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Effect of Acute Aquatic Plyometric Training on Muscle Strength, Edema and Pain

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Abstract

The purpose of this study was to investigate the pre- and post-exercise performance, edema, and pain of plyometrics in water and land environments. Twelve males in their 20s were selected as subjects and performed 10 sets of squat jumps 10 times in 2 environmental conditions (water and ground). There was no significant difference in iEMG of vastus medilais according to exercise conditions and time. In MPV of CMJ, there was no significant difference according to exercise conditions and time. The thigh circumference showed a significant difference according to the exercise condition and time, and was higher in the ground condition after exercise. There was a significant difference in pain according to the exercise condition and time, and it was found to be high after exercise, 48 hours, and 72 hours in the ground condition. We believe that plyometric training in an aquatic environment will have less swelling and pain compared to plyometric training conducted in a land environment, and the pain will improve quickly, so we think that training can be conducted in a relatively shorter period than in the land environment.

Keywords: *Plyometric Training, Water Exercise, EMG, CMJ Velocity, Circumference, Pain*

1. Introduction

Plyometric training is a training technique that generates explosive power by inducing energy utilization in the series elastic component(SEC) composed of muscle-tendon units and parallel elastic component(PEC) composed of muscle spindle and non-elastic tissue in muscle by utilizing motions such as jumping, running, and hopping. The rapid renal contraction of the muscles and the powerful shortening contraction that follows after the short amortization increase the neuromuscular activity [1]. Plyometric training has the effect of average power and velocity, maximum power and acceleration, energy storage of SEC, and increase of muscle activity [2-4], and is applied as an essential component of training programs and rehabilitation programs for conditioning and performance improvement [5].

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The eccentric contractions during plyometric training are 10-40% larger than those of the concentric contractions, and have the disadvantage of causing micro-traumatic damage to connective tissues while the muscles are extended, resulting in strong fatigue and damage [6, 7].

Excessive plyometric training is known to result in reduced exercise muscle strength, temporary loss of exercise range, edema, and severe pain, and as an alternative to supplement these shortcomings, it is known that plyometric training in underwater environment is being presented [8-12].

Underwater environments are less burdened on muscle, bone and connective tissue than ground environments, and provide three-dimensional resistance to all movements of flooded segments, thus reducing renal contraction and requiring additional muscle activity to perform ground-like operations [9, 13]. The training using underwater resistance was reported to bring significant improvements to exercise performanc, and many previous studies reported that muscle strength training in underwater environments brought improvements similar to ground environment [14, 15].

Resistance exercise in underwater environments has been proved to be lower muscle damage than ground environment [16, 17], and it is proposed that underwater activities should be included in training programs to strengthen muscle strength in sports rehabilitation field, but studies on acute responses of exercise for microcycle configuration of training periodization are still insufficient.

This study aims to compose reference data for the short-term training frequency of underwater plyometric training by comparing and analyzing factors of ground plyometric and pre-post exercise electromyography(iEMG), mean propulsive velocity(MPV) of countermovement jump(CMJ), edema, and pain for practical application of underwater plyometric training.

2. Experiment Materials and Methods

2.1 Subject

The study was conducted on 12 healthy men in their 20s who were attending C city D university. The researcher fully explained the significance, purpose and procedure of the study to the subjects, and selected only the subjects who voluntarily signed their own autographs in the consent for participation in the study while they were fully aware of the contents of this study. In order to obtain accurate research results, before the experiment, moderate or higher physical activity was refrained from smoking and drinking. The characteristics of the subjects are as shown in Table 1.

Table 1. Characteristics of the subjects

	Height(cm)	Weight(kg)	Muscle mass(kg)	body fat (%)	BMI
N=12	174.25±5.01	73.83±10.69	33.57±4.29	19.69±3.71	24.19±2.22

2.2 Study Design

This study was conducted in A-hour D-spa, and the subjects were randomly divided into ground and underwater exercise conditions, and exercised twice a week with one condition. EMG, MPV of CMJ, and Circumference were measured before and after exercise, and pain was measured before, after, after 48 hours, and after 72 hours.

