

## Effects of Maximum Repeated Squat Exercise on Number of Repetition, Trunk and Lower Extremity EMG Response according to Water Depth

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### Abstract

*The purpose of this study was to investigate the difference in the number of repetitions and the change in electromyographic response during the maximum speed squat exercise according to the depth conditions and the maximum speed squat exercise according to the time of each depth. Ten men in their 20s were selected as subjects and the maximum speed squat was performed for one minute in three environmental conditions (ground, knee depth, waist depth). We found that the number of repetitions according to the depth of water showed a significant difference, and as a result of the post-mortem comparison, the number of repetitions was higher in the ground condition and the knee depth than in the waist depth. And the muscle activity of rectus abdominis, erector spinae, rectus femoris, biceps femoris was increased during ground squat exercise, activity of all muscle was decreased during knee depth squat exercise, and activity of rectus abdominis, erector spinae, biceps femoris, tibialis anterior, gastrocnemius was decreased during waist depth squat. In conclusion, muscle activity of lower extremities during squat exercise in underwater environment can be lowered as the depth of water is deep due to buoyancy, but muscle activity of trunk muscles can be increased rather due to the effect of viscosity and drag.*

**Keywords:** *Squat, Repetition, EMG, Water Depth*

### 1. Introduction

Underwater exercise is a planned physical activity performed in the water environment, and it can be performed more safely than ground exercise. Therefore, it is possible to participate even if muscles or joints are weak. Due to special advantages such as buoyancy, water pressure, and drag, it is widely applied in the early and mid-stage of sports rehabilitation [1]. In particular, the weight burden reduction effect due to buoyancy is

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reduced to 50% at the anterior superior iliac spine (ASIS), 25% at the xiphoid process level, and 10% at the cervical vertebra 7 depth [2]. This can help improve balance and balance ability [3], greatly reducing weight load stress on muscles and joints [4], and can also proceed with exercise in situations with mild pain [5]. Viscous and drag, one of the factors that can change the exercise effect in the water, are proportional to the speed and area of movement in the liquid, and the resistance increases as the moving speed and area of the human body segments are large, and it is possible to move in multi-directionally because it acts regularly on all the inundated segments [6]. In addition, repeated motion in the water generates concentric contraction of the muscle group which is opposite to each other and constants the movement speed, resulting in similar effects to isokinetic muscle contraction [7]. Due to this speciality, exercise in the underwater environment has the advantage of being able to carry out exercise programs with the strength suitable for individuals without using expensive tools.

Squat is a typical closed chain exercise method that strengthens the muscle strength of the lower limbs, including joints and muscle movements of the lower limbs and trunk, and exercises that overcome gravity through coordination of various muscle groups due to more ankles, knees and hip movements than single joint exercises [8].

It has been confirmed that fatigue applied to muscles may vary depending on the depth of water in the water environment [9], but since the movement was performed according to the controlled execution speed, it is necessary to confirm the change of muscle activity when viscosity and drag are generated at the maximum motion speed.

In addition to the characteristics of the neuromuscular system, electromyogram(EMG) can provide information on muscle activation patterns [10], joint moment and neural control strategies, and underwater EMG is a reliable technique for analyzing muscle activation through appropriate waterproofing procedures [11]. Comparing EMG responses between ground and water, it is reported that the overall muscle activity is lower in underwater activities [12]. However, although it is accurate for the reduction of muscle activity in water, the reason is still unclear and there are some studies reported, so more follow-up studies are needed [13].

As mentioned above, underwater exercise can have different motor effects from the ground environment due to various water characteristics, which can be changed by factors such as buoyancy, viscosity and drag. In this study, we investigated the effect of exercise on the time-lapse of each depth when viscous and drag were maximized by investigating the body and lower limb muscle activity when squat motions that generate weight load and movement of various joints were performed at a rapid speed under different depth conditions.

