Comparison of Aquatic and Land Plyometric Training on

Strength, Power and Agility

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Research Report
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This research was funded in part by a Widener University Provost Grant
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The authors wish to thank Dr. Robert Wellmon, PhD, PT, NCS for his statistical expertise, Mr. Bob Piotti for his cooperation in the use of the pool, and the Widener University Grants and Awards Committee for their assistance in funding this research.
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Abstract

BACKGROUND: Plyometrics are used to increase explosiveness and strength. Whereas, aquatic activities are used to decrease joint compression forces via the benefits of buoyancy. There is interesting potential in the blending of these two techniques.

PURPOSE: The purpose of this study was to compare the effectiveness of an aquatic and a land plyometric program. SUBJECTS: Forty-two (24 female, 18 male; 24.5 ± 3.5 yrs) volunteers were randomly divided into three groups: control, land, and aquatic.

METHODS: Each participant completed a pre-test, mid-test (after intervention phase I), and post-test (after intervention phase II) protocol to assess quadriceps strength, power, and agility. Intervention phases I and II included 4 (120-foot contacts) and 5 (180-foot contacts) plyometric exercises, respectively. Each phase consisted of 6 sessions (2x/wk x 3 wks). RESULTS: ANOVA with repeated measures revealed a main effect for time for all 3 dependent variables. Post-hoc analysis revealed a significant difference between the control and experimental groups, as well as some differences between land and aquatic groups. CONCLUSIONS: The implications of this study are that plyometric aquatics are comparable to a land plyometric program. Furthermore, the protection of joints from compression forces via the effects of buoyancy may make aquatic plyometrics a more attractive form of training and rehabilitation.

KEY WORDS: aquatic exercise, plyometrics, strength, power, agility
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REVIEW OF THE LITERATURE

Introduction

Plyometrics involves a combination of eccentric and concentric muscle activity, which allows the muscles to produce a greater force than typical concentric activities alone (Wagner & Kocak, 1997). Plyometrics are known to help increase explosiveness and strength of the lower extremities through use of vertical jumps, hops, and/or bounding movements (Wilk, 1997). Sports involving jumping and sprinting have incorporated this training technique to optimize performance. On the other hand, aquatic training has the benefit of the buoyancy of the water. The water provides resistance to help strengthen the muscles while reducing joint compression forces (Prins & Cutner, 1999; Thein & Brody, 1998). There is interesting potential in the blending of these two techniques.

Effectiveness of Plyometrics

In a current survey of training preferences, 94% of college strength and conditioning coaches used plyometric training (Durell, Pujol, & Barnes, 2003). Plyometric exercise utilizes the stretch-shortening cycle to train muscles to do more work in a short amount of time (Holcomb, Lander, Rutland, & Wilson, 1996; Komi, 1988). In plyometric exercise the muscle switches from an eccentric to concentric contraction, leaving little time for the muscle to relax; the stored elastic energy of the muscle and stretch reflex together allows the muscle to create a greater force (Hedrick & Anderson, 1996; Holcomb et al.,
Plyometric training increases power output and vertical jump performance (Luebbers et al., 2003; McLaughlin, 2001; Potteiger et al., 1999). Luebbers et al. (2003) showed that four- and seven-week plyometric program improved vertical jump height, vertical jump power, and anaerobic power. The increase seen in muscle power production may be the result of muscle fiber size that would be consistent with the observed increase in body mass of the participants. Likewise, Potteiger et al. (1999) found that plyometric training increased leg power production and muscle fiber size of both Type I and Type II fibers. This study also showed that 8-weeks of high intensity, short rest interval plyometric training increased vertical jump height and VO$_2$max (Potteiger et al., 1999). McLaughlin (2001) demonstrated that plyometrics improves explosiveness and endurance. However, plyometric training on land involves a high degree of compressive forces on the joints and a sufficient level of strength must be present to tolerate the eccentric forces.

**Effectiveness of Aquatic Programs**

Although exercising in the water has not been studied as much as on land, water is known to help reduce joint stresses (Prins & Havriluk, 1991; Rivera, 1994; Thein & Brody, 1998). The success of aquatic rehabilitation is based on two properties of water: buoyancy and viscosity (Prins & Cutner, 1999; Prins & Havriluk, 1991; Rivera, 1994). The effects of buoyancy are immediately felt when one enters the water. Buoyancy decreases the weight of an individual in proportion to the amount of the body immersed. Whereas, the viscosity of the water can be used to provide accommodating resistance (White & Smith, 1999). Water has been reported to offer twelve times the resistance of movement in air.
resulting in significant muscle strengthening (White & Smith, 1999). But since the resistance of the water corresponds to the force exerted, the likelihood of injury is notably reduced in the water (Prins & Cutner, 1999; Prins & Havriluk, 1991; Rivera, 1994).

