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The Impact of Water Depth and Speed on Lower Muscles Activation During Exercise in Different Aquatic Environments

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Abstract

This study aimed to investigate the effects of water depth and speed on the activation of lower muscles during squat exercises, utilizing electromyography(EMG). It involved ten male participants in there. Participants performed 30 squats over a minute at a speed of 60bpm and maximum speed squats until exhaustion within a minute. The Integrated electromyography(iEMG) readings for the rectus femoris showed statistically significant differences due to water depth and speed, with a significant interaction effect between depth and speed during squat exercises. The iEMG readings for the biceps femoris also showed statistically significant differences, with a significant interaction effect between depth and speed during squat exercises. The iEMG readings for the gastrocnemius showed statistically significant differences according to water depth and speed. However, the interaction effect of water depth and speed during squat exercises did not show a statistically significant difference. In contrast, the iEMG readings for the tibialis anterior demonstrated statistically significant differences, with a statistically significant interaction effect during squats. These findings suggest that water depth and speed positively influence the activation patterns of lower muscles. Therefore, appropriately tailored aquatic exercises based on water depth for individuals with musculoskeletal discomfort, including the elderly or those with physical impairments, can effectively reduce physical strain and enhance balance, as well as physical and perceptual aspects. It is concluded that such exercises could provide a safer and more effective method of exercise compared to ground-based alternatives.

Keywords: *Aquatic Exercise, Squat, Lower Muscles, iEMG, Depth, Speed*

1. Introduction

Aquatic exercise stands out as an effective means for increasing range of motion, muscle strength, and endurance due to the physical properties of water such as hydrostatic pressure, buoyancy, and viscosity, utilizing the various characteristics and capabilities of water [1-3]. The sensory signals provided by the viscosity of water are said to stimulate the muscles [4]. Additionally, aquatic exercise is known for its superior exercise effects and safety compared to ground-based exercise environments, allowing for exercise without physical strain [5]. The instability generated by the properties of water is known to increase with depth, making

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aquatic environments more unstable than ground [6]. Therefore, exercising in deeper water creates more instability compared to ground-based exercises, which leads to the generation of greater force in the body to maintain stability [7-10].

Aquatic exercise alters the load applied to the body weight depending on the depth of water. At the depth of the ASIS, the body weight load is 50%, at the depth of the xiphoid process, it is 25%, and at the depth of the 7th cervical vertebra, the load decreases to 10% [11]. Therefore, the difference in water depth affects the exercise load, and buoyancy reduces the load on the spine and joints, thus differing in training effects and reducing the intensity and frequency of pain in musculoskeletal disorders [12-16].

The squat, one of the most commonly used movements in various weight training regimes, is an exercise aimed at strengthening the muscles of the lower. Exercises like the squat, which involve coordinated actions of multiple muscle groups in a closed chain, require more joint movement compared to open chain exercises [17, 18] and are more effective in stimulating proprioception along with stability [19]. Moreover, squat exercises can improve the function of lower muscles, including the hip and ankle joints [20, 21]. In their study on varying the speed of squat exercises, stated that slow-speed squats can increase the efficiency of movement due to muscle activation [22-24], and reported that fast-speed squats, due to increased exercise volume, exercise energy, and impact, impose less strain on the body than slow-speed exercises [25].

Unlike on ground, in water, the speed of the exercise results in significant resistance due to the water, which increases the intensity of the exercise. This increase in exercise intensity is known to be influenced by the body’s balance, as well as gravity and buoyancy [26]. Squat exercises in water maintain balance through the activation of muscles around the ankle [l], effectively resolving imbalance in water [27]. Therefore, it is presumed that the activation of lower muscles will differ in the distinct environments of ground and water, even for the same movement. Most studies find it challenging to measure muscle activation during exercise in aquatic environments. Consequently, this study aimed to measure the changes in the activation of lower muscles during squat exercises in water, based on depth and speed, using integrated electromyography (iEMG), as the mobilization of the exercise unit increases with greater water depth.

2. Experiments

2.1 Subjects

The subjects of this study were selected as ten men in their twenties with at least six months of resistance training experience. Before participating in the study, subjects were informed about the study details, and only those who voluntarily expressed their willingness to participate signed the consent form for participation. To ensure accurate study results during the participation period, subjects were advised to refrain from intense physical activity before the experiments and were prohibited from smoking and drinking. The characteristics of the study subjects are as shown in Table 1.

