

## Suitability of electrodes waterproofing treatment in underwater surface electromyography measurement.

KOBAYASHI Keisuke<sup>\*</sup>, TAKAGI Hideki<sup>\*</sup>, TSUBAKIMOTO Shozo<sup>\*</sup> and SENGOKU Yasuo<sup>\*</sup>

### Abstract

The purpose of this study was to investigate the suitability of the electrodes waterproofing treatment on the amplitude and spectral characteristics of the surface electromyography (sEMG) signals. Nine healthy male adults participants performed a 2-second isometric palmar flexion exercise with the dominant hand 10 times at 1-minute intervals under the following 3 conditions: in air without waterproofing, in air with waterproofing, and in water with waterproofing. We used three water-resistant adhesive tapes to waterproof the electrodes. Exerted forces were measured by a load cell. The sEMG data was measured using a wireless EMG device and the root mean square (RMS) value and median frequency (MF) were calculated as the characteristics of the amplitude and power spectrum. As results, there were no significant differences between the 3 conditions in the exerted force, RMS, and MF ( $p \geq 0.05$ ). Therefore, it was suggested that the waterproofing treatment was suitable for sEMG measurement during submersion and did not affect the amplitude and spectral characteristics of the sEMG signals.

**Key words:** Water; Muscle activity; Signal amplitude; Power spectrum

### Introduction

Electromyography (EMG) can be used to evaluate muscle activity during movement, and has been used since 1964 in many studies on swimmers. Martens et al.<sup>9)</sup> reported, in a review of 50 years of EMG research in swimming, that 79% of studies used surface electromyography (sEMG) to investigate muscle activity in all four competitive swimming strokes (front-crawl, backstroke, breaststroke and butterfly). Therefore, sEMG is the primary method of investigating muscle activity in swimming.

In conducting sEMG study in swimming, the waterproofing of the EMG electrodes is a matter of concern as the previous studies<sup>2),4),7),8),14),15)</sup>. Rainoldi et al.<sup>13)</sup> investigated the differences of the amplitude and spectral characteristics of the sEMG signals between four conditions which were in air without waterproofing treatment, in static water without waterproofing treatment, in moving water without waterproofing treatment and in moving water with waterproofing treatment. As the results, the authors reported that both the amplitude and spectral characteristics measured in moving water with waterproofing treatment were comparable with the

data measured in air, while the amplitude measured in static water and moving water without waterproofing treatment reduced 90—95% of the amplitude in air. Furthermore, the spectral power in the frequencies among 0—20 Hz increased in moving water condition without waterproofing treatment due to the water movement. Accordingly, it can be considered that the waterproofing treatment of the EMG electrodes was essential to collect the accurate sEMG signals during the underwater movement.

Recently, a small wireless EMG device was developed for sEMG measurement in water (fig1). This device reduces the limitation of swimming movements and the generation of motion artifacts compared with previously used devices that have long leads. Our previous studies used this device to measure the sEMG data during swimming<sup>7),8)</sup>, and we have conducted the electrodes waterproofing treatment with water-resistant adhesive tapes referring to several previous studies<sup>5),16)</sup>. However, the suitability of the waterproofing treatments have not been evaluated in the previous studies regarding on this wireless EMG device. Furthermore, Veneziane et al.<sup>17)</sup> indicated that the pressure of the tapes covering the

---

\* Faculty of Health and Sport Sciences, University of Tsukuba

electrodes could change an area of muscle fiber under the electrode and thus influence the sEMG signals. Therefore, there is a possibility that the sEMG data measured with waterproofing treatment may be not comparable with the sEMG data measured without waterproofing treatment. To accurately interpret the measured EMG data, it is necessary to investigate the effect of the electrodes waterproofing treatment on the sEMG data.

The purpose of this study was to investigate the suitability of the electrodes waterproofing treatment on the amplitude and spectral characteristics of the sEMG signals.



Fig 1 The waterproofing procedures for the electrodes consisted of 3 steps. First, disposable electrodes and a wireless telemeter were covered with a transparent dressing tape. Second, the edges of the dressing tape were reinforced with plastic tape. Finally, the adherence bandage attached the corners to prevent peeling of these tapes.