**Effectiveness of Plyometrics in the Water**

Three studies have explored aquatic plyometric training in healthy individuals with slightly differing results (Martel, Harmer, Logan, & Parker, 2005; Miller, Berry, Bullard, & Gilders, 2002; Robinson, Devor, Merrick, & Buckworth, 2004). Martel et al (2005) reported significant increases in vertical jump and knee peak torque after six-weeks of aquatic and land training programs. Robinson et al (2004) noted improvement in vertical jump, peak torque, and peak velocity with both land and aquatic training after eight weeks. However, the aquatic group experienced significantly less muscle soreness than the land group. Whereas, Miller et al (2002) reported similar improvements in vertical jump, power, and peak torque with no difference in muscle soreness.

**Purpose**

The purpose of this experiment was to examine the effectiveness of an aquatic-based plyometric program compared to a land-based program in improving lower body strength, power, and agility.

**METHODS**

**Participants**

Forty-two university students (24 female, 18 male; 24.5 ± 3.47 yrs; 73.65 ± 17.77 kg) with no formal training in plyometrics read and signed an informed consent approved
by the Widener University Institutional Review Board for the protection of human subjects. Each participant completed a questionnaire to screen for present or prior lower extremity injury. Each participant agreed to hold their activity level as constant as possible for the duration of this study. The volunteers were randomly divided into three groups: control, land, and aquatic.

**Materials**

A MicroFET hand-held dynamometer (Hoggin Industries, Draper, Utah) was used to assess quadriceps strength. A pilot study was conducted with ten volunteers to assess reliability of the device in the testing circumstances use (R=0.943). Intrarater reliability was reported to be 0.93 by Potteiger (1999) and 0.9754 by Luebber et al. (2003). A VerTech jumping system (VerTech Inc, Falls Church, VA) was used to assess vertical jump. The test-retest reliability of this device has been reported to be 0.93 (Martel et al., 2005). A T-run was used to assess agility. This was a timed test that involved running forward 5-meters, left laterally 5-meters, right laterally 10-meters, left laterally 5-meters, and backwards 5-meters to the starting point (r= 0.836). Each point was designated by a mark on the floor. This test was administered using the standardized format described by Semenick (1990).

**Procedure**

Each participant completed a pre-test protocol to assess strength, power, and agility. Strength was assessed via a maximal isometric contraction of the quadriceps muscles at 45° of knee flexion. The measurement was performed with a MicroFET hand-held dynamometer (HHD) while seated in a dynamometer chair with the lever arm locked...
at 45° of knee flexion. This rigid stabilization (Figure 1) was used so the clinician’s upper extremity strength was not a limiting factor in obtaining a maximal muscle contraction (Kimura, Jefferson, Gulick, & Coll, 1996). The participant was instructed to crescendo to a maximal muscle contraction over a 3-second duration. The force was recorded in pounds per square inch. A total of three trials were performed with a 15-second rest between trials. Research has demonstrated that a 3-4:1 (rest:work) recovery ratio is sufficient to replenish the fuel supply for maximal subsequent bouts (McArdle, Katch, & Katch, 2001).

Power was assessed via a vertical jump test. Weight (in kilograms) was assessed at each phase using the same standard medical scale. Participants performed three vertical jumps with 15-seconds of rest between jumps (McArdle, Katch, & Katch, 2001). There were no limitations placed on the depth of the squat prior to the vertical jump but participants were required to begin with their arms at their side and to keep their feet on the floor during the pre-jump movements, i.e. no approach/steps were permitted. The height reached with the participant’s hand was recorded using a VerTech Jumping System. The participant’s standing vertical reach was deducted from the mean of the three jumps to calculate “jump height.” Peak power was calculated using the formula by Harman, Rosenstein, Frykman, Rosenstein, and Kraemer (1991). In a study by Canavan and Vescovi (2004), this equation was found to be more precise than other formulas at estimating peak power.

\[
\text{Peak power (W)} = [61.9 \times \text{jump height (cm)}] + [36 \times \text{body mass (kg)}] - 1822
\]
Agility was assessed via a T-run. Each participant ran forward 5m, sidestepped right 5m, sidestepped left 10m, sidestepped right 5m, and then ran backward 5m to the starting position. A total of three runs were completed with a 30-second rest between trials (McArdle, Katch, & Katch, 2001). The mean of the three trials were used for data analysis.

