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(Citation)

Bulletin of health sciences Kobe, 41:23-38

(Issue Date)

2026-03-31

(Resource Type)

departmental bulletin paper

(Version)

Version of Record

(JaLCD0I)

<https://doi.org/10.24546/0100503596>

(URL)

<https://hdl.handle.net/20.500.14094/0100503596>



Lower extremity muscle activity during aquatic recumbent pedalling exercise: a surface electromyographic analysis

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Abstract

Objective: This study investigated lower limb muscle activity during aquatic recumbent pedalling exercises (AP) and land recumbent pedalling exercises (LP) from different angles.

Methods: The participants were 10 healthy young adult men. Electromyography data of the gluteus medius, rectus femoris, biceps femoris, tibialis anterior (TA), and lateral head of the gastrocnemius (LG) were measured during AP and LP. The top of the rotation locus was set at 0°, and each rotation was divided into 8 sections of 45°. The 8 divided sections were labelled from 0° as Section I to Section VIII.

Results: In the 40-rpm recumbent pedalling exercise, TA was significantly higher in sections I, VI, VII, and VIII for AP than LP; LG was significantly higher in sections II and III for AP than LP. In the 60-rpm exercise, RF was significantly higher in section VII for AP than LP; TA was significantly higher in sections V, VI, and VII for AP than LP; LG was significantly lower in sections IV and V for AP than LP.

Conclusions: AP exercise at an equivalent intensity showed significantly higher lower limb muscle activity than LP at several angles.

Keywords

Electromyography (EMG), Recumbent pedalling, Aquatic exercise

Running title

Electromyographic analysis lower extremity muscle during aquatic exercise

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I. Introduction

Aquatic exercise elicits biological responses that differ from those on land because of water characteristics including buoyancy, water pressure, viscous resistance, and water temperature¹⁾. Buoyancy reduces the load on the musculoskeletal system²⁾ and lower limb muscle activity during treadmill walking in water is 30–60% lower than walking on a land treadmill³⁾. Buoyancy and hydrostatic pressure aid in postural control, making exercise safe in water⁴⁾.

Aquatic pedalling exercise is a type of aquatic exercise that can adjust load using the viscous resistance of water, and studies have evaluated physiological responses during aquatic pedalling exercise⁵⁻⁷⁾. However, we did not find within our research scope any previous studies that evaluated muscle activity during aquatic pedalling exercises.

There are various pedalling exercise styles, including upright and recumbent. The recumbent type has a backrest that makes it more stable than the upright type^{8,9)}. A previous study reported similar lower limb muscle activities during recumbent and upright land pedalling exercises¹⁰⁾.

Therefore, it is expected that muscle activity during aquatic recumbent pedalling exercises (AP) differs from that during land recumbent pedalling exercises (LP) owing to buoyancy and viscous resistance. However, to date, no studies have investigated lower limb muscle activity during AP. This study aimed to clarify lower extremity muscle activity during AP. To achieve this objective, we i) compared lower limb muscle activity during AP and LP and ii) compared lower limb muscle activity during AP and aquatic treadmill walking exercise (AW), which is a common aquatic exercise.

II. Materials and Methods

1. Participants

The participants were 10 young, healthy adult men (average age 23.4 ± 1.9 years, average height 172.2 ± 6.1 cm, average weight: 66.2 ± 9.1 kg, average body mass index: 22.2 ± 2.0 , dominant leg right for all participants). Individuals with a history of cardiovascular disease or motility disorder in the lower limbs were excluded.

In accordance with the Declaration of Helsinki, the purpose, contents, and risks of this study were fully explained orally and in writing to the participants, and written informed consent was obtained before the study was conducted. The study was approved by the Kobe University Graduate School of Health Sciences Health Sciences Ethics Committee (Approval No. 1012-3, March 26, 2024), and permission to conduct the study was obtained.

2. Experimental Environment

The room temperature was 26.0 ± 3.4 °C, the humidity was $50.5 \pm 15.4\%$, and the water temperature was 31.4 ± 1.4 °C. The water level was set at the xiphoid process (105.6 ± 4.5 cm) during AP and at the iliac crest (100.8 ± 5.8 cm) during AW.

3. Electrode Application Site

The electrode application sites were five muscles as follows: gluteus medius (GM), rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), and lateral head of the gastrocnemius (LG), based on the SENIAM guidelines¹¹⁾. Two disposable electrodes (BlueSensor P, Ambu) were attached to each muscle, and one ground electrode was affixed to the tensor fascia femoris tendon. The right side was measured, and the distance between the two electrodes in each muscle was 2.0 cm.