2.3 Flyometric Exercise Method

The subjects were given a short preparatory exercise consisting of 10 minutes of general leg muscle stretching, and 10 sets of maximum squat jumps, which were proven protocols in inducing damage to the knee extensor by plyometric exercise, and had a recovery time of 60 seconds between sets[18, 19]. Before performing the maximum squat jump, the subjects performed the maximum squat jump for reference in the field, and at this time the maximum height reached by the head end was designated as the highest point of the jump. The minimum target height of each jump during exercise is up to 95% of the maximum height, and the monitors for each subject are kept during the exercise to continuously observe and maintain the height of the jump. In the landing motion, the knee joints were bent to about 90 degrees, and the hip joints were bent to minimize bending. During the exercise, the subjects were asked to put their hands behind their heads to prevent the intervention of jump due to arm movement. During the break between sets, participants were allowed to move freely, sit down, or stretch lightly.

2.4 EMG Measurement

To check muscle activity before and after exercise, a surface electrode was attached to the vastus medial muscle using a 4-channel EMG(Korean, Laxtha). The maximum voluntary isomeric contraction(MVIC) posture induced maximum contraction of the knee extensor by placing the subject on the chair and fixing the bending angle of the right knee at 45~60°. Vastus medillais was placed on the upper part of the knee bone as far as four fingers. When attaching the electrodes, two were attached each to the site 1 cm apart from the insertion site of the intramuscular electrode. It was monitored by designating the channel of the muscle at the electrode attachment site in the EMG program.

2.5 MPV of CMJ

To measure the MPV of CMJ, a radio speed measuring device (CANADA, PUSH) was attached to a plastic bar to be located on the upper and rear triangular muscles of the shoulder bone of the subject. In the stand-up position, the knee was bent to 90° and then ordered to jump with maximum force.

2.6 Circumference

The circumference measurement of the femur was used with a flexible and non-elastic tape measure. The subjects measured the maximum circumference of the center of the femur in a posture with the measured position on the support and the knee bent at 90°. In order to reduce the error in measurement, subcutaneous fat tissue was not pressed.

2.7 Pain

The pain questionnaire used in this study was listed in the number of 1~10 and the case of feeling severe pain was 10, and the NRS(numeral rating scale) was used to designate the pain-free state as 1. The pain measurement was performed before and after exercise, 48 hours after exercise, and 72 hours after exercise.

2.8 Statistical Analysis

For data processing measured in this experiment, the mean and standard deviation of all variables were calculated using the IBM SPSS Statistics (ver 22.0) statistical program. All variables were analyzed by repeated measurement two-way ANOVA method. In case of significant difference, post-hoc was conducted by using Bonferroni method. Statistical significance level was set to =.05.

3. Result

3.1 Change of iEMG

There was no significant difference in iEMG of Vastus Medialis according to the performance conditions and time, and there was no interaction effect. Table 2 shows the results of repeated measures two-way ANOVA of the difference in iEMG of Vastus Medialis according to the performance conditions (aquatic environment and land environment) and time (before and after) during plyometric exercise.

Table 2. Change of iEMG(μV)

Part	Condition	Pre	Post		F	p
Vastus	Water	198.02±56.84	188.79±54.61	Condition	0.006	0.938
medialis	Ground	196.66±64.65	187.99±35.51	Time	0.475	0.505
				C x T	0.000	0.987

3.2 Change of CMJ-MPV

There was no significant difference in MPV-CMJ according to the performance conditions and time, and there was no interaction effect. Table 1 shows the results of repeated measures two-way ANOVA of the difference in MPV-CMJ according to the performance conditions (aquatic environment and land environment) and time (before and after) during plyometric exercise.

