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SYSTEMATIC REVIEW

A Systematic Review of the Efficacy of Lower Body Aquatic Plyometric Training. The Development of Evidence-Based Recommendations for Practitioners

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Abstract
Objectives*:* Plyometric exercises are often prescribed for enhancing athletic performance; however, this form of training can elicit significant skeletal loading, which may defer practitioners from utilizing these exercises throughout rehabilitation. **Purpose**: 1) complete a systematic review to critically examine the efficacy of plyometric training performed in water when compared to land for eliciting changes in musculoskeletal markers of performance, and 2) to provide evidence-based recommendations for practitioners on how best to utilize this form of training in rehabilitation and return-to-play. **Methods:** A systematic review was undertaken with relevant studies identified that compared changes in performance markers (e.g., strength, sprinting, and jumping) between the same aquatic- and land-based plyometric program were eligible for inclusion. Data was extracted using a standardized extraction form as confirmed by three reviewers. Data extraction included population characteristics, program design, and pre- and post- adaptations in strength, speed, and vertical jump. **Results***:* Eight studies were included comparing performance outcomes following aquatic- and land-based plyometric training. The results of this review suggest that aquatic plyometric training is as effective as land-based plyometric training at improving lower body strength, sprint, and vertical jump performance. **Conclusions***:* The utilization of aquatic plyometric training can be an important piece of the rehabilitation and return-to-play process in order to improve lower body strength, speed, and power while reducing the physical stress of land-based plyometric training. **Health and Fitness Journal of Canada 2019;12(1):17-33.**
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Introduction

Plyometric training is a popular form of explosive training commonly used in sport and health-related settings. Previous literature has demonstrated the effectiveness of plyometric training to increase various performance markers (such as vertical jump, muscular strength, and speed (Johnson, Salzberg, & Stevenson, 2011; Markovic, 2007)). By design, plyometric training increases the stress placed on muscles and joints. The increased stress experienced in connective tissue may deter practitioners from implementing plyometric exercises with athletes recovering from an injury. Recently, aquatic plyometric training has become a popular alternative to land-based plyometric training due to the buoyancy of the water reducing a large amount of the gravitational stress typically observed with land-based plyometrics (Donoghue, Shimojo, & Takagi, 2011), as well as resulting in smaller levels of muscle damage indicators (Wertheimer, Antekolovic, & Matkovic, 2018). For instance, peak impact force and impact force rate is lower in water than on land, whereas peak concentric force has shown to be higher for aquatic plyometric training during both double leg and single leg jumping (Colado, et al., 2010; Triplett et al., 2009). This observation may be of particular interest to practitioners while their athletes are recovering from injury or in the return to play stage. The positive effects of plyometric training are well understood and dependent on program duration, number of sessions and number of jumps per session (de Villarreal, Kellis, Kraemer, & Izquierdo, 2009). Therefore, the primary purpose of this review was to 1) complete a systematic review to critically examine the efficacy of plyometric training performed in water when compared to land for eliciting change in musculoskeletal markers of performance, and 2) to provide evidence based recommendations for practitioners on how best to utilize this form of training.

Methods

Inclusion and exclusion criteria

A systematic approach was used to find relevant articles that compared the effect of plyometric training in water and on land according to the PRISMA guidelines (Liberati et al., 2009). Studies that involved the same plyometric program between land and water groups and measured changes in performance measures [such as strength, speed, and power (vertical jump)] were eligible for inclusion. Excluded studies included those utilizing equipment to increase resistance, studies without human participants, studies in which participants completed different programs between land and water, studies that included complex training of plyometrics and strength, studies that did not include strength, speed or vertical jump performance measures, case studies and review studies. The criteria for study inclusion was also limited to journal articles published in English with full-text available.

Search Strategy

The following electronic databases were used to complete literature searches:

- MEDLINE (OVID Interface);
- EMBASE (OVID Interface);
- SPORTDiscus (EBSCO Interface).

Broad medical subject headings and key words were used as search terms to identify appropriate articles. The search strategy and results for each electronic database is included in Table 1. All search results were subsequently downloaded onto RefWorks (Bethesda, MD, USA), an online bibliographic management program.

Study selection

Three reviewers screened all identified articles using a multi-step process. At each level of the process, discrepancies were recorded and reassessed by consensus. The number of articles that were excluded at each step of screening was also recorded (Figure 1). The combined articles from the three electronic databases were reviewed and duplicates were excluded. Titles and abstracts were then screened for inclusion. Once all of the articles were identified following the abstract screening, full-text were obtained. Full-text articles were screened in full by two reviewers for inclusion. A reason for an excluded article during full-text was noted (Figure 1). A thorough review of the references of the included articles was completed by two reviewers to identify additional articles that were eligible for inclusion.

Data extraction

Articles included in this review are provided in Table 2. Data was extracted from the included articles using a standardized extraction form as confirmed by three reviewers. The focus of the extraction was the comparison of plyometric training on land and in water. Data extraction included the population characteristics, the program design and the pre- and post- adaptation in strength, speed, and vertical jump following land- and water-based plyometric training.

Level of evidence

A modified Downs and Black scoring system (Downs & Black, 1998) was used to score the quality of the included studies. The questions from the original Downs and Black scoring system that were considered relevant to the topic of this systematic review were included to measure the level of evidence. Two reviewers completed the scoring of the articles independently and consensus was reached through discussion as necessary. The outcomes of the modified Downs and Black scoring system is provided (Table 3).