4. Skin Treatment and Waterproofing

To minimize the electrical resistance from the skin, the area where the electrode was applied was dehaired with a hair-removal cream. Subsequently, the electrical resistance of the skin was further reduced with a skin treatment agent, and the area was thoroughly wiped with cotton alcohol. After skin treatment, electrodes were applied to the measured muscles, and the electromyography (EMG) data of all muscles at rest on land were checked to confirm that there was no baseline deviation or noise in the stationary waveform caused by the AC power supply. By submerging the left upper limb in an aquatic treadmill (Flowmill X, Japan Aquatech) without a power supply and driving the treadmill, we confirmed that no baseline shift or AC power-induced stationary waveform noise was observed in the EMG data when the power supply was used in an aquatic environment. If noise was observed in any of the aforementioned cases, the skin processing was repeated and adjusted until no noise was observed in the EMG data.

After confirming there was no noise in the EMG data at rest in all measured muscles, the EMG data were subjected to water immersion effects¹²⁾. Following established procedures from previous studies¹³⁾, waterproofing was performed by applying a waterproof film to cover the electrodes, applying a liquid adhesive plaster to the four sides of the waterproof film and around the lead wires, and applying a waterproof film to the four sides of the waterproof film. Additionally, waterproofing was performed by attaching a waterproof film over the four edges of the waterproof film, and a measurement protocol was implemented.

5. Measurement Protocol (Figure 1)

1) Intensity Settings for Exercise Intensity Unification of Different Exercise Modalities

a. Measurement of Exercise Intensity During AP

The recumbent ergometer used in this study can change exercise intensity based on both pedal rotations per minute (rpm) and the angles of the six paddles. In this study, all six paddles were fixed at an angle that maximised the effect of viscous resistance, and two pedal speeds (40- and 60-rpm) were set. Using the exercise intensities at 40 and 60 rpm during AP as a reference, the intensities of LP and AW were standardized within the same participants. After measuring body composition, the saddle position of the recumbent ergometer was adjusted. Participants were instructed to keep their backs off the backrest and hold onto the handlebars on either side of the saddle. Additionally, the right pedals

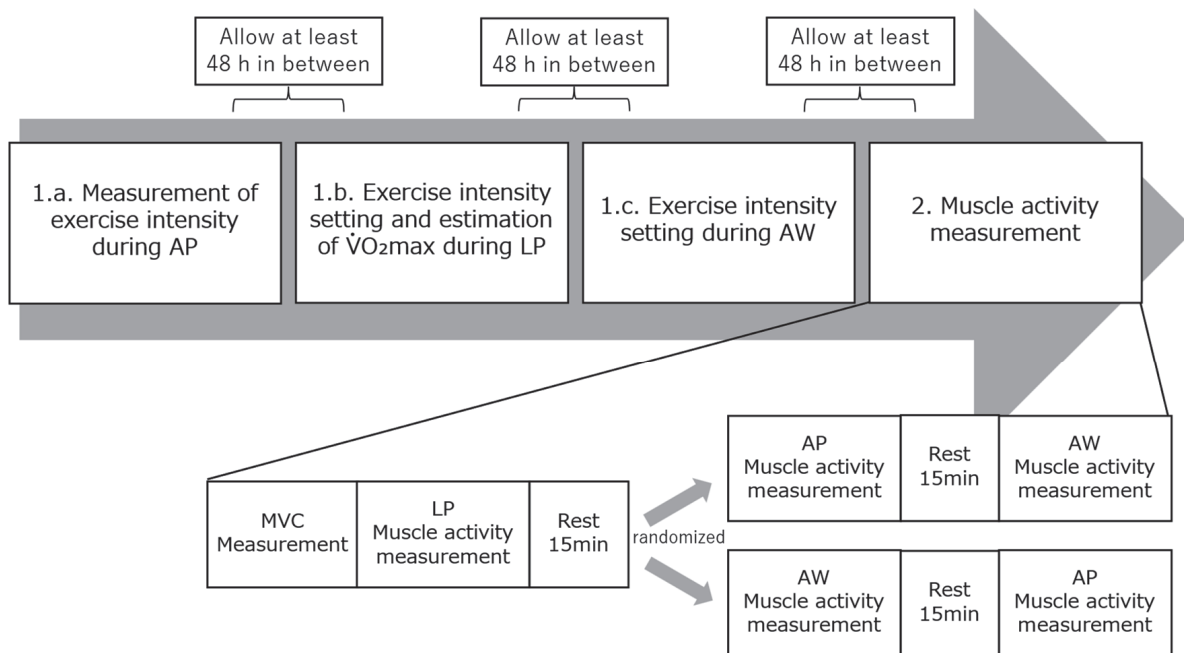


Figure 1. Measurement protocol

were adjusted such that the right knee joint flexion was 90° at the uppermost point (0°). Following a 5-min of seated rest on land, participants moved to the water, and after 5-min of seated rest on the aquatic recumbent ergometer, AP was performed for 5-min at 40-rpm to the sound of an electronic metronome. Subsequently, the participants performed the same pedalling exercise at 60-rpm for 5-min. Exhaled gas was collected using the Douglas bag method during the latter 2-min of each 5-min period at each pedal speed, and oxygen uptake ($\dot{V}O_2$) was measured using an exhaled gas analyzer (AR-1 Type-4, Arco Systems, Inc.).