Table 3. Change of CMJ-MPV(m/s)

Part	Condition	Pre	Post		F	p
CMJ	Water	1.69±0.13	1.66±0.15	Condition	0.122	0.733
MPV	Ground	1.70±0.18	1.69±0.19	Time	3.070	0.108
				C x T	0.981	0.343

3.3 Change of circumference

There was a statistically significant difference in the circulation according to the conditions and time. As a result of post-test, both conditions were significantly increased after exercise, and ground conditions were higher than water conditions. The results of repeated measurement two-way ANOVA and post-hoc for the circulation are as shown in Table 4.

Table 4. Change of circumference(cm)

Part	Condition	①Pre	②Post	Post-hoc		F	p
Thigh	ⒶWater	52.00±3.30	53.00±3.07	①<②**	Condition	15.821	0.002

Circumfe	ⒷGround	52.42±3.12	54.17±3.01	①<②***	Time	49.296	0.000
rence	Post-hoc		Ⓐ>Ⓑ***		C x T	9.000	0.012

*M±SD, C x T: Interaction effect, **p<.01,***p<.001*

3.2 Change of pain

Pain showed statistically significant difference according to the conditions and time. As a result of post-test, both conditions were significantly increased after exercise and decreased after 72 hours. The ground condition was found to be greater than the water condition. The results of repeated measurement two-way ANOVA and post-verification for pain are as shown in Table 5.

Table 5. Change of pain

Part	Condition	①Pre	②Post	③Post 48h	④Post 72h	Post-hoc		F	p
NRS	ⒶWater	1.00 ±0.00	3.50 ±1.45	3.33 ±0.98	1.08 ±0.51	①<②*③>④***	Condition	123.347	0.000
	ⒷGround	1.00 ±0.00	6.25 ±1.91	6.83 ±0.72	2.17 ±1.03	①<②③>④***	Time	86.609	0.000
	Post-hoc		Ⓐ>Ⓑ***	Ⓐ>Ⓑ***	Ⓐ>Ⓑ**		C x T	28.780	0.000

*M±SD, C x T: Interaction effect, **p<.01,***p<.001*

4. Discussion

Traditionally, plyometric training has been conducted only in land-based environments, and it has shown the advantage of greatly improving motor ability because it can cause power full contraction of muscles, but there are disadvantages that cause injury of muscle-tendon unit [20, 21]. Underwater activity reduces joint compressive force and weight load, and provides 12 times air resistance due to high density, which can produce exercise effects similar to ground training [22, 23]. Recently, an underwater plyometric training is proposed to reduce the injury rate and improve the athletic ability. This study aims to construct reference data for setting training frequency by investigating the exercise performance, edema, and pain before and after the exercise of plyometric in underwater and ground environment.

The iEMG, one of the iEMG methods, is used as an indicator of muscle activity and increases as the mobilization of exercise units and the exercise strength increase [24]. In this study, iEMG of vastus medialis showed no statistically significant difference, but it showed a similar decrease after exercise. This suggests that the plyometric training, which exerts maximum power, has caused the nerve muscle to become tired, and the training effects of two environments (water, ground) are similar[25].

CMJ is measured to monitor lower body power output and is used as an indicator of motor performance because it provides insight into neuromuscular function and fatigue [26]. In this study, MPV of CMJ did not show any difference according to conditions and time, but showed a slight decrease after exercise. It is a result of the decrease of muscle activity of vastus medialis, one of the main muscles of CMJ, and it is believed that it was influenced by plyometric training. As such, it shows that the effect of underwater plyometrics shows neuromuscular fatigue similar to that of the ground environment, and shows a view consistent with previous studies that the training effect was similar[15, 27].

