International Journal of Advanced Smart Convergence Vol.13 No.1 185-193 (2024)
http://dx.doi.org/10.7236/IJASC.2024.13.1.185

IJASC 24-1-20

The Effect of Water Depth and Exercise Speed on Physiological Responses Immediately After Aquatic Squat Exercise

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Abstract

This study aimed to investigate the immediate physiological responses, including heart rate, blood pressure, and rate pressure product (RPP), following squat exercises performed at three water depths (ground, knee depth, waist depth) and two speed conditions (60bpm speed, Max speed). The participants consisted of 10 men in their 20s with over 6 months of resistance exercise experience. For the 60bpm speed squats, participants performed 30 repetitions in 1 minute at a rate of 2 seconds per repetition, while for Max speed squats, they performed at Max speed without a set limit on the number of repetitions for 1 minute. All experiments were conducted with a random assignment. The study results showed that immediately after the aquatic squat exercise, the average heart rate, blood pressure, and cardiac load were higher in the order of knee depth, ground level, and waist depth at both 60bpm speed and Max Speed. At 60bpm speed, the heart rate was higher in the order of ground level, knee depth, and waist depth. Overall, exercise in an aquatic environment was considered to impose relatively lower physical burden compared to land-based exercise. Therefore, it is suggested that depending on individual fitness levels and exercise goals, appropriately combining aquatic exercise, which imposes lower immediate physiological burden, and land-based exercise may lead to safer and more effective exercise methods.

***Keywords**: Aquatic Exercise, Squat, Heart Rate, Blood Pressure, RPP*

1. INTRODUCTION

Aquatic exercise utilizes the properties of water such as hydrostatic pressure, buoyancy, and viscosity, thereby reducing physiological stress on the body [1]. It allows for the application of various training methods such as support, assistance, and resistance [2]. The characteristics of water provide an environment for three-dimensional resistance exercise at all angles, and by utilizing the resistance of water with one's own body [3], it is known to offer superior exercise effectiveness and stability compared to land-based exercise [4].

The load on the body varies depending on the depth of water [5]. The weight-bearing at the level of the anterior superior iliac spine (ASIS) is 50%, at the level of the xiphoid process it is 25%, and at a depth

Manuscript Received: February. 1, 2024 / Revised: February. 10, 2024 / Accepted: February. 20, 2024
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corresponding to the 7th cervical vertebra, the weight-bearing decreases to 10% [6]. Therefore, differences in water depth affect the exercise load, leading to different training effects [7, 8].

In a study by [9] that examined different speeds during squat exercises, it was suggested that slow-speed squats could increase muscle activation and enhance the efficiency of body movement [10, 11]. Conversely, fast-speed squat exercises were reported to result in increased exercise volume, energy expenditure, and impact, leading to lower cardiovascular and blood pressure burdens and less delayed muscle soreness compared to slow-speed exercises [12]. However, unlike on land, in an aquatic environment, fast-paced movements result in greater resistance from the water, leading to increased exercise intensity. Such exercise intensity is known to be influenced by the body's balance, gravity, and buoyancy [13].

Therefore, this study aims to elucidate the physiological changes following squat exercise in an aquatic environment based on depth and speed, which proportionally increase due to resistance from buoyancy and hydrostatic pressure, resulting in varying exercise intensity and load. This will be achieved through the observation of changes in heart rate, blood pressure, and RPP [14-16] immediately after squat exercises, according to depth and speed.

2. EXPERIMENTS

2.1 Subject

The subjects of this study were 10 men in their 20s with over 6 months of resistance exercise experience, currently enrolled at D University, C City. All participants were provided with comprehensive information regarding the study, and only those who expressed willingness to participate signed the informed consent form before joining the study. To ensure accurate results during the study period, the participants were instructed to refrain from excessive physical activity before the experiment, and smoking and alcohol consumption were prohibited before the experiments. The characteristics of the participants are shown in <Table 1>.

Table 1. Characteristics of research 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 Study Design and Procedure

This experiment was conducted with approval from the Institutional Review Board (IRB File No. 2020-10-019). It took place at the P Spa indoor aqua center in A City. Participants arrived 30 minutes before the start of the experiment to allow for stabilization, during which their heart rate, blood pressure, and were measured. For the 60bpm speed condition, the participants performed 30 repetitions in 1 minute at a rate of 2 seconds per repetition, while for the Max speed condition, they performed at Max speed for 1 minute. They were randomly assigned to perform squats under all conditions. Heart rate, blood pressure, and RPP were measured immediately after the exercise. During the study period, the participants were instructed to avoid excessive physical activity and to get adequate rest the day before participation. The specific study design is outlined in <Figure 1>.