To standardize the two exercise intensities based on the $\dot{V}O_2$ obtained in the AP, the exercise intensity was set by performing progressive load exercise in the LP and AW.

b. Exercise Intensity Setting and Estimation of Maximal Oxygen Uptake ($\dot{V}O_{2max}$) During LP

In the LP, incremental load exercises were performed at two pedal speeds, 40- and 60-rpm, with increasing pedal load (W). After a 1-min seated rest on the land recumbent ergometer, participants performed LP at each pedal speed, with incremental loads adjusted every 2-min according to their exercise capacity, for a total of 3 phases (6-min). $\dot{V}O_2$ was measured continuously using an exhaled gas analyzer until the end of the exercise. The average $\dot{V}O_2$ during the last minute of each stage at each pedal speed was used. Heart rate (HR) was measured continuously using an electrocardiograph (Memory Heart Rate Monitor LRR-03, GMS) until the end of the exercise. The obtained $\dot{V}O_2$ and W were used to calculate the W corresponding to the exercise intensity during AP at 40- and 60-rpm. Additionally, $\dot{V}O_{2max}$ was estimated using the predicted maximum HR (220 - age) derived from the obtained $\dot{V}O_2$ and HR.

c. Exercise Intensity Setting During AW

In the AW, incremental load exercises were performed by increasing the walking speed. After a 1-min rest on the aquatic treadmill, participants performed AW at 5 phases (total of 15-min), with walking speed increased every 3-min according to their exercise capacity. Exhaled gas was collected using the Douglas bag method during the latter 2-min of each 5-min phase, and $\dot{V}O_2$ was measured using an exhaled gas analyzer. The obtained $\dot{V}O_2$ and walking speed were used to calculate the walking speed corresponding to the exercise intensity during AP at 40- and 60-rpm.

These three intensity settings were performed on separate days with at least 48-h between each session.

2) Muscle Activity Measurement

On a separate day, at least 48-h after the end of the intensity setting, the EMG of the three types of exercise was measured. The participant had electrodes attached to the five lower limb muscles as previously mentioned, and the electromyogram during the maximum voluntary contraction (MVC) of each muscle was measured on land. The EMG data of the five lower-extremity muscles were measured at predetermined exercise intensities using three different exercise modalities. After each exercise was stabilized, EMG data were recorded for 10 rotations during the pedalling exercise and for 10 steps during the treadmill walking exercise. To minimize the effect of water immersion on EMG data¹²⁾, the LP was performed first, followed by the two exercises, AP and AW, which were performed randomly. Each exercise was followed by a 15-min rest period between exercises.



Figure 2. Muscle Activity Measurement: The saddle position of the recumbent ergometer was adjusted. Participants were instructed to keep their backs off the backrest and hold onto the handlebars on either side of the saddle. Additionally, the right pedals were adjusted such that the right knee joint flexion was 90° at the uppermost point (0°). After pedalling exercise was stabilized, EMG data were recorded for 10 rotations during the pedalling exercise.

6. Surface EMG

Raw EMG data were amplified using an 8-channel versatile bio amplifier (BA1008m, Nihon Suntech) and recorded using an AD converter (PowerLab 8/35, AD Instruments) with a sampling frequency

of 1000 Hz. An isolation transformer (SM-202V, Nihon Kohden) was used to minimize electrical noise affecting the EMG data. Of the devices used for the EMG measurements, battery-powered devices were disconnected from the power supply, whereas devices requiring a power supply were connected to the power supply via an isolation transformer. The EMG measurement equipment and the aquatic treadmill used were connected to different power supplies and grounding points, which caused electrical noise. For one pedalling cycle, the uppermost point was 0° and the lowermost point was 180° and divided into 8 equal sections of 45° each, and the sections divided into 8 equal sections from 0° were designated as section I–VIII, respectively. For the recorded EMG data, the root-mean-square was calculated for each section for each pedalling motion comparison and normalised using the MVC, and the mean%MVC for a total of 10 pedalling cycles was calculated as the mean%MVC. The time required for each pedalling cycle and section was calculated, and the percentage of time was calculated for each section. The mean%time for each section of the 10 pedalling cycles was calculated as the mean%time. The section where the %MVC was the maximum value during one pedalling cycle for each of the five muscles was calculated as peak timing was calculated as peak timing. For aquatic exercise comparisons, the root-mean-square of one pedalling cycle and one step (from heel contact to the next heel contact) was calculated and normalised using MVC, and the mean%MVC of 10 pedalling cycles and 10 steps was calculated as the mean%MVC. The mean%MVC of the five muscles was calculated as the mean%MVC of equivalent exercise intensity. The mean%MVC of the five muscles was compared only between modes of aquatic exercise at equivalent exercise intensities.