An increase in muscle circumference due to a one-time exercise means an edema phenomenon that occurs due to an increase in the amount of blood flowing into the muscle, not an increase in the muscle hypotrophy. During exercise, muscles obtain substances necessary for energy synthesis through blood vessels or discharge waste and by-products after energy synthesis. This phenomenon acutely increases body circumference after exercise, It is known to be associated with strength[28]. During acute plyometric exercise in this study, the circumference of the thigh showed a statistically significant increase after exercise than before exercise in both underwater and ground conditions, and the degree of increase was relatively higher in ground condition. Exercise in water reduces the load on the lower extremities by 50-90% of the body weight depending on the depth due to buoyancy [13]. This buoyancy can affect the exercise intensity during the upper-lower pattern exercise, and it is thought that stronger flexural contraction occurred during the squat jump in the ground condition than in the water condition. eccentric contraction requires greater force than concentric contraction and activates more motor units[29]. Therefore, in this study, the increase in the circumference of the thigh after exercise than before exercise is considered to be an edema phenomenon caused by acute plyometric exercise, and it is thought that the circumference of the ground condition increased significantly due to the decrease in the load due to buoyancy.

Muscle fatigue during exercise is caused by several factors and mainly occurs in skeletal muscle. Delayed onset muscle soreness(DOMS) is known to increase as the total amount of exercise increases [30, 31], and peaks at 24-72 hours after exercise cessation and decreases thereafter [32]. It is known that DOMS is caused by causes such as lactic acid, muscle spasm, connective tissue damage, muscle damage, inflammation, and enzyme leakage [33]. The higher the total amount of exercise, the higher the DOMS [34]. In this study, DOMS increased in both land and water conditions, and was highest after 48 hours, and recovered again after 72 hours. Also, immediately after exercise, 48 hours, and 72 hours after exercise, the above-ground conditions showed higher values than the underwater conditions. This showed the same pattern as the point of time when pain occurred in the study that the DOS was highest and gradually decreased at 24-72 hours after exercise, and the higher DOMS in the ground condition was 50% higher than the weight bearing in the ground condition due to buoyancy in the aquatic condition. It is thought to be the result of exercise with a low load [13].

5. Conclusion

This study showed the following results by examining the speed of vastus medialis, iEMG and CMJ of vastus medialis, vastus lateralis, and CMJ before and after exercise during plyometric training according to aquatic and terrestrial environments. There was no statistically significant difference in iEMG of vastus medialis according to exercise conditions and time. The MPV of the CMJ did not show a statistically significant difference according to the exercise conditions and time. The thigh circumference showed a statistically significant difference according to the exercise condition and time, and was higher in the ground condition after exercise. There was a significant difference in pain according to the exercise condition and time, and it was found to be high after exercise, 48 hours, and 72 hours in the ground condition. As a result of analyzing the results of this study, we found that the plyometric training conducted in the aquatic environment showed relatively lower swelling and pain immediately after exercise compared to the plyometric training conducted in the land environment, and the recovery trend of delayed muscle pain was also relatively low. found something positive. Through this, we believe that plyometric training conducted in water can be performed more frequently with a relatively shorter cycle than on land if the amount and intensity of exercise are adjusted, compared to plyometric training conducted on the ground.

References

[1] E. S.-S. de Villarreal, et al., "Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis," The Journal of Strength & Conditioning Research, 23, 2, 495-506, March 2009. DOI: https://doi.org/10.1519/JSC.0b013e318196b7c6

[2] J. Hill and M. Leiszler, "Review and role of plyometrics and core rehabilitation in competitive sport," Current sports medicine reports, 10, 6, 345-351, Nov 2011. DOI: https://doi.org/10.1249/JSR.0b013e31823b3b94

[3] M. M. Jarvis, P. Graham-Smith, and P. Comfort, "A methodological approach to quantifying plyometric intensity," Journal of strength and conditioning research, 30, 9, 2522-2532, Sep 2016. DOI: https://doi.org/10.1519/JSC.0000000000000518

[4] E. S.-S. De Villarreal, B. Requena, and R. U. Newton, "Does plyometric training improve strength performance? A meta-analysis," Journal of science and medicine in sport, 13, 5, 513-522, Sep 2010. DOI: https://doi.org/10.1016/j.jsams.2009.08.005