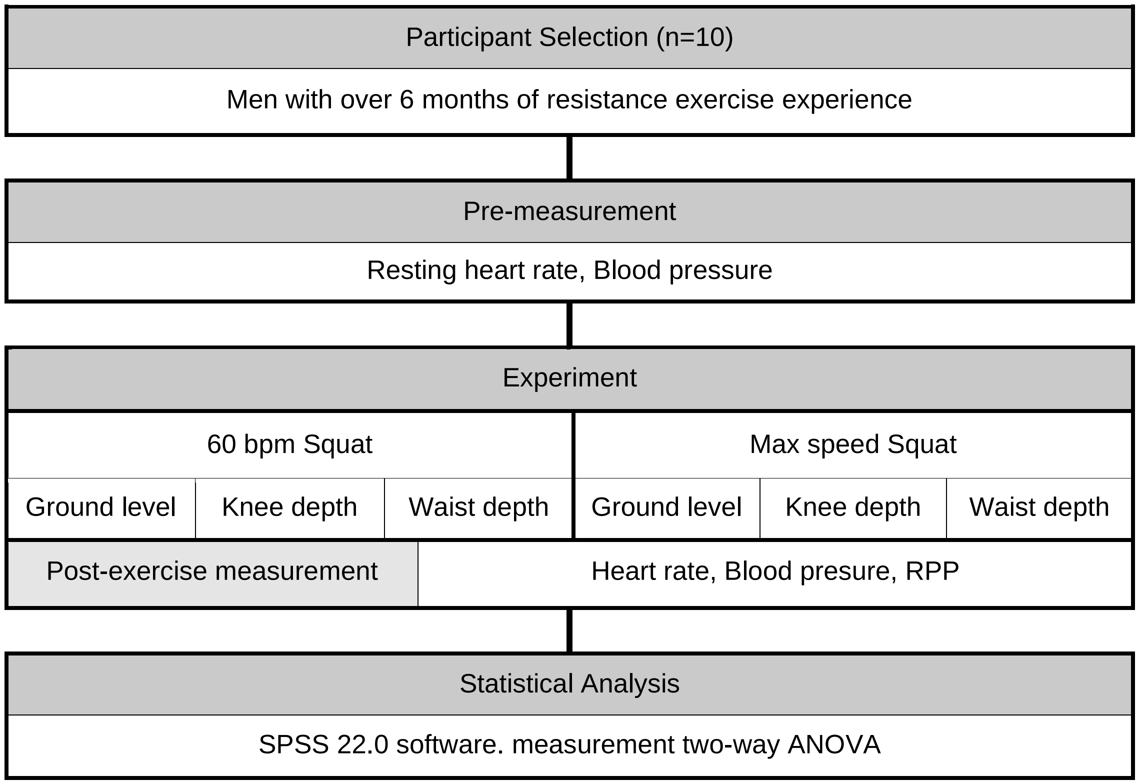

Figure 1. Study design

2.3 Squat Exercise According to Water Depth

In this experiment, participants were instructed to ensure that the angle of their knees was 90 degrees during squat exercises performed at both 60bpm speed and Max speed, and that their thighs were parallel to the ground. To maintain a constant speed during the 60bpm speed exercise, a metronome app was used to set the pace at 60bpm, allowing for 30 repetitions in 1 minute at a rate of 2 seconds per repetition. For the Max speed condition, where squats were performed at maximum speed, an assistant was present to prevent the participants' heels from lifting off the ground. During the squat exercise, the participants' arms were raised behind the head, feet were spread 15cm apart, and gaze was directed straight ahead. The water temperature was maintained at

28 ℃ to 30 ℃ to minimize physiological changes and stabilize core temperature

2.4 Heart Rate Measurement

Heart rate was measured as the average heart rate immediately after exercise. Heart rate measurements were taken at 10-second intervals for 1 minute under both 60bpm speed and Max speed conditions. A wireless heart rate monitoring sensor (Polar) was used for measurement, positioned on the xiphoid process of the chest, and synchronized with the Polar Beat software app for measurement.

2.5 Blood Pressure Measurement

Blood pressure was measured at rest and immediately after exercise while seated, using a blood pressure monitor (FT500R PLUS).

2.6 RPP (Rate Pressure Product) Measurement

In this experiment, RPP was calculated by multiplying the average heart rate and blood pressure measured immediately after exercise. The calculation formula is illustrated in <Figure 2>.

Heart rate × blood pressure = RPP (Rate Pressure Product)

Figure 2. RPP (rate pressure product) Calculation Formula

2.7 Static Analysis

Data processing for this study involved using the IBM SPSS Statistics software (version 22.0) to calculate the mean and standard deviation of all variables. Heart rate, blood pressure, and RPP according to water depth (3) and speed (2) during aquatic squat exercises were analyzed using repeated measures two-way ANOVA. In cases where significant differences were observed between water depths, post-hoc comparisons (contrast) using the repeated and Simple (first) methods were applied. The statistical significance level was set at $\alpha = .05$.