7. Statistical Analyses

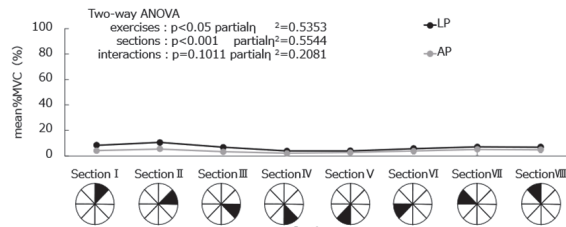
All values are expressed as mean $\pm$ standard deviation. The Shapiro–Wilk test was used to test normality. Mauchly's sphericity test was performed on the mean%MVC and mean %time for each muscle during the recumbent pedalling exercise. When the significance level was <5% and sphericity was not found, the degrees of freedom were adjusted using Greenhouse-Geisser's ϵ correction. A repeated measure two-way analysis of variance (ANOVA) was used for the two factors of exercises and sections to compare the mean%MVC and mean%time for each muscle in the recumbent pedalling exercise. When significant differences were observed in the interactions, Holm tests were performed as post-hoc tests. The statistical analysis for the peak timing data of the four muscles, excluding the LG, was performed with one cycle from section V to section IV to obtain a normal distribution. The Friedman test was used to compare the peak timing of each muscle. The Holm test was performed as a post-test. Corresponding t-tests were utilised to compare the mean%MVC of each muscle during water exercise. All statistical analyses were performed using the R ver. 4.3.1 with a significance level of <5%.

III. Results

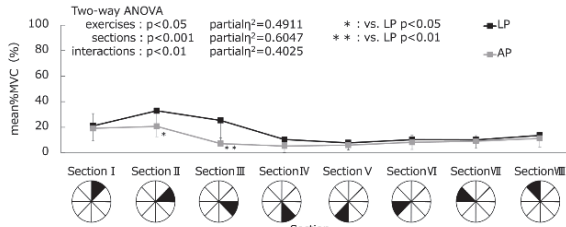
Table 1 presented the results of the %VO₂max, W for the LP, and walking speed for the AW at the same intensity. The detailed results for each of the 10 participants are provided in Supplementary Table 1.

Table 1. Results of the % $\dot{V}O_2$ max, W for the LP, and walking speed for the AW at the same intensity

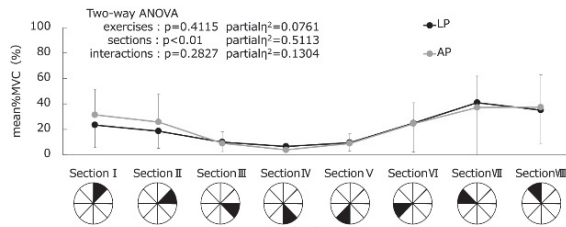
Exercise intensity	Types of exercise	Rotation per minute	Pedal load	Walking speed
27.3 $\pm$ 7.4 % $\dot{V}O_2$ max	AP	40 rpm	-	-
	LP	40 rpm	49.2 $\pm$ 14.4 Watt	-
	AW	-	-	3.72 $\pm$ 0.38 km/h
76.1 $\pm$ 26.9 % $\dot{V}O_2$ max	AP	60 rpm	-	-
	LP	60 rpm	160.3 $\pm$ 32.0 Watt	-
	AW	-	-	5.94 $\pm$ 0.49 km/h