Table 1. Physical characteristics of the subjects

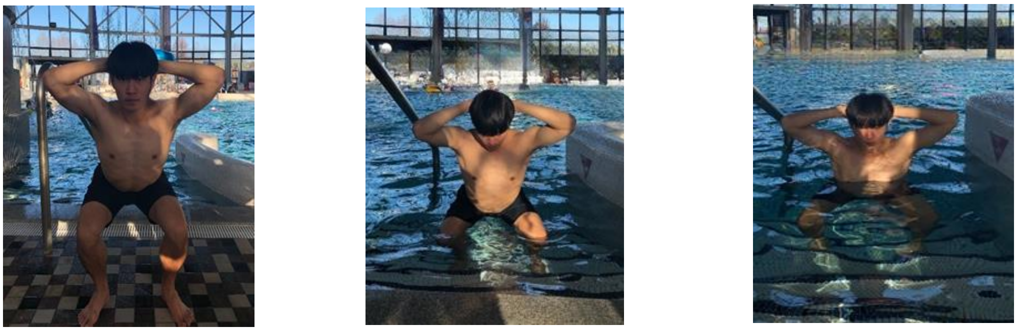
Age (yr)	Weight (kg)	Height (cm)	Exercise Experience (yr)
26.30±1.16	80.74±7.59	176.21±4.69	1.80±1.03

2.2 Experimental Design and Procedure

This experiment was conducted indoors at P Spa in city A. Participants arrived 30 minutes before the experiment to attach surface electrodes to the EMG measurement sites. Squats at a 60bpm Speed squats were performed for a total of 30 repetitions over one minute, and Max Speed squats were carried out at the maximum speed until exhaustion within a minute. The squat conditions were randomly assigned to ensure that participants could perform squats under all conditions. EMG signals were measured during the squat performance, and participants were advised to avoid intense physical activities other than their routine activities during the study period and to ensure sufficient rest the day before participating in the experiment.

2.3 Squat Execution According to Water Depth

The study participants performed squats at a 60bpm for a total of 30 repetitions over one minute according to water depth and speed, and Max Speed squats were carried out at the maximum speed until exhaustion within a minute. For both the 60bpm Speed and Max Speed squats, the knee angle was maintained at 90 degrees, ensuring the thighs were parallel to the ground. To consistently control the speed during the 60bpm Speed squats, a metronome app was used to perform the movement once every 2 seconds, and for the Max Speed squats, an assistant was present to ensure that the heels did not lift off the ground during maximum speed performance. During the squat exercises, participants raised their arms behind their head and spread their feet 15cm apart, facing forwards. The water temperature was maintained at 28°C to 30°C to minimize physiological changes during exercise. The specific methods of performing squats according to water depth are illustrated in Figure 2 (a), (b), (c).



(a). Ground (b). Knee Depth (c). Waist Depth

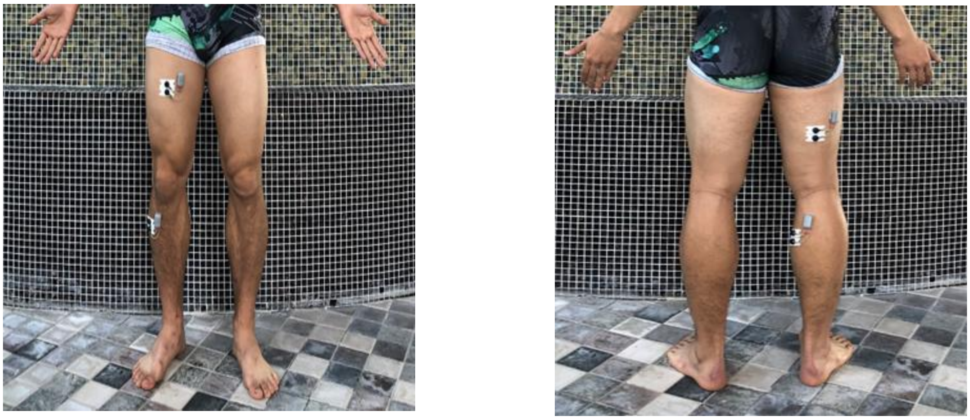
Figure 2. Methods of performing squat according to water depth

2.4 EMG Measurement Methods

(a), (b) in Figure 3 is EMG attachment sites were measured on the lower muscles, and a wireless underwater EMG measuring device was used to measure muscle activation. To ensure accurate data collection before measurement, the electrode attachment site was shaved to remove body hair and disinfected with alcohol swabs. Surface electrodes were attached 1cm apart from the electrode insertion site, following the guideline, with two electrodes per site. The specific attachment sites are shown in Table 2 and Figure 3.