3. RESULTS

3.1 Changes in Post-Exercise Mean Heart Rate Following Aquatic Squat Exercise According to Water Depth and Speed

The results of the repeated measures two-way ANOVA analysis on the changes in post-exercise mean heart rate following squat exercise according to water depth and speed, along with the descriptive statistics and post-hoc comparisons, are presented in <Tables 2>. There was a statistically significant difference in post-exercise mean heart rate according to water depth ($p < .001$). Additionally, there was a statistically significant difference in post-exercise mean heart rate according to speed ($p < .001$). Furthermore, there was a significant interaction effect of water depth and speed on post-exercise mean heart rate during squat exercise ($p < .001$).

Table 2. Descriptive statistics and Post-Hoc comparison results of post-exercise mean heart hate according to water depth and speed in squat exercise(bpm)

	① Ground	② Knee Depth	③ Waist Depth	contrast		F	p
Ⓐ 60bpm Speed	126.10±10.03	122.60±6.79	109.80±8.08	①②>③***	Depth	17.548	.000
Ⓑ Max Speed	131.00±14.82	153.80±8.36	124.30±11.69	①>②**>③ ***	Speed	44.845	.000
contrast	NS	Ⓐ<Ⓑ***	Ⓐ<Ⓑ**		D X S	12.168	.000

M±SD **p<.01,***p<.001

3.2 Changes in Post-Exercise Blood Pressure Following Aquatic Squat Exercise According to Water Depth and Speed

The results of the repeated measures two-way ANOVA analysis on the changes in post-exercise blood pressure following squat exercise according to water depth and speed, along with the descriptive statistics and post-hoc comparisons, are presented in <Tables 3>. There was a statistically significant difference in post-exercise blood pressure according to water depth ($p < .01$). Additionally, there was a statistically significant difference in post-exercise blood pressure according to speed ($p < .05$). However, there was no significant interaction effect of water depth and speed on post-exercise blood pressure following squat exercise.

Table 3. Descriptive statistics and Post-Hoc comparison results of post-exercise blood pressure according to water depth and speed in squat exercise(mmhg)

	① Ground	② Knee Depth	③ Waist Depth	contrast		F	p
Ⓐ 60bpm Speed	143.90±17.27	149.60±11.78	139.40±11.89	①②>③*	Depth	5.448	.014
Ⓑ Max Speed	158.70±16.69	161.50±10.86	150.20±15.19	①②>③*	Speed	19.111	.002
contrast	Ⓐ<Ⓑ**	Ⓐ<Ⓑ*	Ⓐ<Ⓑ**		D X S	.351	.709

M±SD **p<.01,***p<.001

3.3 Changes in RPP Following Aquatic Squat Exercise According to Water Depth and Speed

The results of the repeated measures two-way ANOVA analysis on the changes in post-exercise RPP following squat exercise according to water depth and speed, along with the descriptive statistics and post-hoc comparisons, are presented in <Tables 4>. There was a statistically significant difference in post-exercise RPP according to water depth during aquatic squat exercise ($p < .001$). Additionally, there was a statistically significant difference in post-exercise RPP according to speed ($p < .001$). Furthermore, there was a significant interaction effect of water depth and speed on post-exercise RPP during squat exercise ($p < .01$).

Table 4. Descriptive statistics and Post-Hoc comparison results of post-exercise RPP according to water depth and speed in squat exercise(Hg/ the number of times/min)

	① Ground	② Knee Depth	③ Waist Depth	contrast		F	p
Ⓐ 60bpm Speed	18226.40± 3160.33	18338.40± 1702.78	15301.40± 1661.01	①②>③**	Depth	19.379	.000
Ⓑ Max Speed	20751.20± 2805.54	24885.90± 2707.79	18680.60± 2713.55	①<②**>③***	Speed	54.429	.000
contrast	Ⓐ<Ⓑ**	Ⓐ<Ⓑ***	Ⓐ<Ⓑ**		D X S	8.011	.003

M±SD **p<.01,***p<.001

4. DISCUSSION

In this study, heart rate was used as an indicator of exercise intensity, defined as the number of heartbeats per unit of time, commonly utilized in sports settings. The post-exercise average heart rate showed statistically significant differences according to water depth during squat exercises. Post-hoc comparisons revealed that at 60bpm speed, knee-depth immersion resulted in higher heart rates compared to waist-depth immersion, while at Max speed, knee-depth immersion consistently showed higher heart rates than waist-depth immersion. The post-exercise average heart rate also exhibited statistically significant differences according to exercise speed, with knee-depth immersion at Max speed showing higher heart rates compared to 60bpm speed. This can be attributed to the buoyancy effect of water reducing weight load by up to 41% at knee depth, as suggested by [2]. Knee-depth immersion may not necessarily reduce weight load due to buoyancy effects, but rather, during the descent phase of the squat movement, some parts of the feet, knees, and hip joints are immersed in water, causing water molecules to adhere to the body surface and increase resistance due to drag during the ascending phase. Additionally, during squat movements, irregular movements occur as water fluctuates, creating eddies and increasing friction on the body surface, leading to increased resistance, as suggested by [2]. It is believed that these characteristics of knee-depth immersion tense the muscles, resulting in increased heart rate compared to other depth conditions.