## **2. Experiment Materials and Methods**

### **2.1 Subject**

The subjects of this study were 10 men in their 20s who had more than 6 months of resistance exercise experience in C city, Chungcheongnam-do, who voluntarily expressed their intention to participate in the study after hearing the significance of the study and the explanation of the experiment method. The selected subjects received a consent form for participation in the study, which included their autographs, and explained that they could quit at any time during the experiment period. In addition, in order to obtain accurate results during the experiment period, the subjects were taught to refrain from physical activities above the medium intensity before the experiment, and smoking and drinking were prohibited. The characteristics of the subjects are as shown in Table 1.

**Table 1. The characteristics of the subjects**

N	Age(year)	Weight(kg)	Height(cm)	Career(year)
10	26.40±1.17	81.60±8.55	174.60±4.16	1.40±0.70

M±SD

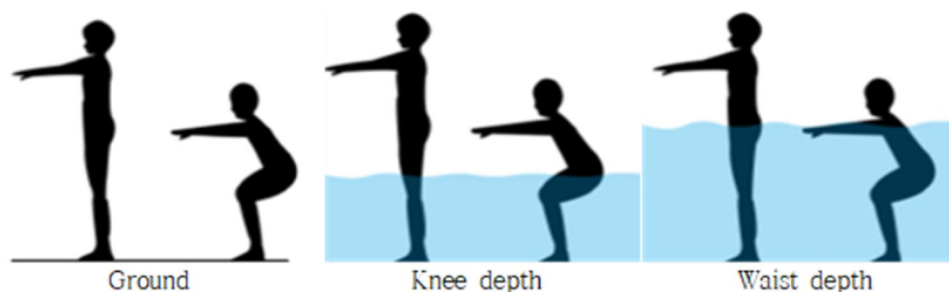
## 2.2 Study Design

The experiment was conducted at the A-city P-spa indoor aqua center, and the subject arrived 30 minutes before the experiment and was stabilized and attached with the surface electrode and measured MVIC for each part.

After that, the preparatory exercise was conducted for 10 minutes, and the squat operation was performed at a maximum speed for 1 minute by random arrangement allocating three water depth conditions. Supporters were placed to prevent heels from falling during exercise, and subjects were advised to avoid excessive exercise other than routine activities and to take sufficient sleep during the study period.

## 2.3 Squat Exercise Method

The subjects were at maximum speed for 1 minute following the squat motion at all depths. In the sitting position, the knee angle was 90°, and both arms were placed behind the head, both feet were opened at 15cm intervals and the gaze was directed forward. The temperature of water during exercise was maintained at 28°C ~ 30°C to minimize physiological changes and stabilize the deep temperature. The water depth condition for the experimental progress is the same as Figure 1.

**Figure 1. Water depth**

## 2.4 EMG Measurement

The EMG attachment sites were the rectus abdominis, erector spinae, rectus femoris, biceps femoris, tibialis anterior, gastrocnemius. To measure muscle activity, a wireless electromyography measuring device (Wave Plus, Cometa) and a waterproof-coated bio-signal transmitter (Mini Wave Waterproof, Cometa) were used. To obtain accurate data before measurement, the skin layer hair was removed by shaving the electrode attachment site, and the skin surface was disinfected by alcohol cotton after shaving. The surface electrodes were attached to the site 1 cm apart from the insertion part of the needing electrode by referring to the guideline, and the specific attachment part was the same as Figure 2.



**Figure 2. Surface electrode attachment site**

In order to standardize the action potential of each muscle, muscle activity was measured during maximum isometric contraction in muscle manual test posture. After collecting data for 5 seconds, the average EMG signal amount for 3 seconds except for the first and last seconds was used as %MVIC. After collecting data for 5 seconds, the average EMG signal amount for 3 seconds except for the first and last seconds was used as %MVIC. The measured data were extracted to observe the muscle activity in the raw data measured during exercise. The data were collected with 1,000 Hz signals per second, and the frequency range was set to 0-1,000 Hz, and then the input signal was amplified and converted into digital signals. For the comparison within the same subjects, the EMG signal average value of the target subjects was converted into maximum isometric contraction (%MVIC) integral EMG and analyzed by filtering (30Hz low pass, 350Hz high pass) and rectifying data values and converting them into RMS values.

