephedrine, etc. were ineligible to participate in this study. Participants were instructed to continue their normal daily activities outside the study and to refrain from any strenuous lower-body physical activity for at least one day prior to their training sessions. It was also advised that all participants maintain their current diet during the 10-weeks. Daily activities and diet were not monitored outside of the study. As the plyometric training program progressed participants who missed more than two sessions were excluded. Prior to participation in the study, participants were notified about the experimental procedures and any potential risks and benefits associated with the study, and signed an informed consent form that was approved by the Institutional Review Board of The University of Akron. Additionally, participants completed a Physical Activity Readiness Questionnaire (PAR-Q) and Godin Leisure Time Physical Activity Questionnaire (7) to gauge physical activity and fitness levels. Participants were then randomly assigned to either a control group (C) (*n* = 11) that only completed pre- and post-testing, land-based plyometric group (L) (*n* = 11) that took part in the eight-week land plyometric training program, or aquatic-based plyometric group (W) (*n* =

12) that took part in the eight-week aquatic plyometric training program.

Protocol

Weeks one and 10 consisted of pre- and post-testing, respectively, of the following performance variables: balance, vertical jump height, and isokinetic quadriceps and hamstring strength. Testing order, established by the National Strength and Conditioning Association (NSCA) was as follows: balance, vertical jump height, and isokinetic quadriceps and hamstring strength (1). During the assessment of balance on the Biodex Balance System (Biodex Medical Systems, Inc., Shirley, NY), each participant competed a single-leg balance test. Participants were instructed to balance on their dominant leg (shoes on) with eyes open, three times for 20-seconds each. After three-minutes of rest participants then completed a vertical jump test which was measured using a vertical jump device (Vertec, JUMPUSA, Sunnyvale, CA). Each participant performed three attempts while allowing for three-minutes of rest between each attempt. In order to establish a baseline reach, participants were instructed to stand and reach with their dominant arm and push forward the highest vane. Participants then performed a countermovement without a preparatory or stutter step, by flexing the knees and hips, moving the trunk forward and downward slightly, and swinging the arms backward simultaneously. During the jump, participants slapped the highest vane forward with their dominant hand at the peak of their jump. Measurements were taken from the highest vane moved. The best of three trials was recorded to the nearest 0.5 inch. Baseline reach was then subtracted from the highest vertical jump to obtain overall height difference. Once the third attempt was completed and after-three minutes of rest, participants' isokinetic quadriceps and hamstring strength was assessed via the Biodex Multi-Joint System (Biodex Medical Systems, Inc., Shirley, NY). Participants were given a familiarization trail where they flexed and extended their dominant knee as fast as possible for one set of five repetitions. Participants were then given a one-minute rest period. Following the rest period the same protocol was first done at 60 degrees per second and then at 120 degrees per second.

The C group met during weeks one and 10 to complete pre- and post-testing. Along with the pre- and post-testing sessions the L and W groups met two times per week to complete the 60-minute plyometric training program. The L group participants had the option to come during Monday/ Wednesday morning or Tuesday/Thursday afternoon. Participants in the W group had to be staggered throughout the day to only allow for one participant to be in the aquatic pool at a time. Participants were required to allow for at least 48-hours of rest between plyometric training sessions.

Participants first completed a five-minute warm-up on a treadmill (L group: land treadmill, W group: aquatic treadmill), in which the speed progressively increased from 4.0 MPH to 6.0 MPH (speed increased by 0.5 MPH increments every 60-seconds). Afterwards a three-minute rest period was implemented. Following the three-minute rest period the plyometric training was initiated (Table 1). Exercises were completed in the following order: depth jumps, squat jumps, calf pops, lunge jumps, knee tuck jumps, box jumps, single-leg (SL) squat jumps, and SL ski jumps. To the best

Table 1. Plyometric training program.