Table 1: Details of Search Strategy

No	Search history	Results
MEDLINE (via OVID)		
1	Plyometric exercise (exploded)	303
2	Jump [a]	22974
3	Squat jump	640
4	Depth jump	63
5	Drop jump	495
6	Stretch shortening cycle	356
7	Countermovement jump	280
8	1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7	23185
9	Water (exploded)	157701
10	Aquatic [a]	40736
11	Pool	89965
12	9 OR 10 OR 11	284989
13	8 and 12	453
14	Limits: English, Full-Text, Humans	**44**
EMBASE (via OVID)		
1	Plyo* (exploded)	506
2	Jump* (exploded)	5918
3	Squat jump	497
4	Depth jump	39
5	Stretch shortening cycle	376
6	Drop jump	413
7	Countermovement jump	267
8	1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7	7037
9	Water (exploded)	460466
10	Aquatic*	48686
11	Pool	99507
12	9 OR 10 OR 11	589975
13	8 AND 12	206
14	Limits: Full-Text, Human, English Language	**25**
SPORTDiscus (via EBSCO)		
1	Plyometrics	920
2	Plyometric training	377
3	Jump training	174
4	1 OR 2 OR 3	1034
5	4 AND aquatic exercise	**920**
	Limits of English language, Academic Journal, Article set prior to search	

[a] is the truncation character.

Results and Discussion

Strength

Five articles examined muscular strength following aquatic and land plyometric training (Arazi & Asadi, 2011; Miller, Berry, Bullard, & Gilders, 2002; Ploeg et al., 2010; Ravasi, Mansournia, Kordi, Shiran, & Ziaee, 2008; Robinson, Devor, Merrick, & Buckworth, 2004). Results are presented in Table 4. Strength was examined using the back squat (Ravasi et al., 2008), leg press (Arazi & Asadi, 2011), and by isokinetic knee torque (Miller et al., 2002; Ploeg et al., 2010; Robinson et al., 2004). Of these articles, two reported enhanced strength outcomes following aquatic and land plyometric training with no differences between the conditions (Ravasi et al., 2008; Robinson et al., 2004). Increases reported in the study by Robinson et al. (2004) were for both concentric and eccentric strength. Arazi and Asadi (2011) reported no significant differences in one-repetition maximum leg press in both groups. Ploeg et al. (2010) found no significant differences in peak torque in the land training group, the matched aquatic training group, and the second aquatic training group that completed twice as many jumps as land.

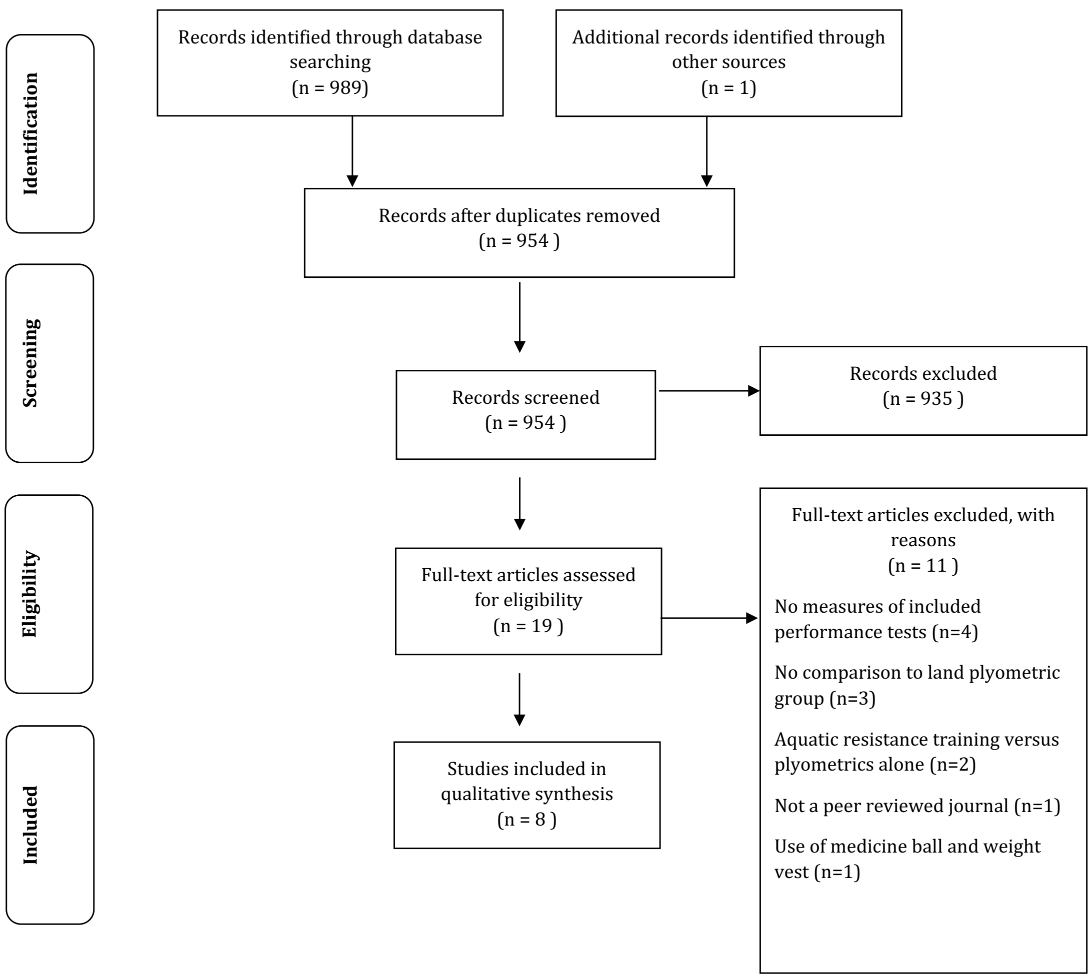

Figure 1: PRISMA flow diagram for search strategy.