*Intervention Phase I* involved a basic plyometric training program (Elite Training Tips: Jump Around, 2000) with a total of 120-foot contacts. The four plyometric exercises included ricochets, tuck jumps, high knee skips, and 18-inch box drops (Figure 2, 3, 4, 5). Participants performed three-sets of ten repetitions of each exercise. The land-based and aquatic-based training groups each performed the exact same exercises in the respective mediums while the control group had no intervention. The training frequency was two times per week for three weeks. The researchers oversaw the training sessions to assure the safe and proper performance of the techniques. At the conclusion of Phase I, the pre-test measurements were repeated in the standardized format (mid-test).

*Intervention Phase II* progressed the participant to an intermediate plyometric program (Elite Training Tips: Jump Around, 2000) that included 180 foot contacts per training session. The plyometric exercises performed on land or in the water were forward and sideward ricochets over a hurdle (Figure 6), tuck jumps, high knee skips, and 18-inch box drops. Training sessions included three-sets of 12 repetitions of each plyometric exercise. Participants continued to train two times per week for three weeks. The researchers oversaw the training sessions to assure the safe and proper performance of the techniques. Upon completion of the twelve plyometric training sessions, all dependent
variables were re-assessed (Post-test). A summary of the entire intervention procedure is displayed in Table 1.

Results

Means and standard errors for all variables across time are displayed in Table 2. Analyses of variance with repeated measures revealed a main effect for time for all three dependent variables. The results are displayed in Table 3. A comparison of the land and aquatic influence on strength, power, and agility are displayed in Figures 7, 8, and 9, respectively.

Clinical Relevance

The results of this study are similar to that of previous studies (Martel et al, 2005; Miller et al, 2002; Robinson et al, 2004; White, & Smith, 1999; Wyatt, Milam, Manske, & Deere, 2001). This study demonstrated that both land and aquatic plyometrics are effective in improving strength, power, and agility in untrained young adults. Land plyometrics utilize body weight and gravity to eccentrically load the muscles. The elastic properties of musculotendinous unit serve as store-houses of potential energy. The stretch reflex provides a defense mechanism to protect against sudden, forceful muscular stretches. The combination of the stretch reflex response and a maximal voluntary muscle contraction can be very effective at improving muscle force generation. Although the stretch reflex and the amount of eccentric loading are reduced in water by the effects of buoyancy, the viscosity of the water provides greater than normal resistance (Martel et al, 2005). Thus, the buoyancy of the water facilitates the concentric muscular component and decreases the amortization phase of the plyometric task. Therefore, the aquatic group lands with a lower
load but have a faster transition time (Behm & Sale, 1993; Miller et al, 2002). This is important for improving power. Whereas, the viscosity of the water tends to increase the resistance to lateral movements and may be an important component in the improvement in agility in the aquatic group.

Given that both the aquatic and land programs resulted in improvements in strength, power, and agility, another consideration is the criteria for safe implementation of a plyometric program. The National Strength and Conditioning Association recommendation for implementation of a land plyometric program is the capacity to squat 150% of an individual’s weight for males and 75% for females (Potach & Chu, 2000). These criteria would require significant lower extremity strength to accommodate the shock absorption of these explosive, ballistic movements. However, when an individual is submerged in water, he/she experiences a significant reduction in weight bearing. In waist-high water, a person weighs 50% of the land weight. At chest-high water, a person weighs 25% of the land weight. When submerged to the neck, an individual only weighs 10% of the land weight (Bates & Hanson, 1996). Thus, a person weighing 80 kilograms on land would only need to squat 8-40 kilograms, depending on the level of submersion, to safely participate in an aquatic plyometric program. This could be a significant advantage to the athlete rehabilitating an injury. The buoyancy of the water would permit early access to plyometrics and incorporation of sport-specific tasks. Likewise, many activities of daily living have ballistic components to them. If incorporated into a therapeutic exercise program, plyometric tasks in the water could enhance an individual’s tolerance to these activities.
In summary, the results of this study support the positive effects of aquatic plyometrics with the added benefit of reduced joint compression forces (Prins & Havriluk, 1991; Rivera, 1994; Thein & Brody, 1998). Coaches, athletic trainers, and physical therapists should be aware of these advantages when constructing a rehabilitation or strength and conditioning program. Aquatic plyometrics should be considered as a primary intervention technique as opposed to a substitute when an individual is unable to perform land plyometrics.
References


Kimura IF, Jefferson LM, Gulick DT, Coll RD. Intratest reliability and intertest reliability when using the Chatillon & MicroFET hand-held dynamometers to


Table 1. Intervention and assessment sequence.