Week	Sets	Repetitions	Water Temperature (°F)
Two	1	10 (SL: 5 each; calf pops 20)	92°
Three	2	10 (SL: 5 each; calf pops 20)	100°
Four	2	12 (SL: 6 each; calf pops 22)	92°
Five	2	12 (SL: 6 each; calf pops 22)	104°
Six	3	12 (SL: 6 each; calf pops 22)	104°
		WV: 6lbs; MB 4lbs	
Seven	3	12 (SL: 6 each; calf pops 22)	95°
		WV: 9lbs; MB 6lbs	
Eight	3	15 (SL: 7 each; calf pops 24)	88°
		WV: 9lbs; MB 6lbs	
Nine	3	15 (SL: 7 each; calf pops 24)	90°
		WV: 9lbs; MB 6lbs	

SL: single leg, WV: weight vest, MB: medicine ball

of our knowledge this combination of exercises have not been used in previous aquatic plyometric training programs. According to the NSCA 80-100 touches should be completed at the beginning of a plyometric training program (1). Sets and repetitions increased progressively at weeks three and six to allow for a new training stimulus, prevent adaptation from occurring, and to decrease the potential for any injuries and/or muscle soreness from a training overload. During weeks six-nine a weight vest between 1.5 and 6 lbs was worn by the W group and a medicine ball (MB) between 1.5 to 6 lbs was used by the L group to increase the training stimulus and increase the intensity of the program. For the W group water height was between mid chest (nipple line) to waist (umbilicus) deep on all participants. Water temperature was between 26-28 degrees Celsius (79-82 degrees Fahrenheit) and this temperature is recommended for conductive heat dissipation (4).

Statistical Analysis

Pre-post test differences over time were analyzed using a two-way repeated measures ANOVA with Statistical Packages of the Social Sciences (SPSS) V.18.0 software

Table 2. Control group performance variables means and standard deviations.

Performance Variable	Mean	SD
Pre-Balance	2.97	1.71
Post-Balance	2.68	1.91
Pre-Vertical Jump	18.1 in	3.48
Post-Vertical Jump	19.7 in	4.34
Pre-Quad Strength at 60°/sec	119.85	12.99
Post-Quad Strength at 60°/sec	127.8	13.44
Pre-Ham Strength at 60°/sec	64.72	14.28
Post-Ham Strength at 60°/sec	70.63	19.6
Pre-Quad Strength at 120°/sec	82.44	14.41
Post-Quad Strength at 120°/sec	93.15	20.02
Pre-Ham Strength at 120°/sec	50.16	10.9
Post-Ham Strength at 120°/sec	57.4	11.32

(Chicago, IL). The aquatic- and land-based plyometric training programs were the independent variables. Dependent variables were balance, vertical jump height, and isokinetic quadriceps and hamstring strength at 60 and 120 degrees per second. Post-hoc paired samples t-test analysis, when appropriate, was performed to determine where differences between groups occurred. Statistical significance was set *a priori* at $p < 0.05$.

RESULTS

A two-way repeated measures ANOVA revealed a significant main effect of condition ($F = 346.95$, $p < 0.001$) and interaction between condition by time ($F = 1.88$, $p = 0.01$). Paired samples t-tests revealed a significant difference for the W group from pre- to post-testing for balance ($t = 3.90$, $p = 0.003$) (Figure 1), vertical jump height ($t = -3.42$, $p = 0.008$) (Figure 2), isokinetic quadriceps strength at 60 ($t = -4.59$, $p = 0.001$) and 120 ($t = -5.27$, $p \leq 0.001$) degrees per second, and hamstring strength at 120 degrees per second ($t = -2.556$, $p =$

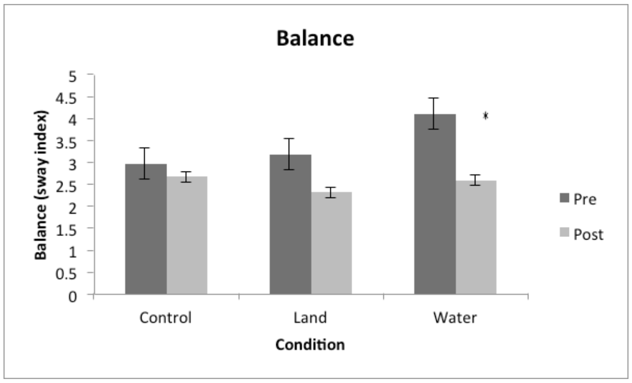

Figure 1. Statistically significant difference from pre- to post-testing in W group balance ($p = 0.003$).