Table 2: Studies Included in the Aquatic Plyometric Training Review

Publication	Population	Age, years (mean ± SD)	Program Frequency and Duration	Number of Jumps per Session	Water Depth	Performance Tests Included
Atanaskovic, Georgiev, & Mutavdzic, 2015	30 male children	12.9 ± 1.5	2x/week for 6 weeks	Progressed from 90-160	1.3 m (~77% of the body submerged)	Vertical jump: Squat Jump and CMJ
Shiran, Kordi, Ziaee, Ravasi, & Mansournia, 2008	21 male wrestlers	20.3 ± 3.6	3x/week for 6 weeks	Progressed, but not recorded.	Not reported	Strength: back squat Speed: 5m, 10m, 20m
Arazi, Coetzee, & Asadi, 2012	18 male semi-professional basketball players	Overall: 18.8 ± 1.4 Aquatic: 18.0 ± 0.6 Land: 18.0 ± 1.3 Control: 20.4 ± 0.6	3x/week for 8 weeks	Progressed from 117-183	Chest deep	Vertical Jump: CMJ
Stemm & Jacobson, 2007	21 physically active, college aged men	24 ± 2.5	2x/week for 6 weeks	135	Knee depth	Vertical Jump: CMJ
Miller, Berry, Bullard, & Gilders, 2002	40 (21 women, 19 men) inactive to recreationally active individuals	Aquatic: 22.0 ± 2.5 Land: 21.5 ± 3.6 Control: 23.0 ± 5.5	2x/week for 8 weeks	Progressed from 80-120	Waist depth	Vertical Jump: CMJ Strength: Knee Isokinetic Torque
Ploeg, Miller, Holcomb, O'Donoghue, & Berry, 2010	39 (16 males, 23 females) untrained individuals	6 Males: 21.8 ± 2.3 Female: 22.4 ± 3.5	2x/week for 6 weeks	Progressed from 90-120 (second aquatic group: 180 - 240)	1.07 m (~61% of the body submerged)	Vertical Jump: CMJ Strength: Knee Isokinetic Torque
Robinson, Devor, Merrick, & Buckworth, 2004	32 physically active women	Overall: 20.2 ± 0.3 Aquatic: 19.8 ± 0.3 Land: 20.6 ± 0.6	3x/week for 8 weeks	Progressed In 3-4 sets of 10-20 reps for 10 exercises	1.2 – 1.4 m (~73% of the body submerged)	Vertical Jump: CMJ Speed: 40 m Strength: Knee Isokinetic Torque
Arazi & Asadi, 2011	18 male semi-professional basketball players	Overall: 18.8 ± 1.5 Aquatic: 18.0 ± 0.6 Land: 18.0 ± 1.4 Control: 20.4 ± 0.6	3x/week for 8 weeks	Progressed from 117-183	Chest deep	Strength: Leg press Speed: 36.5 m and 60 m

CMJ = Counter Movement Jump

Table 3: Modified Downs and Black Scoring System (listed in order to total score)

No.	Article	Q1 (/1)	Q2 (/1)	Q3 (/1)	Q4 (/1)	Q5 (/2)	Q6 (/1)	Q7 (/1)	Q9 (/1)	Q10 (/1)
1	Robinson et al., 2004	1	1	1	1	2	1	1	1	1
2	Miller et al., 2002	1	1	1	1	1	1	1	1	0
3	Atanaskovic et al., 2015	1	1	1	1	1	1	0	1	1
4	Ploeg et al., 2010	1	1	1	1	1	1	1	1	1
5	Shiran et al., 2008	1	1	1	0	0	1	1	1	1
6	Stemm and Jacobson, 2007	1	1	1	1	1	1	0	1	0
7	Arazi et al., 2012	1	1	1	1	1	1	0	1	0
8	Arazi and Asadi, 2011	1	1	1	1	1	1	0	1	0
No.	**Article**	**Q17 (/1)**	**Q18 (/1)**	**Q19 (/1)**	**Q20 (/1)**	**Q21 (/2)**	**Q22 (/1)**	**Q23 (/1)**	**Q26 (/1)**	**Q27 (/1)**
1	Robinson et al., 2004	1	1	1	1	1	1	1	1	**5**
2	Miller et al., 2002	1	1	1	1	1	1	1	1	**5**
3	Atanaskovic et al., 2015	1	1	1	1	1	1	0	1	**5**
4	Ploeg et al., 2010	1	1	0	1	1	1	1	1	**4**
5	Shiran et al., 2008	1	1	1	1	1	1	1	1	**4**
6	Stemm and Jacobson, 2007	1	1	1	1	1	1	1	1	**4**
7	Arazi et al., 2012	1	1	1	1	1	1	1	1	**3**
8	Arazi and Asadi, 2011	1	1	1	1	1	1	1	1	**3**

The testing was completed at 60 ° • s^{-1}, which is the same protocol as in Robinson et al. (2004) that reported significant increases in strength. The training program used in Ploeg et al. (2010) was six weeks in duration with two sessions per week, whereas Robinson et al. (2004) trained for eight weeks with three sessions per week. Miller et al. (2002) performed tests of concentric knee flexion and extension at three speeds, 90 ° • s^{-1}, 180 ° • s^{-1}, and 360 ° • s^{-1}. Significant improvement in strength output was observed in knee flexion at the highest velocity (360 ° • s^{-1}) in both the aquatic and land plyometric training groups, with no differences between conditions. Given the increase in sprint performances in distances greater than 20-m and the importance of the hamstrings during maximal running speed (36-100-m) (Delecluse, 1979), it is interesting to note the only significant increase in muscle torque was with knee flexion versus extension at the highest velocity. Taken together, these results suggest aquatic plyometric training is as effective as land plyometric training at increasing lower body strength.