## 2.5 Statistical Analysis

The data processing of this study was calculated by using IBM SPSS Statistics (ver 22.0) statistical program to calculate the average and standard deviation of all variables. The number of repetitions according to the depth of water condition during maximum speed squat motion for 1 minute was analyzed using the repeated measurement one-way ANOVA method, and the %MVIC value for each depth condition for 10 seconds was analyzed using the repeated measurement one-way ANOVA method. When significant differences occur, the repeated and simple methods of contrast were applied, and the statistical significance level was set  $\alpha=.05$ .

## 3. Result

### 3.1 Differences in the Number of Repetition according to the Depth

The number of repetitions according to the depth of water showed a significant difference, and the result of post comparison showed that the number of repetitions was higher than the waist depth in ground conditions and the waist depth in knee depth than the waist depth. The results of the one-way ANOVA and contrast of the repeated number according to the depth of water during the maximum speed squat exercise are as shown in Table 2.

**Table 2. Differences in the number of repetition according to the depth**

	Ground	Knee depth	Waist depth	F	<i>p</i>	contrast
Number of Repetition	68.90±3.87	67.30±3.56	58.80±2.25	46.020	0.000	Ⓐ<Ⓒ*** Ⓑ<Ⓒ***

M±SD, \*\*\**p*<.001

### 3.2 Changes in Muscle Activity by Time during Ground Squat Exercise

In the ground squat exercise, all muscles except the gastrocnemius showed significant changes. The contrast results showed that the rectus abdominis, rectus femoris, tibialis anterior, and the erector spinae increased from 20 seconds to 40 seconds. The results of repeated measurement one-way ANOVA and contrast of muscle activity by time during ground squat exercise are as shown in Table 3.

**Table 3. Changes in muscle activity by time during ground squat exercise**

	10sec	20sec	30sec	40sec	50sec	60sec	F	<i>p</i>
Rectus abdominis	272.25 ±30.62	*312.14 ±31.29	316.03 ±38.08	321.38 ±30.28	324.65 ±33.28	286.84 ±41.41	4.160	0.003
Erector spinae	701.74 ±29.41	683.38 ±26.89	692.02 ±33.09	*729.99 ±35.25	755.00 ±26.02	745.59 ±27.76	10.017	0.000
Rectus femoris	1495.22 ±109.20	*1630.32 ±109.68	1556.73 ±95.14	1587.35 ±124.41	*1435.39 ±97.83	1421.92 ±104.17	7.195	0.000
Biceps femoris	268.71 ±23.74	278.47 ±25.54	282.36 ±26.28	288.90 ±19.89	315.99 ±26.17	319.34 ±31.08	7.507	0.000
Tibialis anterior	2775.35 ±158.09	**2511.88 ±142.89	***1974.55 ±118.98	1849.60 ±171.97	**1668.69 ±184.14	1586.43 ±148.39	110.844	0.000
Gastrocnemius	277.93 ±21.79	275.13 ±27.48	270.80 ±30.15	270.73 ±33.98	281.05 ±25.89	271.81 ±22.45	.381	0.859

M±SD, Significant differences between time of before: \**p*<.05, \*\**p*<.01, \*\*\**p*<.001

### 3.3 Changes in Muscle Activity by Time during Knee Depth Squat Exercise

The knee depth squat exercise showed significant changes in all muscles. The results of contrast showed that the rectus abdominis and gastrocnemius decreased from 40 seconds, the erector spinae and biceps femoris decreased from 30 seconds, the rectus femoris and tibialis anterior decreased from 20 seconds. The results of repeated measurement one-way ANOVA and contrast of muscle activity by time during knee depth squat exercise are as shown in Table 4.