[5] G. J. Davies and B. L. Riemann, Curr.0ent Concepts of Plyometric Exercises for the Lower Extremity, in Return to Sport after ACL Reconstruction and Other Knee Operations. Springer, 277-304, Nov 2019. DOI: https://doi.org/10.1007/978-3-030-22361-8_13

[6] D.K. DeNuccio, G.J. Davies, and M.J. Rowinski, "Comparison of quadriceps isokinetic eccentric and isokinetic concentric data using a standard fatigue protocol," Isokinetics and Exercise Science, 1, 2, 81-86, Feb 1991. DOI: https://doi.org/ 10.3233/IES-1991-1205

[7] J.C. Gray and J.M. Chandler, "Percent decline in peak torque production during repeated concentric and eccentric contractions of the quadriceps femoris muscle," Journal of Orthopaedic & Sports Physical Therapy, 10, 8, 309-314, Feb 1989. DOI: https://doi.org/10.2519/jospt.1989.10.8.309

[8] P.M. Clarkson, K. Nosaka, and B. Braun, "Muscle function after exercise-induced muscle damage and rapid adaptation," Medicine and science in sports and exercise, 24, 5, 512-520, May 1992.

[9] D. Clutch, et al., "The effect of depth jumps and weight training on leg strength and vertical jump," Research quarterly for exercise and sport, 54, 1, 5-10, Apr 1983. DOI: https://doi.org/10.1080/02701367.1983.10605265

[10] D.T. Gulick, et al., "Various treatment techniques on signs and symptoms of delayed onset muscle soreness," Journal of athletic training, 31, 2, 145, June 1996.

[11] J.M. Saxton, et al., "Neuromuscular dysfunction following eccentric exercise," Medicine and science in sports and exercise, 27, 8, 1185-1193, Aug 1995. DOI: https://doi.org/10.1249/00005768-199508000-00013

[12] O.A. Donoghue, H. Shimojo, and H. Takagi, "Impact forces of plyometric exercises performed on land and in water," Sports health, 3, 3, 303-309, April 2011. DOI: https://doi.org/10.1177/1941738111403872

[13] M. Layne, Water Exercise. Human Kinetics, 2015

[14] J.D. Stemm and B.H. Jacobson, "Comparison of land-and aquatic-based plyometric training on vertical jump performance," Journal of Strength and Conditioning Research, 21, 2, 568, May 2007.
DOI: https://doi.org/10.1519/00124278-

[15] T.J. Louder, C.J. Searle, and E. Bressel, "Mechanical parameters and flight phase characteristics in aquatic plyometric jumping," Sports biomechanics, 15, 3, 342-356, Nov 2016.
DOI: https://doi.org/10.1080/14763141.2016.1162840

[16] P.D. Pantoja, et al., "Effect of resistive exercise on muscle damage in water and on land," The Journal of Strength & Conditioning Research, 23, 3, 1051-1054, May 2009.
DOI: https://doi.org/ 10.1519/JSC.0b013e3181a00c45

[17] V. Wertheimer, L. Antekolovic, and B.R. Matkovic, "Muscle damage indicators after land and aquatic plyometric training programmes," Montenegrin Journal of Sports Science and Medicine, 7, 1, 13-19, Mar 2018.
DOI: https://doi.org/10.26773/mjssm.180302

[18] C. Twist and R. Eston, "The effects of exercise-induced muscle damage on maximal intensity intermittent exercise performance," European journal of applied physiology, 94, 5, 652-658, May 2005.
DOI: https://doi.org/10.1007/s00421-005-1357-9

[19] V. Marginson, et al., "Comparison of the symptoms of exercise-induced muscle damage after an initial and repeated bout of plyometric exercise in men and boys," Journal of Applied physiology, 99, 3, 1174-1181, Sep 2005.
DOI: https://doi.org/10.1152/japplphysiol.01193.2004