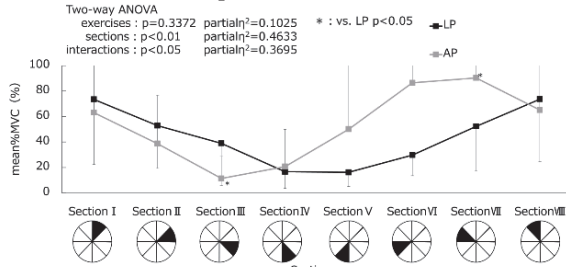
3-a. GM at 40-rpm



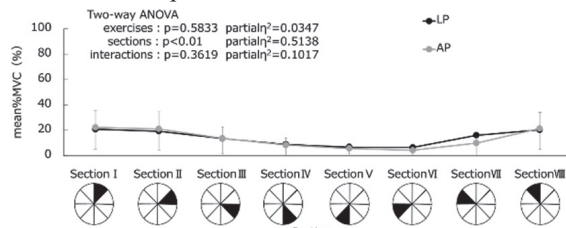
3-b. GM at 60-rpm



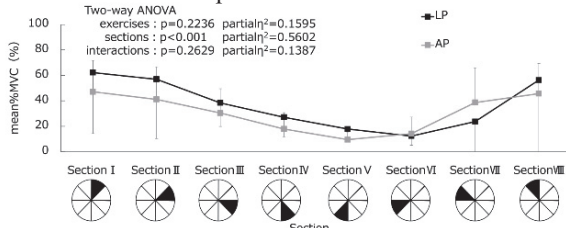
3-c. RF at 40-rpm



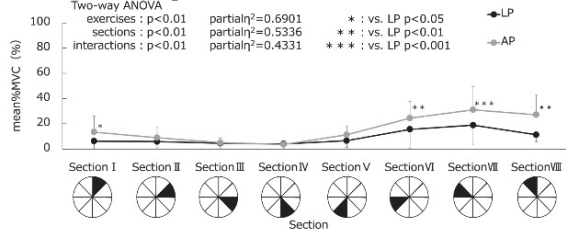
3-d. RF at 60-rpm



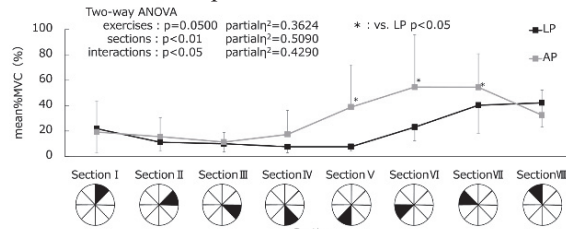
3-e. BF at 40-rpm



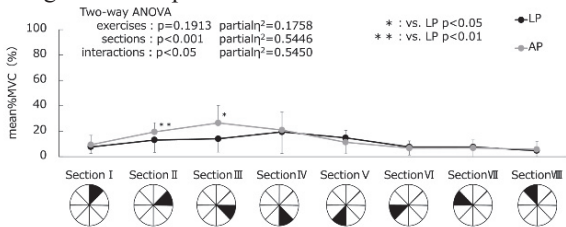
3-f. BF at 60-rpm



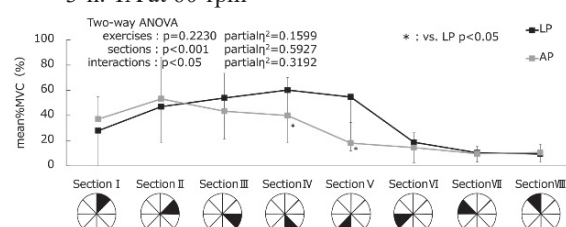
3-g. TA at 40-rpm



3-h. TA at 60-rpm



3-i. LG at 40-rpm



3-j. LG at 60-rpm

Figure 3. Mean%MVC of each muscle at each section during the recumbent pedaling exercise for each exercise intensity

* : A statistically significant difference ($p < 0.05$) was observed in comparison with LP.

** : A statistically significant difference ($p < 0.01$) was observed in comparison with LP.

*** : A statistically significant difference ($p < 0.001$) was observed in comparison with LP.

Figure 3 illustrates the mean%MVC of each muscle at each section during the recumbent pedalling exercise for each exercise intensity. In the recumbent pedalling exercise at 40-rpm, TA exhibited significantly higher activity for the AP than for the LP in sections I, VI, VII, and VIII; LG demonstrated significantly higher activity for the AP than for the LP in sections II and III; and GM, RF, and BF showed no significant differences between exercises or sections. In the 60-rpm recumbent pedalling exercise, the GM activity was significantly lower in sections II and III and in the AP than in the LP. RF was significantly lower in section III for AP than in LP and significantly higher in section VII for AP than in LP. The TA showed significantly higher values during the AP than during the LP in sections V, VI, and VII. LG demonstrated significantly lower than LP in sections IV and V. BF showed no significant differences between exercises or sections.

Figure 4 illustrates the mean%time per section during the recumbent pedalling exercise for each exercise intensity. In the 40-rpm recumbent pedalling exercise, the AP was significantly higher than the LP in sections II, III, and IV. Moreover, sections II, III, and IV were significantly higher than the other sections in the AP. In the 60-rpm recumbent pedalling exercise, the AP was significantly higher than the LP in sections II and III. In the AP, sections II, III, and IV were significantly higher than those at other sections. Section IV was significantly higher than section VIII during the LP.

Figure 5 displays the peak timing of each muscle at each section during the recumbent pedalling exercise. In the 40-rpm recumbent pedalling exercise, the peak timing of the AP was significantly earlier than that of the LP in the GM and LG groups. No significant differences were observed between the environments in the RF, BF, and TA. In the 60-rpm recumbent pedalling exercise, the AP resulted in a significantly earlier peak timing than the LP in all five muscles. In the AP, the GM exhibited a significantly slower peak timing at 60-rpm than at 40-rpm. Conversely, the RF, BF, TA, and LG muscles demonstrated significantly faster peak timings at 60-rpm than at 40-rpm. In the LP, the GM, RF, and TA showed significantly earlier peak timing at 60-rpm than at 40-rpm, while the BF and LG showed no significant differences between the two rotational speeds.

Figure 6 displays the mean%MVC for the AP and AW for each exercise intensity. At all exercise intensities, the GM and LG were significantly lower for the AP than for the AW. Conversely, the RF, BF, and TA did not differ significantly between the exercises.