Table 2. Surface electrodes attachment sites

Area	Attachment site
Biceps femoris	Midpoint between the head of the fibula and the ischial tuberosity
Rectus femoris	Midpoint between the anterior superior iliac spine and the patella
Tibialis anterior	Four finger widths below the tibialis and one finger width lateral to the tibial crest
Gastrocnemius	Five finger widths below the popliteal line towards the medial side of the calf



(a). Front (b). Back

Figure 3. Surface EMG electrode attachment sites

2.5 Data Processing Methods

The data processing methods in this study involved calculating the mean and standard deviation for all variables using the statistical program IBM SPSS Statistics (ver 22.0). The EMG of the lower muscles based on depth (3) and speed (2) was analyzed using the repeated measurement two-way ANOVA method. In cases where significant differences were observed due to depth or speed, post-hoc comparisons (contrast) employing both repeated and simple (first) were used. The statistical significance level was set at α=.05.

3. Results

3.1 Changes in Biceps Femoris Iemg According to Depth and Speed During Squat Exercise

The results of the repeated measures two-way ANOVA and post-hoc comparisons on the Iemg changes in the biceps femoris according to depth and speed during squat exercises are as shown in Table 3. The Iemg of the biceps femoris muscle showed statistically significant differences according to depth and speed (p<.001, p<.001). The interaction effect of depth and speed during squat exercises also showed a statistically significant difference (p<.001).

Table 3. Changes in biceps femoris iEMG according to depth and speed

	Ground	Knee	Waist		F	p
60bpm	790.19±104.11	1421.05±215.78	763.38±145.86	Depth	260.773	.000
				Speed	275.057	.000
Max	1728.30±177.19	3100.64±267.62	1212.78±147.38	D X S	105.498	.000

M±SD **p<.01,***p<.001

3.2 Changes in Rectus Femoris iEMG According to Depth and Speed During Squat Exercises

The results of the repeated measures two-way ANOVA and post-hoc comparisons on the iEMG changes in the rectus femoris according to depth and speed during squat exercises are as shown in Table 4. The iEMG of the rectus femoris showed statistically significant differences according to depth and speed (p<.001, p<.001). The interaction effect of depth and speed during squat exercises also showed a statistically significant difference (p<.001).

Table 4. Changes in rectus femoris iEMG according to depth and speed

	Ground	Knee	Waist		F	p
60bpm	4289.42±401.52	3519.88±412.01	1972.07±321.64	Depth	1431.740	.000
				Speed	1055.027	.000
Max	8923.91±395.52	8663.58±425.44	4128.18±447.53	D X S	117.361	.000

M±SD **p<.01,***p<.001

3.3 Changes in Gastrocnemius iEMG According to Depth and Speed During Squat Exercises

The results of the repeated measures two-way ANOVA and post-hoc comparisons on the iEMG changes in the gastrocnemius according to depth and speed during squat exercises are as shown in Table 5. The iEMG of the gastrocnemius showed statistically significant differences according to depth and speed (p<.001, p<.001). However, the interaction effect of depth and speed during squat exercises did not show a statistically significant difference.

Table 5. Changes in gastrocnemius iEMG according to depth and speed

	Ground	Knee	Waist		F	p
60bpm	987.85±174.04	787.35±118.35	856.76±112.27	Depth	10.153	.001
				Speed	398.744	.000
Max	1597.63±211.06	1490.50±156.24	1433.99±192.73	D X S	.957	.403

M±SD **p<.01,***p<.001

3.4 Changes in Tibialis anterior iEMG According to Depth and Speed During Squat Exercises

The results of the repeated measures two-way ANOVA and post-hoc comparisons on the iEMG changes in the tibialis anterior according to depth and speed during squat exercises are as shown in Table 6. The iEMG of the tibialis anterior showed statistically significant differences according to depth and speed (p<.001, p<.001). The interaction effect of depth and speed during squat exercises also showed a statistically significant difference (p<.001).

Table 6. Changes in tibialis anterior iEMG according to depth and speed

	Ground	Knee	Waist		F	p
60bpm	7992.15±660.80	5889.43±551.81	4459.51±382.45	Depth	245.669	.000
				Speed	697.882	.000
Max	12311.84±922.28	9851.30±760.58	6412.07±563.90	D X S	12.525	.000

M±SD **p<.01,***p<.001

4. Discussion

The core muscles are the origin of all movements and play a role in stabilizing the body during exercise, where the arms and legs movements stabilize the body and spine [28]. From a biomechanical perspective, the squat exercise is executed through bending and extending movements as the thighs and torso come closer together or move apart while the feet remain fixed to the ground. As the speed of exercise performance increases, the bending and extending movements intensify, leading to an increase in the muscle activation of the trunk flexor and extensor muscles [29].

During the squat movement, the biceps femoris muscle and the rectus femoris contribute to the stability of the knee joint through their simultaneous contraction activity, which also affects the muscle activation levels of the tibialis anterior and the calf muscles [30]. Additionally, the muscle activation of the biceps femoris during the descending phase is related to the erector spinae muscles, which rotate the pelvis backward and forward during the ascending phase [29].