Clinical Recommendations:

I. Aquatic plyometric programs can be used for improving concentric and eccentric muscular strength once the athlete is capable of withstanding the required skeletal loading during the rehabilitation process. Impact forces can be progressed from chest-deep water (lower impact forces) to knee-deep water (increased impact force) as tolerable.
II. Practitioners are encouraged to include aquatic plyometric exercises in rehabilitation and the return-to-play process for developing power output prior to entering competition.
III. Aquatic plyometric training can be used for maintaining muscular strength during periodized rest weeks within the yearly training plan. Alternatively, this form of training can be used during the off season adequately reducing the loading and volume of training to allow for rest and recovery without negatively impacting muscular performance.

Sprinting

Three articles examined sprint performance following aquatic and land plyometric training (Arazi & Asadi, 2011; Ravasi et al., 2008; Robinson et al., 2004). Results are presented in Table 5. Robinson et al. (2004) observed that peak speed during a 40-m sprint was significantly increased following both aquatic and land plyometric training, with no difference between the groups. Arazi and Asadi (2011) found a significant improvement in sprint performance over 36.5-m and 60-m in both land and aquatic plyometric training, with no difference between groups. Ravasi et al. (2008) measured sprint time over 5-m, 10-m and 20-m, where a significant improvement over 20-m following land plyometric training was present. Although a significant improvement was demonstrated in 20-m sprint performance in the land group following training, an insignificant improvement between the aquatic and land group when comparing the difference in post-test and pre-test measurements was observed. These findings suggest a possible improvement in sprint performance over longer distances following land and aquatic plyometric training. It is possible that plyometric training may help increase maximal speed compared to acceleration. Sprint performance is often viewed multi-dimensionally as an acceleration phase (0-10 m), a phase of maximum running speed (36-100-m) and a transition phase in between (Delecluse, 1979). A previous investigation has suggested that the hamstrings, the adductor magnus, and the gluteus maximus are considered to make the most important contribution in producing the highest level of speed (Delecluse, 1979). One may postulate that the increases in maximum speed versus acceleration relate to the increases in lower body power through the Margaria-Kalamen test versus a counter movement jump in regard to similarity of movement and duration of the test. It appears that both aquatic and land plyometric programs provide a stimulus capable of increasing sprint ability, especially for distances greater than 20-m.

Table 4: Strength Adaptations Between Aquatic and Land Plyometric Training

Study	Program Frequency and Duration	Water Depth	Number of Jumps per Session	Strength			
				Land Group		Aquatic Group	
				Pre	Post	Pre	Post
Shiran, Kordi, Ziaee, Ravasi & Mansournia, 2008	3x/week for 6 weeks	Not reported	Progressed, but not recorded.	Back Squat: 131 ± 14.2 kg	Back Squat: 147 ± 19.5 kg[a]	Back Squat: 118 ± 17.2 kg	Back Squat: 129 ± 25.7 kg[a]
Miller, Berry, Bullard & Gilders, 2002	2x/week for 8 weeks	Progressed from 80-120	3x/week for 6 weeks	**Flexion** 90 ° • s^{-1}: 71.6 ± 19.5 180 ° • s^{-1}: 59.6 ± 16.9 360 ° • s^{-1}: 46.3 ± 15.5 **Extension** 90 ° • s^{-1}: 137.4 ± 35.6 180 ° • s^{-1}: 100.3 ± 28.5 360 ° • s^{-1}: 71.2 ± 19.7	**Flexion** 90 ° • s^{-1}: 84.4 ± 19.5 180 ° • s^{-1}: 69.4 ± 16.9 360 ° • s^{-1}: 57.5 ± 16.9[a] **Extension** 90 ° • s^{-1}: 139.0 ± 43.2 180 ° • s^{-1}: 104.3 ± 34.5 360 ° • s^{-1}: 73.3 ± 37.7	**Flexion** 90 ° • s^{-1}: 71.4 ± 17.1 180 ° • s^{-1}: 59.1 ± 16.4 360 ° • s^{-1}: 47.3 ± 16.4 **Extension** 90 ° • s^{-1}: 137.0 ± 46.5 180 ° • s^{-1}: 102.5 ± 37.3 360 ° • s^{-1}: 74.6 ± 25.0	**Flexion** 90 ° • s^{-1}: 81.0 ± 26.4 180 ° • s^{-1}: 66.0 ± 23.7 360 ° • s^{-1}: 53.8 ± 19.0[a] **Extension** 90 ° • s^{-1}: 140.7 ± 45.6 180 ° • s^{-1}: 103.8 ± 37.4 360 ° • s^{-1}: 75.9 ± 25.7
Ploeg, Miller, Holcomb, O'Donoghue & Berry, 2010	2x/week for 6 weeks	1.07 m (~61% of the body submerged)	AG1: Progressed from 90-120 AG2: Progressed from: 180 - 240	**Flexion** 1.05 rad·s^{-1}: 71.3 ± 21.0 **Extension** 1.05 rad ·s^{-1}: 123.5 ± 24.2	**Flexion** 1.05 rad ·s^{-1}: 69.2 ± 20.4 **Extension** 1.05 rad ·s^{-1}: 124.0 ± 24.3	**Flexion** AG1: 1.05 rad ·s^{-1}: 66.9 ± 21.9 AG2: 60 ° • s^{-1}: 75.4 ± 31.5 **Extension** AG1: 1.05 rad ·s^{-1}: 119.4 ± 37.7 AG2: 1.05 rad ·s^{-1}: 115.0 ± 37.2	**Flexion** AG1: 1.05 rad ·s^{-1}: 68.1 ± 26.5 AG2: 1.05 rad ·s^{-1}: 73.5 ± 33.0 **Extension** AG1: 1.05 rad ·s^{-1}: 117.1 ± 39.9 AG2: 1.05 rad ·s^{-1}: 118.2 ± 37.6