<table>
<thead>
<tr>
<th>Week</th>
<th>Sessions</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Pre-test &amp; Phase 1, session 1 &amp; 2</td>
</tr>
<tr>
<td>2</td>
<td>Phase 1, session 3 &amp; 4</td>
</tr>
<tr>
<td>3</td>
<td>Phase 1, session 5 &amp; 6</td>
</tr>
<tr>
<td>4</td>
<td>Mid-test &amp; Phase 2, session 1 &amp; 2</td>
</tr>
<tr>
<td>5</td>
<td>Phase 2, session 3 &amp; 4</td>
</tr>
<tr>
<td>6</td>
<td>Phase 2, session 5 &amp; 6</td>
</tr>
<tr>
<td>7</td>
<td>Post-test</td>
</tr>
</tbody>
</table>

Table 2. Means ± Standard Error

<table>
<thead>
<tr>
<th>Group</th>
<th>Time</th>
<th>Strength (ft*lbs)</th>
<th>Power (W)</th>
<th>Agility (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Pre-test</td>
<td>63.86 ± 4.69</td>
<td>6777 ± 228</td>
<td>10.77 ± 0.33</td>
</tr>
<tr>
<td></td>
<td>Mid-test</td>
<td>70.93 ± 5.32</td>
<td>6912 ± 227</td>
<td>10.65 ± 0.28</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>73.87 ± 5.53</td>
<td>6913 ± 226</td>
<td>10.64 ± 0.25</td>
</tr>
<tr>
<td>Land</td>
<td>Pre-test</td>
<td>62.92 ± 3.71</td>
<td>7543 ± 180</td>
<td>10.69 ± 0.26</td>
</tr>
<tr>
<td></td>
<td>Mid-test</td>
<td>69.42 ± 4.20</td>
<td>7528 ± 179</td>
<td>9.94 ± 0.22</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>77.08 ± 4.37</td>
<td>7598 ± 179</td>
<td>9.54 ± 0.20</td>
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<tr>
<td>Aquatic</td>
<td>Pre-test</td>
<td>59.54 ± 3.71</td>
<td>7123 ± 180</td>
<td>10.81 ± 0.26</td>
</tr>
<tr>
<td></td>
<td>Mid-test</td>
<td>71.27 ± 4.20*</td>
<td>7270 ± 179*</td>
<td>10.04 ± 0.22*</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>77.73 ± 4.37*</td>
<td>7292 ± 179</td>
<td>9.69 ± 0.20*</td>
</tr>
</tbody>
</table>

* p< 0.05

Table 3. Summary of the analyses of variance for strength, power, and agility.

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>3879.844</td>
<td>2</td>
<td>1938.422</td>
<td>23.074</td>
<td>0.000*</td>
</tr>
<tr>
<td>Strength x Group</td>
<td>317.446</td>
<td>4</td>
<td>79.362</td>
<td>0.945</td>
<td>0.443</td>
</tr>
<tr>
<td>Power</td>
<td>215339.318</td>
<td>2</td>
<td>107669.659</td>
<td>4.441</td>
<td>0.015*</td>
</tr>
<tr>
<td>Power x Group</td>
<td>113080.504</td>
<td>4</td>
<td>28270.126</td>
<td>1.166</td>
<td>0.332</td>
</tr>
<tr>
<td>Agility</td>
<td>13.435</td>
<td>2</td>
<td>6.717</td>
<td>20.760</td>
<td>0.000*</td>
</tr>
<tr>
<td>Agility x Group</td>
<td>3.995</td>
<td>4</td>
<td>0.999</td>
<td>3.087</td>
<td>0.021*</td>
</tr>
</tbody>
</table>

*p < 0.05
Figure 1. Quadriceps strength testing position using a MicroFET handheld dynamometer.
Figure 2. Ricochets
Figure 3. Tuck jumps
Figure 4. High knee skips
Figure 5. Box drops
Figure 6. Ricochets over hurdles
Figure 7. Comparison of Strength for Control, Land, and Aquatic Groups
Figure 8. Comparison of Power for Control, Land, and Aquatic Groups

![Bar chart showing comparison of power levels for Control, Land, and Aquatic groups across Pre-Test, Mid-Test, and Post-Test times. The chart displays the average watts for each group at each time point.](image-url)
Figure 9. Comparison of Agility for Control, Land, and Aquatic Groups