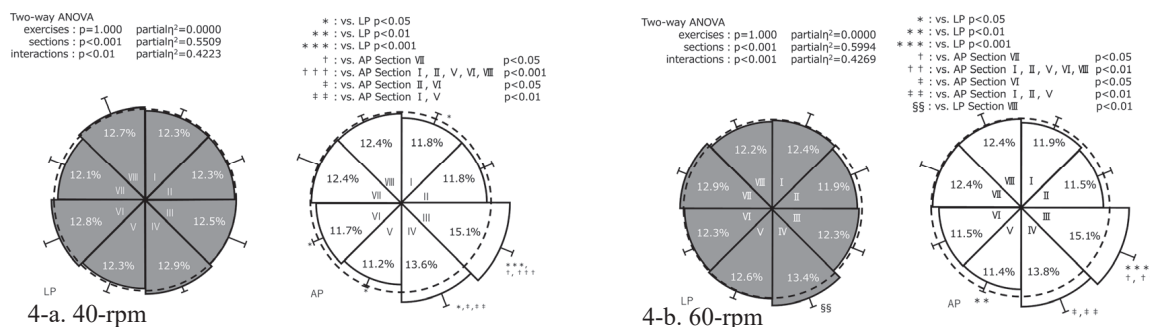


Figure 4. Mean%time per section during the recumbent pedaling exercise for each exercise intensity

The left gray circle represents the mean %time for each section of LP, while the right white circle represents that of AP. The dashed circle indicates 12.5% time, assuming constant-speed cycling is possible.

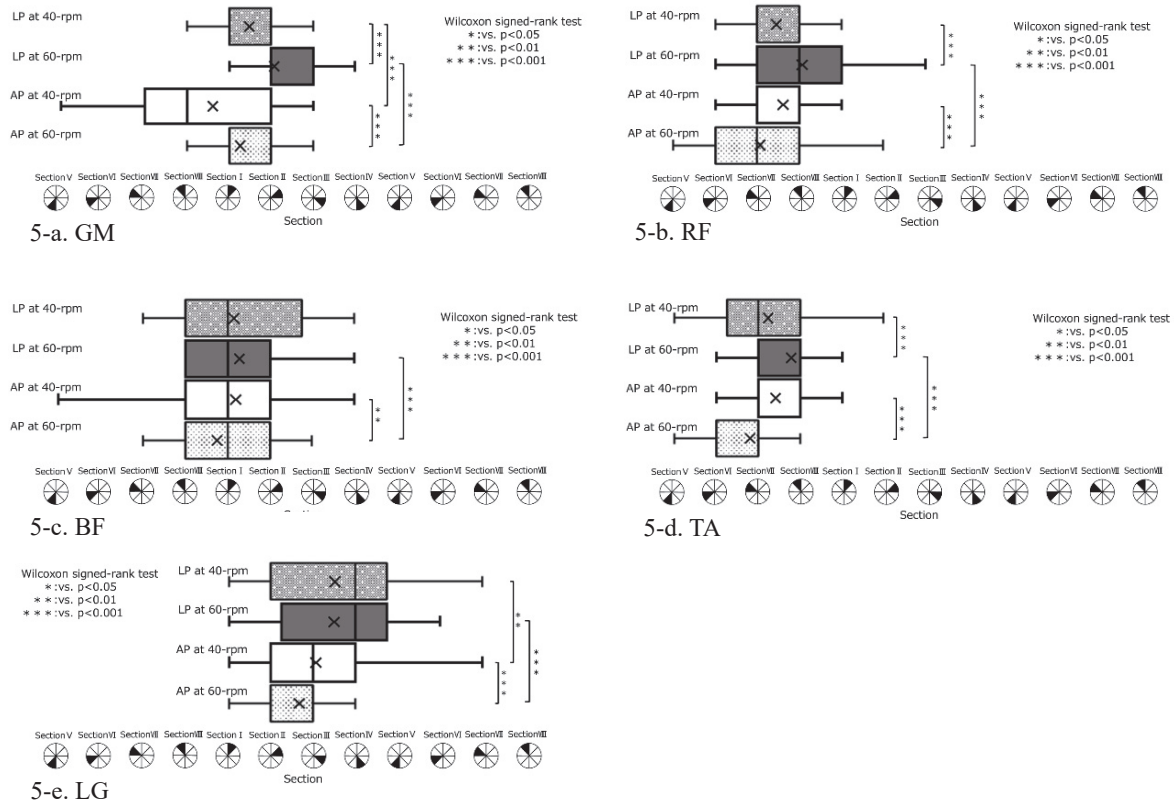


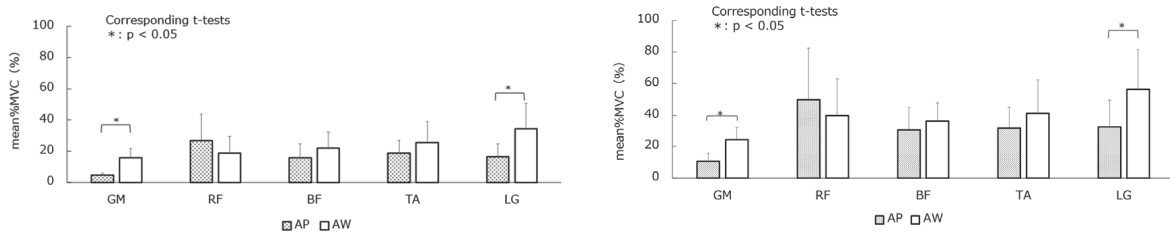
Figure 5. Peak timing of each muscle at each section during the recumbent pedaling exercise

* : A statistically significant difference ($p < 0.05$) was observed between the 2 groups.