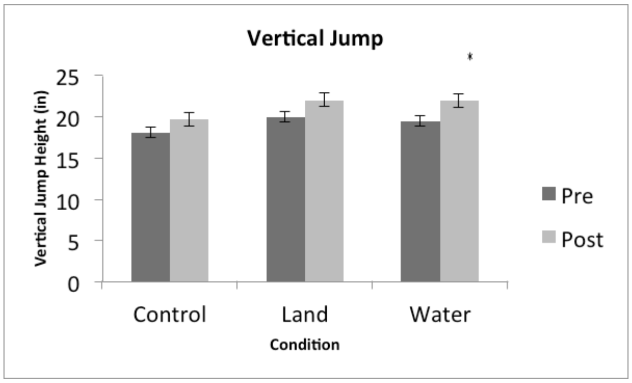

Figure 2. Statistically significant difference from pre- to post-testing in W group vertical jump height ($p = 0.008$).

0.03) (Figure 3). Also, paired samples *t*-tests revealed a significant difference for the L group from pre- to post-testing for isokinetic quadriceps strength at 60 degrees per second (t = -2.79, *p* = 0.02) and hamstring strength at 120 degrees per second (t = -2.72, *p* = 0.02) (Figure 3). Pre- to post-test means and standard deviations are provided in Tables 2, 3, and 4 for the C, L, and W groups, respectively.

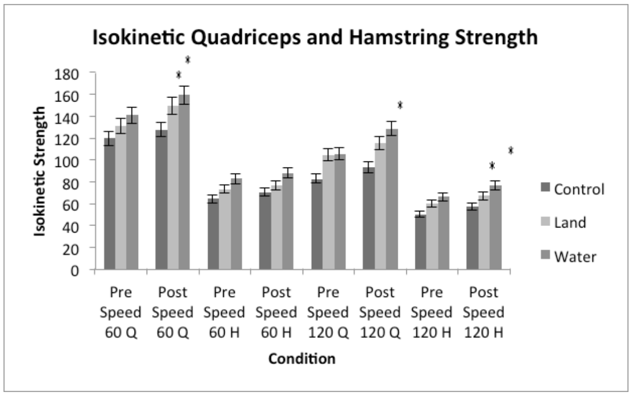

Figure 3. Statistically significant difference from pre- to post-testing in L group isokinetic quadriceps strength at 60°/sec (*p* = 0.02) and hamstring strength at 120°/sec (*p* = 0.02); and W group isokinetic quadriceps strength at 60 (*p* = 0.001) and 120°/sec ($p \leq 0.001$) and hamstring strength at 120°/sec (*p* = 0.03).

DISCUSSION

The purpose of this study was to compare the effects of an aquatic- (W) and land-based (L) plyometric program on balance, vertical jump height, and isokinetic quadriceps and hamstring strength. It was hypothesized that the W group would have significant improvements in all performance variables when compared to the L and C groups. Results of the current study revealed that the eight-week plyometric training program yielded significant results in the W group for balance, vertical jump height, isokinetic quadriceps strength at 60 and 120°/sec, and isokinetic hamstring strength at 120°/sec when compared to the L and C groups. These results are encouraging because it demonstrates that participants who engage in an eight-week aquatic plyometric training program can improve balance, force production, and isokinetic strength in the quadriceps and hamstrings while concurrently decreasing ground impact forces.

Improvements in balance may have been observed from pre- to post-testing because during plyometric exercises muscle spindles, which are proprioceptive organs, are stimulated at a greater rate than during traditional exercises. Proprioceptors, located in joints, tendons, and the inner ears, regulate posture and movement in response to stimuli (8). Performing plyometric exercises increases proprioception, which in turn improves postural stability and balance (1, 9). Furthermore, buoyant forces and lift are two properties of water that affect an individuals' balance when performing aquatic plyometrics. Buoyancy is the upward force exerted on a submerged object while lift is a resistance force that acts on a body in a fluid and tends to slow the body while it is moving through the fluid (8). So, as an individual is performing aquatic plyometrics that individual must overcome the disruptive forces that are created by buoyancy (upward force) and lift (force that slows a body moving through water). Like stated earlier, the amortization phase is considered the most important and must be completed quickly to increase force production during the subsequent concentric phase. However, while performing aquatic plyometrics an individuals' balance may be disrupted due to buoyant and lift forces that were

Table 3. Land group performance variables means and standard deviations.