These results indicate that during the descending phase of the squat movement, the contraction of the rectus abdominis muscle, a core flexor muscle, is involved. It is believed that in the water, muscles around the hip and ankle joints for posture control and balance maintenance were more activated compared to on ground [31]. Relatively, in deeper water levels around the waist, the buoyancy leads to a decrease in the load relative to body weight, which is thought to result in reduced muscle activation around the hip, knee, and ankle joints, as well as decreased activation in the core flexor muscles.

The muscle activation of the biceps femoris showed high levels during 60bpm Speed squats and Max Speed squats at knee depth, suggesting that the activation of the biceps femoris during exercise is more closely related to the core's flexor muscles, such as the rectus abdominis, than to the influence of the knee and ankle joints. On the other hand, the activation level of the biceps femoris muscle during the 60bpm Speed squats was relatively lower compared to the Max Speed squats, indicating that, as observed in the group with high muscle activation, the biceps femoris is also activated in accordance with the rectus abdominis during Max Speed squats. Additionally, the lower muscle activation of the biceps femoris at waist depth is thought to be related to the decrease in activation around the hip and knee joints due to the reduction in the core's flexor muscles and the buoyancy of water. Therefore, it can be seen that the core's flexor muscles and the erector spinae muscles are influenced by water depth.

In the biomechanical aspect of squat exercises, it is reported that the body's center line is positioned within the base of the foot during exercise movements, and the weight load is shared between the knee and hip joints. At this time, the muscles of these joints, the biceps femoris and the rectus femoris, simultaneously contract to increase the stability of the knee joint, resulting in increased muscle activation of both muscles [32].

Particularly, in this study, the muscle activation of the biceps femoris and the rectus femoris significantly increased at knee depth during Max Speed squats. This is thought to be influenced by the increased external resistance due to drag and flow, phenomena where water molecules adhere to the body surface, and it can be said that this factor led to the measured muscle activation being higher at knee depth compared to other depths. Furthermore, knee depth is considered to have a higher exercise intensity compared to other depths, and it is believed that knee depth has a direct association with the application of exercise intensity in water, indicating that there are differences in muscle activation of the biceps femoris muscle and the rectus femoris depending on the depth.

The cooperative action of the foot and ankle joint provides a mechanical contribution in terms of force transmission and distribution, and the fixation of the axis, significantly affecting bodily movements [33]. In the descending phase, posture is regulated through the control of the calf muscles and the tibialis anterior by the ankle joint strategy [29], and simultaneously, the angle of the ankle is related to the biomechanical and biomechanical functions of the knee and hip joints. This suggests that muscle mobilization is occurring in the chain movement of each and the muscle action in the proximal parts of each joint. The squat movement in water relies on the oscillation in the anterior-posterior direction, depending on the alternating activation of the tibialis anterior and the medial calf muscle, and the activation of the tibialis anterior begins before the body collapses forward beyond the vertical line, with the muscles in front of the knees and pelvis cooperating to provide body stability [34].

This study suggests that during the execution of squats, the calf muscles exhibit differences in muscle activation due to the reduction in relative weight bearing on the hip, knee, and ankle joints caused by buoyancy and drag when parts of the body come into contact with water during the descending phase. It is inferred that there will be differences in the degree of muscle activation based on water depth and speed. Moreover, significant differences were observed in the muscle activation of the tibialis anterior according to water depth and speed. This aligns with previous findings that in water, the weight load varies with depth [35], and the decrease in weight load can reduce muscle activation [36]. Squat movements in water rely on the activation of the tibialis anterior due to swaying in the front-to-back direction, and the activation of this muscle begins before the body tilts forward beyond the vertical line, with the muscles in front of the knees and pelvis working together to provide stability to the body. Therefore, it is believed that the Max Speed squat showed higher muscle activation compared to the 60bpm Speed squat, and the squat execution speed involves the use of hip and ankle postural adjustment mechanisms to maintain posture and balance during exercise.

5. Conclusion

This study aimed to investigate the effects of water depth and speed on the activation of lower muscles(Biceps femoris, Rectus femoris, Tibialis anterior, Gastrocnemius) during squat exercises, utilizing electromyography (EMG). It involved ten male participants in their 20s. Participants performed 30 squats over a minute at a speed of 60bpm and maximum speed squats until exhaustion within a minute. Integrating the above content, it was confirmed that the muscle activation of the lower muscle has a positive impact depending on the depth and speed of water. It suggests that aquatic exercises, appropriately structured according to the depth for individuals with musculoskeletal discomfort and the elderly or those with physical challenges, can reduce physical strain and contribute to improving balance abilities, physical, and perceptual aspects. Thus, it is deemed to be an efficient exercise method that could be safer and more effective than ground-based exercises when initiating exercise programs.

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