[20] H. Arazi and A. Asadi, "The effect of aquatic and land plyometric training on strength, sprint, and balance in young basketball players," Mar 2011.
DOI: https://doi.org/10.4100/jhse.2011.61.12

[21] L.E. Robinson, et al., "The effects of land vs. aquatic plyometrics on power, torque, velocity, and muscle soreness in women," Journal of Strength and Conditioning Research, 18, 1, 84-91, Feb 2004.
DOI: https://doi.org/https://doi.org/10.1519/00124278-200402000-00012

[22] M.G. Miller, et al., "Comparisons of land-based and aquatic-based plyometric programs during an 8-week training period," Journal of Sport Rehabilitation, 11, 4, 268-283, Nov 2002.
DOI: https://doi.org/https://doi.org/10.1123/jsr.11.4.268

[23] D.T. Gulick, et al., "Comparison of aquatic and land plyometric training on strength, power and agility," The Journal of Aquatic Physical Therapy, 15, 1, 11-18, Apr 2007.

[24] C.J. Mottram, et al., "Motor-unit activity differs with load type during a fatiguing contraction," Journal of neurophysiology, 93, 3, 1381-1392, Mar 2005.
DOI: https://doi.org/10.1152/jn.00837.2004

[25] B. Jidovtseff, et al., "Influence of jumping strategy on kinetic and kinematic variables," Journal of sports medicine and physical fitness, 54, 129-138, Feb 2014.

[26] J.J. McMahon, et al., "Understanding the key phases of the countermovement jump force-time curve," Strength & Conditioning Journal, 40, 4, 96-106, Aug 2018.
DOI: https://doi.org/10.1152/jn.00837.2004

[27] J. Whitehill Jr, N. Constantino, and M. Sanders, "Balance and agility performance responses to a water exercise program for land athletes," International Journal of Aquatic Research and Education, 4, 328-329, Aug 2010.

DOI: https://doi.org/10.25035/ijare.04.03.10

[28] G. Sjogaard, R.P. Adams, and B. Saltin, "Water and ion shifts in skeletal muscle of humans with intense dynamic knee extension," American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 248, 2, R190-R196, Feb 1985.
DOI: https://doi.org/10.1152/ajpregu.1985.248.2.R190

[29] P.V. Komi, V. Klissouras, and E. Karvinen, "Genetic variation in neuromuscular performance," Internationale Zeitschrift für angewandte Physiologie einschließlich Arbeitsphysiologie, 31, 4, 289-304, Dec 1973.
DOI: https://doi.org/10.1007/bf00693714

[30] M. Izquierdo, et al., "Effect of loading on unintentional lifting velocity declines during single sets of repetitions to failure during upper and lower extremity muscle actions," International journal of sports medicine, 27, 09, 718-724, June 2006.
DOI: https://doi.org/10.1055/s-2005-872825

[31] D.J. Szymanski, "Recommendations for the avoidance of delayed-onset muscle soreness," Strength & Conditioning Journal, 23, 4, 7, Aug 2001.
DOI: https://doi.org/10.1519/00126548-200108000-00009

[32] M. Cleak and R. Eston, "Muscle soreness, swelling, stiffness and strength loss after intense eccentric exercise," British journal of sports medicine, 26, 4, 267-272, Dec 1992.
DOI: https://doi.org/10.1136/bjsm.26.4.267

[33] K. Cheung, P.A. Hume, and L. Maxwell, "Delayed onset muscle soreness" Sports medicine, 33, 2, 145-164, Oct 2003.
DOI: https://doi.org/0112-1642/03/0002-0145/$30.00/0

[34] K. Pierce, R. Rozenek, and M.H. Stone, "Effects of high volume weight training on lactate, heart rate, and perceived exertion," J Strength Cond Res, 7, 4, 211-215, Nov 1993.
DOI: https://doi.org/10.1519/1533-4287(1993)007<0211:eohvwt>2.3.co;2