Performance Variable	Mean	SD
Pre-Balance	3.18	2.55
Post-Balance	2.32	0.75
Pre-Vertical Jump	20 in	3.72
Post-Vertical Jump	22.04 in	4.85
Pre-Quad Strength at 60°/sec	130.75	42.3
Post-Quad Strength at 60°/sec *	149.39	50.81
Pre-Ham Strength at 60°/sec	72.82	24.97
Post-Ham Strength at 60°/sec	76.45	21.8
Pre-Quad Strength at 120°/sec	104.76	36
Post-Quad Strength at 120°/sec	115.14	40.17
Pre-Ham Strength at 120°/sec	60.25	21.38
Post-Ham Strength at 120°/sec*	67.25	21.85

* Significant difference from pre- to post-testing. Quad: quadriceps, Ham: hamstring

Table 4. Water group performance variables means and standard deviations.

Performance Variable	Mean	SD
Pre-Balance	4.12	1.77
Post-Balance *	2.59	0.94
Pre-Vertical Jump	19.5 in	4.52
Post-Vertical Jump *	21.95 in	5.56
Pre-Quad Strength at 60°/sec	141.02	33.19
Post-Quad Strength at 60°/sec *	159.36	39.84
Pre-Ham Strength at 60°/sec	83.04	23.03
Post-Ham Strength at 60°/sec	87.88	26.28
Pre-Quad Strength at 120°/sec	105.44	28.88
Post-Quad Strength at 120°/sec *	128.15	31.94
Pre-Ham Strength at 120°/sec	66.45	22.29
Post-Ham Strength at 120°/sec*	76.66	23.11

* Significant difference from pre- to post-testing. Quad: quadriceps, Ham: hamstring

mentioned earlier, therefore possibly causing a longer amortization phase. It is imperative for trainers to instruct individuals to focus on having a quick amortization phase while training in the water. Hewett and colleagues demonstrated no significant improvements in any of their performance variables such as balance after the completion of several neuromuscular-related interventions, which was attributed to the duration of the interventions being only 6-weeks in length, low intensity plyometric exercises that were performed, and the participants having previous orthopedic injuries (9). Unlike Hewett and colleagues study our improvements in balance may have possibly been attributed to our program design being eight-weeks in length which is suggested by Baechle and Earle (1) to be long enough to elicit physiological changes, our plyometric exercises progressively increasing in intensity, our participants having no prior orthopedic injuries, and possible improvements in proprioception from completing plyometric exercises in a more challenging environment (buoyancy and lift forces present).

Vertical jump height may have been improved from pre- to post-testing due to the specificity of the plyometric training program. Plyometrics are known to improve muscular force and power due to the elastic energy that is stored during the eccentric phase. When followed immediately by a concentric contraction the total force production is increased making for a more powerful and higher jump (1). Performing plyometrics in the water can be more beneficial at improving force production then on land because of the resistance that is provided by water (2). This resistance is equal to the amount of force exerted by the individual and varies according to the velocity and speed at which the exercise is performed (9). All plyometric exercises selected for this training program recruited both the quadriceps and hamstring muscles, therefore possibly explaining the improvements seen in isokinetic strength. Robinson et al. (16) found significant improvements in power, torque, and velocity and this was similar to our findings possibly due to the program length being eight-weeks in duration and a progressive increase in exercise intensity.

Due to the intense nature of most plyometric programs it is imperative that trainers follow proper safety precautions, use available research, and have sufficient practical experience before applying this type of training regimen with their athletes. The ultimate goal is to improve athletes' performance while decreasing the likelihood of injury. Specific attention must be directed towards the amortization phase when performing aquatic plyometrics. Balance may potentially be disrupted due to the buoyant forces and lift within a water environment, therefore elongating the amortization phase. If the amortization phase is long in duration force production will be lost, causing a subsequent decrease in force production during the concentric phase. However, if the amortization phase is kept short in duration, force production will be increased ultimately leading to an improvement in performance. Limitations of the current study include no familiarization period before initiation of the plyometric training program. The inclusion of a familiarization period may have allowed for participants to become accustomed to the exercises as well as the water environment. Also, the population chosen consisted of recreationally active participants. In the future, an athletic population would be desirable in order to see if this training stimulus has the same effect. Furthermore, in an ideal situation it would be desirable to control or limit outside training regiments, so that the results can be solely based off of this training protocol and possibly not some outside training stimulus. This current study demonstrates that with a periodized aquatic-based plyometric program athletes can maintain or even increase their performance over a traditional land-based plyometric program while decreasing ground impact forces and possibly their risk for injury. While this study yields novel and useful information, future research should observe what affect alternative plyometric exercises and training variables (sets, repetitions, rest intervals, intensity) has on other performance measures and how athletes respond to this form of training.

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