**Table 4. Changes in muscle activity by time during knee depth squat exercise**

	10sec	20sec	30sec	40sec	50sec	60sec	F	<i>p</i>
Rectus abdominis	358.27 ±30.49	375.79 ±26.67	366.85 ±25.55	*333.70 ±27.46	322.92 ±29.09	317.23 ±31.02	6.479	0.000
Erector spinae	671.34 ±31.25	641.46 ±35.39	**602.48 ±24.54	*630.17 ±28.67	650.65 ±37.56	619.89 ±40.97	5.707	0.000
Rectus femoris	1535.36 ±89.32	**1405.29 ±133.68	*1503.01 ±140.34	1455.62 ±84.18	1427.18 ±95.12	1445.31 ±121.87	2.508	0.044
Biceps femoris	454.44 ±35.01	489.41 ±32.06	**437.65 ±26.06	404.84 ±32.78	**481.33 ±31.60	489.21 ±37.17	10.116	0.000
Tibialis anterior	2078.90 ±200.97	***1697.55 ±114.52	*1583.75 ±115.90	1521.48 ±138.64	1452.27 ±130.08	**1258.73 ±114.36	48.243	0.000

Gastrocne mius	264.66 ±28.87	280.06 ±28.29	269.39 ±35.35	*241.68 ±30.47	244.20 ±29.63	*234.13 ±29.65	5.752	0.000
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M±SD, Significant differences between time of before: \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

### 3.4 Changes in Muscle Activity by Time during Waist Depth Squat Exercise

In the waist depth squat exercise, all muscles except the rectus femoris showed significant changes. The results of contrast showed that the rectus abdominis decreased from 40 seconds, the erector spinae and tibialis anterior and gastrocnemius decreased from 20 seconds, the biceps femoris decreased from 50 seconds. The results of repeated measurement one-way ANOVA and contrast of muscle activity by time during waist depth squat exercise are as shown in Table 5.

**Table 5. Changes in muscle activity by time during waist depth squat exercise**

	10sec	20sec	30sec	40sec	50sec	60sec	F	p
Rectus abdominis	161.28 ±19.39	157.44 ±18.19	171.44 ±20.61	*148.28 ±16.44	154.36 ±13.95	148.92 ±19.93	2.703	0.032
Erector spinae	582.56 ±42.05	*541.63 ±32.21	*586.92 ±36.01	550.34 ±39.35	575.41 ±39.32	591.85 ±50.54	2.810	0.027
Rectus femoris	759.52 ±76.87	720.84 ±91.74	762.47 ±86.51	766.89 ±80.51	769.40 ±93.84	741.43 ±79.30	.767	0.578
Biceps femoris	212.58 ±21.97	233.67 ±22.77	231.47 ±19.16	231.01 ±18.94	**208.71 ±18.96	204.55 ±23.41	4.316	0.003
Tibialis anterior	1412.76 ±117.58	**1239.98 ±109.62	**1124.56 ±111.54	1114.87 ±109.34	1034.31 ±146.22	*866.93 ±101.93	30.396	0.000
Gastrocne mius	280.64 ±22.40	*239.66 ±21.06	247.13 ±28.09	252.70 ±30.36	250.44 ±28.69	230.53 ±20.64	6.206	0.000

M±SD, Significant differences between time of before: \* $p < .05$ , \*\* $p < .01$

## 4. Discussion

Underwater exercise can have different exercise effects from the ground due to the characteristics of water such as buoyancy, viscosity and drag, and it can also be a factor that can change the exercise intensity. Therefore, this study aims to discuss the difference in the number of repetitions and the change in EMG response in the maximum speed squat exercise according to the water depth condition and the maximum speed squat exercise according to the time of each water depth.

Repetition includes the following: continuous completion of a specific motion; and the duration of the motion until it is impossible to perform the motion due to muscle fatigue (set to failure), or counting the number of motions performed within a predetermined time [14]. The factors that reduce the number of repetitions during the maximum recursive exercise are reduction of neuroconductivity due to fatigue of the central nerve [15], depletion of energy substrates in the local area due to anoxic exercise performance and leakage of metabolic products [16]. Viscosity, defined as surface friction with objects moving in water due to the property that water molecules do not want to fall off, generates drag acting in the opposite direction of the direction of the fluid moving, increasing the workload required for the muscles [17], and this drag generates resistance in all movements of the flooded body segments, resulting in muscle tone and oxygen consumption. It was said that consumption would be increased [17]. In addition, the movement of the body in the water causes short muscle contraction

in both concentric and eccentric directions due to drag and maintains the motion speed constant [7].