AG1 = same number of jumps as land; AG2 = double the number of jumps as land; [a] = significant difference between pre-training and post-training

Table 4: Strength Adaptations Between Aquatic and Land Plyometric Training (continued)

Study	Program Frequency and Duration	Water Depth	Number of Jumps per Session	Strength			
				Land Group		Aquatic Group	
				Pre	Post	Pre	Post
Robinson, Devor, Merrick & Buckworth, 2004	3x/week for 8 weeks	1.2 – 1.4m (~73% of the body submerged	Progressed in 3-4 sets of 10-20 reps for 10 exercises	**Concentric Flexion** 60.16 ° • s-1: 82.7 ± 2.9 **Concentric Extension** 60.16 ° • s-1: 151.0 ± 7.2 **Eccentric Flexion** 60.16 ° • s-1: 185.0 ± 9.3 **Eccentric Extension** 60.16 ° • s-1: 94.8 ± 3.9	**Concentric Flexion** 60.16 ° • s-1: 120.0 ± 4.2[a] **Concentric Extension** 60.16 ° • s-1: 189.0 ± 6.8[a] **Eccentric Flexion** 60.16 ° • s-1: 230.0 ± 10.3[a] **Eccentric Extension** 60.16 ° • s-1: 137.0 ± 4.8[a]	**Concentric Flexion** 60.16 ° • s-1: 86.3 ± 3.4 **Concentric Extension** 60.16 ° • s-1: 161.0 ± 5.2 **Eccentric Flexion** 60.16 ° • s-1: 188.0 ± 7.2 **Eccentric Extension** 160.16 ° • s-1: 96.2 ± 3.3	**Concentric Flexion** 60.16 ° • s-1: 125.0 ± 3.1[a] **Concentric Extension** 60.16 ° • s-1: 201.0 ± 5.4[a] **Eccentric Flexion** 60.16 ° • s-1: 235.0 ± 6.2[a] **Eccentric Extension** 60.16 ° • s-1: 147.0 ± 4.9[a]
Arazi & Asadi, 2011	3x/week for 8 weeks	Chest deep	Progressed from 117-183	Leg Press (kg): 185 ± 15	Leg Press (kg): 200 ± 15	Leg Press (kg): 180 ± 20	Leg Press (kg): 200 ± 20

AG1 = same number of jumps as land; AG2 = double the number of jumps as land; [a] = significant difference between pre-training and post-training

Clinical Recommendations:

I. Aquatic plyometric training can be used for improving sprint ability, particularly maximum running speed, once the athlete is capable of withstanding the required skeletal loading during the rehabilitation process.
II. Practitioners are encouraged to include aquatic plyometric exercises in rehabilitation and the return-to-play process for improving sprinting ability and tolerance prior to competition, particularly if longer runs (>20m) at maximum speed is common in their respective sport.

Vertical Jump

Six articles measured vertical jump performance following plyometric training in water and on land (Arazi, Coetzee, & Asadi, 2012; Atanasković, Georgiev, & Mutavdzić, 2015; Miller et al., 2002; Ploeg et al., 2010; Robinson et al., 2004; Stemm & Jacobson, 2007). Results are presented in Table 6. Of these articles, four identified vertical jump performance to be significantly increased in both land and aquatic plyometric training groups with no significant difference between conditions (Arazi et al., 2012; Atanasković et al., 2015; Robinson et al., 2004; Stemm & Jacobson, 2007). Ploeg et al. (2010) and Miller et al. (2002) found no significant

Table 5: Speed Adaptations Between Aquatic and Land Plyometric Training

Study	Program Frequency and Duration	Water Depth	Number of Jumps per Session	Speed			
				Land Group		Aquatic Group	
				Pre	Post	Pre	Post
Shiran, Kordi, Ziaee, Ravasi & Mansournia, 2008	3x/week for 6 weeks	Not reported	Progressed, but not recorded.	5 m: 1.13 ± 0.1 s 10 m: 1.83 ± 0.2 s 20 m: 3.5 ± 0.2 s	5 m: 1.14 ± 9 s 10 m: 1.78 ± 0.3 s 20 m: 3.37 ± 0.2 s[ab]	5 m: 1.07 ± 8.4 s 10 m: 1.68 ± 0.4 s 20 m: 3.46 ± 0.2 s	5 m: 1.13 ± 9.4 s 10 m: 1.57 ± 0.3 s 20 m: 3.44 ± 0.1 s[b]
Robinson, Devor, Merrick & Buckworth, 2004	3x/week for 8 weeks	1.2 – 1.4 m (~73% of the body submerged	Progressed in 3-4 sets of 10-20 reps for 10 exercises	40 m: 6.70 ± 285.7 s	40 m: 6.30 ± 307.7 s[a]	40 m: 6.50 ± 333.3 s	40m: 6.10 ± 400.0 s [a]
Arazi & Asadi, 2011	3x/week for 8 weeks	Chest deep	Progressed from 117-183	36.5 m: 5.50 ± 0.5 s 60 m: 8.95 ± 0.6 s	36.5 m: 4.98 ± 0.2 s[a] 60 m: 8.05 ± 0.6 s[a]	**F**36.5 m: 5.50 ± 0.5 s 60 m: 8.50 ± 0.7 s	36.5 m: 4.95 ± 0.2 s[a] 60 m: 7.75 ± 0.3 s[a] 37.6