** : A statistically significant difference ($p < 0.01$) was observed between the 2 groups.

*** : A statistically significant difference ($p < 0.001$) was observed between the 2 groups.

To represent peak timing using a normal distribution, the 4 muscles—GM, RF, BF, and TA—were analyzed over one cycle from Section V to Section IV, while only LG was analyzed over one cycle from Section I to Section VIII.



6-a. low intensity (corresponding to 40-rpm in AP)

6-b. high intensity (corresponding to 60-rpm in AP)

Figure 6. Mean%MVC for the AP and AW for each exercise intensity

IV. Discussion

This was the first study to investigate lower extremity muscle activity during AP using EMG at different pedalling angles. This study showed results that differ from previous studies¹⁴⁻¹⁹ suggesting lower limb muscle activity is reduced during aquatic exercise compared to land.

In the recumbent pedalling exercise performed at 40-rpm, analysis of the mean%MVC for five muscles showed no significant differences in the activation levels of GM, RF and BF between aquatic and land environments. This suggests that these muscles contribute similarly to pedalling mechanics regardless

of the medium. Conversely, TA exhibited significantly higher activation during AP in sections I and VI–VIII, and LG showed elevated activity in sections II and III compared to LP. These findings imply that the increased resistance due to water viscosity is compensated by enhanced neuromuscular engagement of the distal lower extremity musculature in the aquatic environment.

In the recumbent pedalling exercise at 60 rpm, analysis of the mean%MVC for five muscles revealed that RF exhibited significantly lower in water than on land in section III and significantly higher in water than on land in Section V. The TA was significantly higher in water than on land in sections V, VI, and VII. LG demonstrated significantly lower in water than on land in sections IV and V. Furthermore, the peak timing of RF, BF, TA, and LG occurred significantly earlier during AP at 60-rpm compared to 40-rpm, suggesting that increased pedalling speed amplifies water viscosity resistance, thereby shifting the timing of muscle activation earlier in the pedalling cycle. Additionally, LG, a biarticular muscle involved in knee flexion^{20,21}), has been reported to assist BF in knee flexion during sections IV and V^{22,23}). Therefore, the significantly lower LG activity in sections IV and V during AP at 60 rpm compared to LP may reflect a shift in muscle activation patterns induced by increased resistance due to higher pedalling cadence. These findings suggest that during the upstroke phase (sections V–VIII) in AP, pedalling strategy may rely on the use of toe clips to facilitate pedal lift through coordinated actions of RF and TA, involving hip flexion, knee extension, and ankle dorsiflexion. However, further investigation of joint kinematics is necessary to elucidate the detailed pedalling strategy employed under aquatic conditions.

The high stability of the recumbent ergometer with its backrest and semi-supine position during AP was assumed to minimize the effects of buoyancy and hydrostatic pressure. In contrast to many previous studies¹⁴⁻¹⁹) that showed that muscle activity during water exercise was lower than that during land exercise, the lower limb muscle activity during AP in this study was higher than that during LP because of the viscous resistance of the water.

The mean%time required for sections III and IV was prolonged for all AP at all rotation speeds. However, there was no increase in mean%time required for sections VII and VIII at symmetrical angles. This finding indicates that the pedalling motion was asymmetrical in the AP. Moreover, the mean%time required for section IV was significantly higher than that required for section VIII in the 60-rpm LP. This demonstrated that the symmetrical pedalling motion was not maintained. Therefore, in recumbent pedalling exercise, not only the viscous resistance of water but also the increase in rotational speed and W may make it difficult to maintain stable pedalling motion.

In pedalling exercises, the internal metabolic power of pedalling is proportional to the cube of the pedalling velocity²⁴) in both water and land environments. In this study, W for the LP was set to match exercise intensity within participants, although it is unclear whether the W for AP and LP matches. $\dot{V}O_2$ in pedalling exercises with matched W and rpm was significantly higher in water than on land²⁴). In the 60-rpm AP, the increase in pedalling speed increased the viscous resistance of the water, and the timing of muscle activity required was faster, resulting in a higher peak than in the 40-rpm AP, and 60-rpm was

assumed to have resulted in a significantly faster peak timing than the 40-rpm AP and 60-rpm LP.

Regarding the mean%MVC of the five muscles during AP and AW, GM and LG showed significantly lower values in AP compared to AW at all exercise intensities. Aquatic bodyweight exercises, such as AW¹⁸⁾ and aquatic squat exercise¹⁹⁾, have lower muscle activity compared to land exercises. In AP, in addition to the effect of buoyancy, the semi-supine position on the recumbent ergometer is also presumed to contribute to the reduction of load on the lower limbs, resulting in lower muscle activity compared to AW. Despite the support for posture control and reduction of load on the lower limbs due to buoyancy and hydrostatic pressure, AW requires kicking movements in the pre-swing phase to overcome the lateral sway during the stance phase and the viscous resistance of water during the swing phase, leading to higher muscle activity in GM and LG compared to AP.