As a result of this study, the number of repetitions according to the depth of water showed a significant difference when the maximum speed squat was performed for one minute, and the waist depth was lower than the ground condition and the knee depth. This is because the waist depth condition is larger than other conditions, so the drag that occurs as the speed moves faster increases, so that the speed of motion is kept constant unlike the intended maximum speed. In addition, there was no difference in the number of repetitions between ground conditions and knee depth conditions, because the body and femoral area were not flooded during squat exercise, and it was thought that it was not influenced by viscosity and drag, which are the characteristics of water. Previous researchers reported high heart rate and lower limb muscle activity under underwater conditions when ground treadmill exercise and underwater treadmill exercise were performed at the same rate [18].

Muscle activity during exercise is caused by calcium release of the musculature network caused by the transfer of the action potential from the central nervous system to the musculature membrane [19], and the test technique that detects and amplifies the fine potential difference in the musculature membrane during this process is called EMG analysis [20]. The iEMG which integrates the rectified signal among the EMG analysis method and produces is used as an indicator to quantify the activity amount of the muscle because the number and rate of the mobilized exercise unit can be known [21]. In this study, the changes in muscle activity were analyzed by 10 seconds when performing squat motion at maximum speed for 1 minute for each condition (ground, knee depth, waist depth).

In ground conditions, the rectus abdominis and rectus femoris increased at 20 seconds, and the erector spinae increased at 40 seconds. The maximum speed squat operation ground conditions can be faster than the underwater environment, and the number of repetitions is high, so that the maximum performance of the individual can be demonstrated [22]. In addition, the increased iEMG is due to the mobilization of additional exercise units for continuous exercise performance, which can be predicted to start muscle fatigue. On the other hand, tibialis anterior tended to decrease, which is thought to be due to the reduction of the rate of ignition and the mobilization of the exercise unit caused by central fatigue rather than local fatigue.

In knee depth, the rectus abdominis, gastrocnemius decreased in 40 seconds, the erector spinae, biceps femoris decreased in 30 seconds, and the rectus femoris and tibialis anterior decreased in 20 seconds. The underwater environment can have the effect of weight loss unlike the ground [23], and the viscosity and drag of fluid increases by resisting the speed and area of moving body segments [6]. This effect is seen as a cause of lower number of repetition than ground conditions because underwater environment keeps the motion speed constant. Unlike the ground where iEMG increases, the tendency to decrease underwater is due to the gain of weight load due to buoyancy in the descent of the squat, and it is thought that the muscle fatigue has occurred due to the effect of weight load relief due to the buoyancy effect of water at the moment when the body segment comes in contact with water outside the water [24]. The tendency of increase of rectus abdominis and erector spinae in the waist depth condition is thought to have caused the burden due to the viscosity and drag because it is flooded from the squat downward position to the trunk. The significant difference between the main muscle, rectus femoris, and the decrease in gastrocnemius activity were thought to be due to the lowest weight load [4].

## **5. Conclusion**

We tried to find out the difference in the number of repetitions and the EMG response changes during maximum speed squat exercise according to the depth condition and each depth time. In this study, it was found that there was a difference in exercise number of repetition and muscle activity during squat exercise at

maximum speed according to ground and underwater conditions. The deeper the depth, the lower the activity of lower extremity muscle and the more the activity of the trunk muscle. This suggests that it is appropriate to exercise at low depths for the training of the lower limbs, and that exercising at deep depths can be helpful for the training of the trunk. In conclusion, it is possible to determine the depth of water suitable for exercise according to the purpose of training and the subjects. If the effect verification of exercise movement using various water current resistance exercise movements is carried out in the future, it will be helpful to write more scientific underwater exercise program.

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