[a] = significant difference between post-training and pre-training
[b] = significant difference between aquatic group and land group

increase in vertical jump performance with either land or aquatic plymetric training. Miller et al. (2002) used the Margaria-Kalamen test as a second measure of lower body power and found that the aquatic group significantly increased power production compared to pre-testing, whereas the land group did not. Additionally, Ploeg et al. (2010) included two aquatic plyometric groups. The first group completed the same plyometric program as the land group, only in water, whereas the second group completed twice as many jumps each session. Neither aquatic group increased vertical jump performance in this study. The findings of Ploeg et al. (2010) were in contrast to previous investigations that demonstrated significant improvement (Arazi et al., 2012; Atanasković et al., 2015; Robinson et al., 2004; Stemm & Jacobson, 2007). One difference was the use of an immersed cone and step. Although participants were asked to provide maximal effort throughout each session, it is possible that when instructed to jump on the step or over the cone, maximal effort was not required to complete the task. Although the authors attempted to match intensity between land and aquatic groups, it is likely that the buoyancy of water opposing gravity required less effort to achieve the task of jumping over a cone or step. It appears that vertical jump performance, and possibly other measures of lower body performance, can be improved following aquatic and land plyometric training, regardless of being on land or in the water.

Clinical Recommendations:

I. Aquatic plyometric training can be used for improving vertical jumping ability once the athlete is capable of withstanding the required skeletal loading during the rehabilitation process. Impact forces can be progressed from chest-deep water (lower impact forces) to knee-deep water (increased impact force) as tolerable.

II. Practitioners are encouraged to include aquatic plyometric exercises in rehabilitation and the return-to-play process for developing power output prior to entering competition, particularly in sports that require a large number of jumps.

III. Aquatic plyometric training can be used for during periodized rest weeks within the yearly training plan in order to prescribe plyometric exercise without overloading the muscular-skeletal system.

Number of Jumps

The articles included consisted of a variety of number of jumps each session throughout the plyometric training program. Interestingly, two articles (Miller et al., 2002; Ploeg et al., 2010) that consisted of the least amount of jumps per session (beginning at 90 and 80, respectively compared to 117 or higher) did not experience increases in vertical jump. The only other article that began at 90 jumps per session was in children and progressed to 160 jumps versus 120. These findings suggest that either the higher increase in jumps throughout the program or the participants being children may have provided a greater stimulus to create positive adaptation. In contrast, Ploeg et al. (2010) also included a second aquatic plyometric group that completed twice as many jumps each session compared to the land group and the other aquatic group. Similar to the matched aquatic and land group, the group that completed twice as many jumps each session (180-240 versus 90-120) did not significantly increase any performance measures. Consequently, it is challenging to conclude how much of a factor the number of jumps in a training session is. One consideration that does appear to be a factor in designing a plyometric training program is that the number of jumps increases throughout the duration of the program as the athlete adapts to the stimulus.

Clinical Recommendations:

I. Aquatic plyometric programs should progress the number of jumps the athlete complete per training session as tolerable. The number of jumps should originally be based off what the athlete can tolerate and how he or she responds to the aquatic plyometric training session.

Duration and Frequency of Training Program

A variety of durations and number of training sessions were used in the protocol designs included in this review. Of the eight included articles, three protocols consisted of training twice per week for a period of six weeks (Atanasković et al., 2015; Ploeg et al., 2010; Stemm & Jacobson, 2007), one protocol was three times a week for a period of six weeks (Ravasi et al., 2008), one protocol was two times a week for eight weeks (Miller et al., 2002), and three protocols were three times a week for eight weeks (Arazi & Asadi, 2011; Arazi et