The post-exercise average heart rate was higher at Max speed compared to 60bpm speed across all water depths. This is believed to be due to the fact that Max speed involved performing squat exercises at a maximal subjective velocity, leading to increased conscious proprioceptive activation through the spinothalamic tract-medial lemniscus pathway and unconscious proprioceptive activation through the spinocerebellar tract [17]. During the 60-second squat exercise at maximal speed, it is inferred that there was an acceleration of the processes involved in muscle contraction for ATP consumption, redistribution of blood flow to supply more oxygen to active muscles, and joint receptor feedback, resulting in an increase in average heart rate. Furthermore, during squat exercises at Max speed, activation of the sensitive III and IV afferent nerves in muscles for contraction and metabolic responses likely transmitted proprioceptive feedback to the central nervous system, leading to an increase in average heart rate at the cardiovascular control center in the brainstem [18].

Blood pressure increases blood pressure due to cardiac output and peripheral vascular resistance [19]. In this study, post-exercise blood pressure according to water depth showed statistically significant differences. Post hoc comparisons revealed that both knee immersion was higher than waist immersion for both 60bpm speed and Max speed. Post-exercise blood pressure varied significantly according to speed, with Max speed being higher than 60bpm speed across all water depths. The characteristics of water, such as hydrostatic pressure and buoyancy, increase venous return as the submerged area deepens, leading to increased peripheral vascular constriction and venous return to the central part of the body [20, 21]. This results in an increase in stroke volume and, according to Starling's law of the heart, a simultaneous increase in arterial blood pressure. Contrary to previous research, this study demonstrated lower blood pressure and heart rate according to water depth during squat exercises. At 60bpm speed, both ground level and knee immersion were relatively less buoyant than waist immersion, resulting in less buoyancy. It is hypothesized that mechanical receptors in the joints exerted greater influence than waist immersion, leading to higher blood pressure. Similarly, at Max speed, ground level and knee immersion were relatively more affected by hydrostatic pressure and buoyancy compared to waist immersion.

RPP reflects the cardiac workload [22], calculated as the product of heart rate and blood pressure. In this study, post-exercise RPP varied significantly according to immersion depth during squat exercises[23]. Post-hoc comparisons revealed that at 60bpm speed, immersion up to the waist resulted in higher values compared to ground level, with knee immersion showing even higher values than waist immersion. At Max speed, knee immersion exhibited higher values than waist immersion. There was a statistically significant difference in post-exercise RPP according to speed, with knee and waist immersion showing higher values at Max speed compared to 60bpm Speed. Notably, across all conditions, waist immersion resulted in the lowest values, indicating a decreasing trend in RPP with increasing immersion depth, likely attributed to buoyancy and hydrostatic pressure. Thus, it can be inferred that immersion in water leads to a reduction in RPP, attributed to the properties of water and varying immersion depths.

5. CONCLUSION

This study aimed to investigate the immediate physiological responses, including heart rate, blood pressure, and rate pressure product (RPP), following squat exercises performed at three water depths (ground, knee depth, waist depth) and two speed conditions (60bpm speed, Max speed). First, there was a significant difference in heart rate in depth and speed, followed by ground, knee depth, and waist depth, and max speed squats in knee and waist depth were higher than 60bpm speed squats. Second, blood pressure showed significant differences in water depth and speed, followed by ground, knee depth, and waist depth, and max speed squats in knee and waist depth were higher than 60bpm speed squats. Third, there was a significant difference in depth and speed in heart rate, ground and knee depth were higher than waist depth in the 60bpm speed squat, and knee depth was higher in the order of knee depth, ground, and waist depth in the max speed squat. In addition, the max speed squat was higher than the 60bpm speed squat.

In summary, it was observed that the patterns of physiological responses varied according to water depth and speed. It was found that as the water depth increased, heart rate, blood pressure, and RPP decreased. Consequently, aquatic exercise was considered to impose relatively lower physiological stress compared to exercise on land. Therefore, it is believed that by appropriately structuring exercise to include both aquatic and land-based activities based on individual fitness levels and exercise goals, a safer and more effective exercise regimen can be achieved.

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