From a clinical application perspective, the recumbent ergometer used in this study features both a saddle and backrest, which serve to reduce body weight loading and enhance postural stability. Consequently, the muscle activity of GM and LG during AP was significantly lower than that observed during AW. This suggests that AP may be more suitable than AW for rehabilitation in individuals experiencing severe knee pain or lower extremity muscle weakness. Given the inherently stable nature of recumbent pedalling, it is presumed that the influence of buoyancy in water is minimized. Therefore, recumbent pedalling appears to be a particularly appropriate exercise modality for patients with knee pain or compromised lower limb strength. However, the present study did not standardize exercise intensity across participants, which limits the generalizability of the findings. Future investigations should aim to control for exercise intensity during recumbent pedalling to more accurately assess lower extremity muscle activity. Such data would enable the development of tailored rehabilitation programs that are optimized for individual patient needs.

V. Limitation

The limitations of this study include the inability to measure joint range of motion due to constraints in the experimental facility and only the dominant leg was measured. The ability to measure joint range of motion would provide a more detailed understanding of lower limb muscle activity during AP in combination with muscle activity. Additionally, the percentage of time results suggest that the participants may be performing asymmetrical recumbent pedalling movements during AP, and it is possible that the left side lower limb muscle activity, which was not measured in this study, may yield different results from those of this study. Furthermore, because the dominant leg of all participants was the right leg, it is possible that the lower extremity muscle activity data would show different results if the left leg was dominant. Based on the above, future studies should investigate lower limb muscle activity during underwater recumbent pedaling exercise in more detail by conducting bilateral EMG measurements and three-dimensional motion analysis.

In this study, since the AP mechanism does not allow for electrical control of pedal resistance,

individual differences in exercise intensity may arise even at the same pedaling cadence, depending on participant characteristics. Therefore, while exercise intensity was standardized within each participant, it could not be unified across participants. This remains a limitation of the study and may have contributed to the large standard deviation in exercise intensity.

Due to the extended measurement period, seasonal variations may have contributed to fluctuations in room temperature and humidity among participants, potentially affecting the results. On the other hand, measurements within each participant were conducted during the same season to minimize the influence of seasonal factors.

VI. Conclusion

To elucidate lower limb muscle activity during aquatic recumbent pedalling exercise, this study compared lower limb muscle activity during AP and LP and compared the lower limb muscle activity during AP with that during AW, which is a common aquatic exercise. In recumbent pedalling exercise at 40-rpm, AP showed significantly higher muscle activity in the lower legs compared to LP. At 60-rpm, AP showed significantly higher muscle activity in the anterior lower limbs compared to LP. Additionally, in aquatic exercise, AP demonstrated significantly lower muscle activity in GM and LG compared to AW at all exercise intensities. These results indicated that the aquatic environment requires higher muscle activity due to the viscous resistance of water compared to land in recumbent pedalling exercise. Furthermore, it was clarified that AP can be performed with lower muscle activity compared to AW at the same exercise intensity.

VII. Acknowledgment

We express our sincere gratitude to all the participants who willingly participated in this study. We thank the members of the Ishikawa Laboratory for their cooperation and advice.

VIII. Ethical Considerations

The study was approved by the Kobe University Graduate School of Health Sciences Health Sciences Ethics Committee (Approval No. 1012-3, March 26, 2024) and was conducted according to the ethical standards of the Declaration of Helsinki. Written informed consent was obtained from all the participants.

IX. Conflict of Interest

The authors have no conflicts of interest relevant to this article.

X. Funding

This work was supported by “Support for Pioneering Research Initiated by the Next Generation” of Japan Science and Technology Agency.

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Supplementary Table 1: The individual data of % $\dot{V}O_2$ max, pedal load, and walking speed.

Participant	AP		LP		AW	
	40-rpm	60-rpm	40-rpm	60-rpm	low intensity (Corresponding to 40-rpm in AP)	high intensity (Corresponding to 60-rpm in AP)
	% $\dot{V}O_2$ max	% $\dot{V}O_2$ max	Pedal load (Watt)	Pedal load (Watt)	walking speed(km/h)	walking speed(km/h)
A	29.7	86.1	59	204	3.6	5.9
B	24.2	51.8	62	125	3.8	5.7
C	19.2	46.8	60	114	3.6	5.1
D	44.1	133.7	59	210	3.0	5.9
E	28.3	62.4	60	125	4.4	5.9
F	23.4	56.1	47	127	3.9	7.1
G	23.9	89.3	16	168	3.3	4.9
H	35.4	102.1	54	183	3.7	5.8
I	22.1	67.7	54	168	4.1	6.8
J	23.3	65.2	34	157	3.4	5.8