Table 6: Vertical Jump Adaptations Between Aquatic and Land Plyometric Training

Study	Program Frequency and Duration	Water Depth	Number of Jumps per Session	Vertical Jump			
				Land Group		Aquatic Group	
				Pre	Post	Pre	Post
Atanaskovic, Georgiev and Mutavdzic, 2015	2x/week for 6 weeks	1.3 m (~77% of the body submerged)	Progressed from 90-160	SJ: 22.61 cm CMJ: 26.27 cm	SJ: 30.16 cm[a] CMJ: 32.99 cm[a]	SJ: 27.37 cm CMJ: 29.76 cm	SJ: 31.21 cm[a] CMJ: 35.75 cm[a]
Arazi, Coetzee and Asadi, 2012	3x/week for 8 weeks	Chest deep	Progressed from 117-183	CMJ: 44.33 cm	CMJ: 57.33 cm[a]	CMJ: 44.33 cm	CMJ: 57.83 cm[a]
Stemm and Jacobson, 2007	2x/week for 6 weeks	Knee depth	135	CMJ: 67 ± 3 cm	CMJ: 72 ± 3 cm[a]	CMJ: 69 ± 4 cm	CMJ: 74 ± 2 cm[a]
Miller, Berry, Bullard and Gilders, 2002	2x/week for 8 weeks	Waist depth	Progressed from 80-120	CMJ: 1046.5 ± 247.3 W	CMJ: 1062.2 ± 253.7 W	CMJ: 1055.4 ± 337.9 W	CMJ: 1092.7 ± 367.7 W
Ploeg, Miller, Holcomb, O'Donoghue and Berry, 2010	2x/week for 6 weeks	1.07 m (~61% of the body submerged)	Progressed from 90-120 (second aquatic group: 180 - 240)	CMJ: 49.4 ± 13.2 cm	CMJ: 48.1 ± 13.9 cm	CMJ AG1: 45.7 ± 11.3 cm AG2: 41.8 ± 9.8 cm	CMJ AG1: 46.0 ± 12.8 cm AG2: 43.1 ± 7.1 cm
Robinson, Devor, Merrick and Buckworth, 2004	3x/week for 8 weeks	1.2 – 1.4 m (~73% of the body submerged	Progressed in 3-4 sets of 10-20 reps for 10 exercises	CMJ: 32.6 ± 1.7 cm	CMJ: 43.2 ± 1.7 cm[a]	CMJ: 31.9 ± 1.6 cm	CMJ: 42.6 ± 1.9 cm[a]

SJ = Squat Jump; CMJ = Counter Movement Jump; AG1 = same number of jumps as land; AG2 = double the number of jumps as land; [a] = significant difference between post-training and pre-training

al., 2012; Robinson et al., 2004). Three of the four studies that completed six weeks of plyometric training significantly enhanced vertical jump and strength, regardless of completing two or three sessions per week. Only Ploeg et al. (2010) did not report performance increases in either the land or the aquatic group. Miller et al. (2002) experienced an increase in peak knee torque at the highest velocity during eight weeks of plyometric training twice a week; however, there was no increase in either group in vertical jump. Considering, Miller et al. (2002) is the only article consisting of two sessions per week for eight weeks, it would be inappropriate to suggest the duration and frequency of the protocol was responsible. During the protocol of eight weeks of plyometric training consisting of three sessions a week, all three investigations demonstrated a significant improvement in both the aquatic and land groups for vertical jump performance (Arazi et al., 2012; Robinson et al., 2004), sprinting performance at 36.5-m, 40-m, and 60-m (Arazi & Asadi, 2011; Robinson et al., 2004), and strength (Arazi & Asadi, 2011; Robinson et al., 2004). Although Robinson et al. (2004) used an 8-week protocol, the authors also included mid-testing during week four. It was found that four weeks of plyometric training significantly increased vertical jump, sprinting and strength performance compared to pre-testing. In addition, there were further significant increases in the three performance measures during post-testing following eight weeks of plyometric training compared to mid-testing in both land and aquatic training groups. The results suggest that a variety of durations of plyometric training between four and eight weeks may provide increases in vertical jump, sprinting and strength. Secondly, a frequency of either two or three times a week may provide similar increases.

Clinical Recommendations:

I. Aquatic plyometric programs should include two to three aquatic plyometric sessions per week for four to eight weeks, and possibly longer depending on the time to return to competition.

Training Status

The articles in this review included a variety of participant fitness levels, including physically active and inactive adults, children aged 11-14, college-aged volunteers, trained wrestlers, and semi-professional basketball players. Interestingly, the only article that experienced no increase in performance in either group for any measure was the only study that used completely untrained participants (Ploeg et al., 2010). Martel, Harmer, Logan, & Parker (2005) suggested that trained individuals might be able to experience larger increases with less within-group variation. It was further suggested that motivation for improvements might be a factor (Martel et al., 2005). Although muscle soreness was not measured by Ploeg et al. (2010) it may be possible that muscle soreness in an untrained population, especially with consistent increases in intensity, may have impacted motivation and ability to perform a maximal effort, or potentially provided too much of a stimulus. The positive adaptations in trained wrestlers and semi-professional basketball provide a promising rationale for implementing aquatic plyometric training with a variety of rehabbing athletes, especially in later stages of the rehabilitation and return-to-play process.

Clinical Recommendations:

I. Aquatic plyometric programs can effectively be incorporated into the rehabilitation programs of a variety of athletes, from children to adults and untrained to high level athletes, to improve strength, sprinting, and vertical jump.

II. Aquatic plyometric programs should consider the current training status of the athlete, as well as the physical demand of the sport that the athlete is returning to.

Water Depth

Various water depths were used in the selected articles for the aquatic groups. Four articles used individualized water depths of either chest, waist- or knee-depth. Of these, two articles used chest-deep water (Arazi & Asadi, 2011; Arazi et al., 2012), one article used waist-depth (Miller et al., 2002), and one article used knee-depth (Stemm & Jacobson, 2007). The remaining studies used a fixed depth, which creates variance for individuals of different heights in the aquatic groups. When comparing the depth to the average height of the individuals, Atanaskovic et al. (2015) had 77% of the body immersed, Robinson et al. (2004) had 73% of the body immersed, and Ploeg et al. (2010) immersed 61% of the body. Only one article did not report the water depth used during aquatic plyometric training (Ravasi et al., 2008). For the purpose of this review, 77% and 73% of the body immersed was considered chest-deep water immersion, whereas 61% of the body immersed was considered waist-depth immersion. For the four articles using chest-deep water immersion, vertical jump and sprinting performance was increased significantly in both groups with no difference between conditions. Strength was significantly increased during both aquatic and land plyometric training in one article (Robinson et al., 2004), but not in another (Arazi & Asadi, 2011). For waist-depth water immersion, there was no increase in vertical jump performance in two articles. Strength was not significantly increased in one article (Ploeg et al., 2010) at a velocity of 60 ° • s^{-1}. In contrast, Miller et al. (2002) observed strength was only significantly increased at the highest velocity (360 ° • s^{-1}) in knee flexion. With knee-depth water immersion, vertical jump, sprinting ability, and strength were increased significantly in both aquatic and land plyometric training groups with no difference between groups. Ploeg et al. (2010) followed a similar protocol to Robinson et al. (2004) with different results in similar performance measures. One difference between the two protocols was that Ploeg et al. (2010) used waist-deep water immersion and Robinson et al. (2004) used chest-deep water immersion. Whether the difference in water depth can explain the difference in the results is unknown. Although there are other variations in programming, it appears that performance measures can be increased at multiple depths of water immersion. Chest-deep and knee-depth water immersion may increase vertical jump, strength, and sprinting performance. For waist-deep water immersion, there were mixed results. It should be noted that the land group followed the same results as the aquatic group, so water depth may not be the only factor. The only difference between groups was during the Margaria-Kalamen test where the aquatic training group had significant improvements. One possible explanation may be that chest-deep water immersion requires greater force and power output during the upward phase of the jump compared to waist-deep water immersion and land-based plyometric exercise due to the resistance of the water (Louder, Searle, & Bressel, 2016). Similarly, knee-deep water immersion is more similar to land and improvements may be made with higher velocity and less water resistance in the upwards phase, combined with greater eccentric forces during the landing due to increased jump height. It is possible that waist-deep immersion is a transition phase that provides too much resistance to increase high velocities, and not enough to experience increases in peak power. Donoghue et al. (2011) compared impact forces and landing impulse between land and aquatic training at a depth of three centimeters below the xiphoid process. The findings presented in this investigation demonstrated that impact forces were 33-54% lower in aquatic groups compared to land groups for various exercises. Of note, counter movement jumps produced a 40% reduction impact forces in the aquatic group. In terms of landing impulse, there was a reduction of 19-54% in the aquatic training group. Considering the improvements at multiple depths of water immersion, it may be recommended for sport practitioners to base the water depth off of impact forces to ensure the amount of stress experienced is appropriate to rehabilitation goals.

Clinical Recommendations:

I. Aquatic plyometric programs should base water-depth on desired impact forces that the athlete can tolerate during various stages of the rehabilitation process
II. Chest-deep water immersion provides a greater resistance during the concentric or upwards movements of the jump while providing lower impact forces. In contrast, knee-deep water immersion is more similar to land in terms of resistance in the upwards movement, as well as impact forces. Both of these depths improved lower-body strength, speed, and power.
III. Using a variety of depths that produce impact forces that the athlete can tolerate and provide a concentric and eccentric load similar to the required demands of his or her sport is recommended as part of the rehabilitation and return-to-sport protocol.

Conclusions

The results of this systematic review suggest that aquatic plyometric training is as effective as land plyometric training at improving markers of performance (including lower body strength, vertical jump, and sprinting performance). One advantage to aquatic plyometric training is that the degree of impact experienced by the connective tissue may be reduced while concurrently enhancing performance. Although individual differences are frequently observed to all training programs, it appears that aquatic plyometric training elicits positive adaptations in many athletes, and does not appear to have detrimental effects on performance measures in those who did not experience increases. Therefore, the use of aquatic plyometric training to improve muscular power, strength, and speed during the rehabilitation process while reducing the additional musculoskeletal load experienced during traditional plyometric training provides a valuable tool for practitioners with rehabilitating athletes.

Practical Applications

The utilization of aquatic plyometric training can be an important piece of a rehabilitation program in order to reduce the stress on the joints and reduce muscle soreness, while improving lower body power. Peak impact force and impact force rate has been demonstrated to be lower in water as compared to land, whereas peak concentric force is higher for aquatic plyometric training during both double leg and single leg jumping (Colado et al., 2010; Triplett et al., 2009). Such an outcome may be beneficial during multiples phases of the rehabilitation process and aid in the primary goal of returning athletes to sport successfully and efficiently. In addition, a reduced perceived muscle soreness following aquatic versus land plyometric training may be experienced by athletes (Robinson et al., 2004). Based on the literature, it is recommended that aquatic plyometric training be incorporated with rehabilitating athletes as a means of improving lower body strength, speed, and power, while reducing the risk of re-injury or exceeding load tolerance. Specifically, the program should progress the number of jumps in a session as tolerable with two to three aquatic plyometric sessions per week for four to eight weeks. Aquatic plyometric programming should consider the current training status of the athlete, as well as the physical demand of the sport that the athlete is returning to. When determining water depth for aquatic plyometric training, it is recommended that practitioners prescribe based on desired impact forces. Chest-deep water immersion provides a greater resistance during the concentric or upwards movements of the jump while providing lower impact forces. In contrast, knee-deep water immersion is more similar to land in terms of resistance in the upwards movement, as well as impact forces. Both of these depths improved lower-body strength, speed, and power. Therefore, using a variety of depths that produce impact forces that the athlete can tolerate and provide a concentric and eccentric load similar to the required demands of his or her sport is recommended as part of the rehabilitation and return-to-sport protocol.

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Authors' Qualifications

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