## Materials and Methods

### 1. Participants

Nine healthy adult males (mean age,  $21.7 \pm 1.5$  years; mean height,  $1.75 \pm 0.07$  m; mean weight,  $70.4 \pm 7.6$  kg) volunteered for this study. All swam regularly; none had a neuromuscular disease, injury of the dominant hand within 3 months or a fear of being in water. The participants consented to participate in this study after being informed of its purpose. All procedures were approved by the ethics committee of the university and performed following the Ethical Principles of the Helsinki Declaration.

### 2. Experimental design

The experimental design was similar to that previously reported by Veneziano et al.<sup>17)</sup>. The participants performed a 2-second isometric palmar flexion exercise using their dominant hand for 10 repetitions with a 1-minute rest.

During the exercise, their elbow was fixed by a brace to eliminate compensatory movements of the elbow joint. The fixed arm was placed in a water tank as shown in fig2. The isometric palmar flexion exercise was performed by pressing a lever arm of the load cell that was attached to the upper portion of the water tank.

The participants performed the exercises under three conditions. The first was in air without waterproofing (NT), the second was in air with waterproofing treatment (T) and the third was in water with waterproofing treatment (WT). Before recording, participants practiced the exercise in each condition to become familiar with it. A rest interval of >20 minutes was scheduled between exercising in each of the three conditions. As the waterproofing tape could not be reused, the order of the exercise began with the NT condition trial followed by the other two trials (T and WT conditions) in randomized order.

In WT condition, the depth was maintained so the forearm and hand was kept completely submerged. It is known that the spectral power of the EMG is affected by the water temperature during submersion<sup>10),11)</sup>. Therefore, the water temperature was maintained among  $29^\circ\text{C}$  to  $32^\circ\text{C}$  by a thermometer (TR-71U, T&D Inc.) and a heater set in the water tank referring to Panek et al.<sup>10)</sup>.

Exerted force during the palmar flexion exercise was measured by a load cell (LUX-B-2KN-ID, KYOWA Inc.). The load cell was connected to a sensor interface (PCD-330B-F, KYOWA Inc.) and the data were recorded at 200 Hz sampling rate, using a computer. The participant monitored the exerted force data via the computer monitor. Maximum exerted force generated during a 5-second voluntary contraction was measured before the experimental trials. To repeat same exercise 10 times, the target exerted force during the 2-second isometric palmar

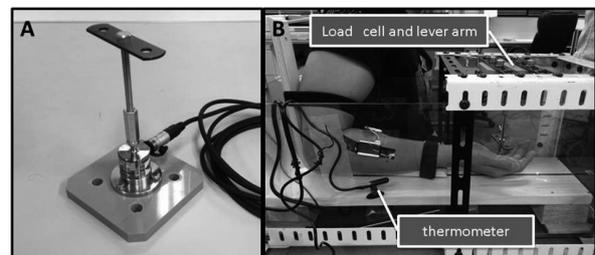


Fig 2 The load cell (A) and the experimental water tank (B). The location of the experimental water tank was determined as the height of elbow when the sitting participant flexes their elbow joint. Therefore, the height of the chair was controlled to fit a sitting position for each participant. Also, the length of the lever arm was adjusted so that participant's wrist joint was fixed at 0 degrees of palmer flexion.

flexion exercise was set at 40% of the maximum force referring to Veneziano et al.<sup>17</sup>).

### 3. Surface EMG recording

sEMG was measured by wireless telemetry (DL-5000, S&ME Inc.) and a data logger (DL-500, S&ME Inc.). sEMG signals were collected by the bipolar derivation method using disposable electrodes (Blue Sensor P-00-S, Ambu Inc.) at a sampling frequency of 2000 Hz. The amplification factor of the sEMG signals was greater than 400 times, the input impedance was 200 M $\Omega$ , and the common mode rejection ratio was over 100 db. The flexor carpi ulnaris on their dominant hand side was considered as the subject muscle, and the location of electrodes was determined as described by Cram et al.<sup>3</sup>). The intra-electrode distance was set at 2 cm. Before electrode fixation, the skin surface was shaved, abraded, and cleaned with alcohol. To protect the electrodes from moisture, the electrodes were waterproofed using three kinds of the water-resistant adhesive tape (Tegaderm roll, 3M Inc.; Cover roll tape, BSN medical Inc.; plastic tape, NITTO Inc.) as previously described<sup>7,8</sup>), as shown in fig1.

The collected sEMG data were analyzed using Biolog2™ software (S&ME Inc.). Raw sEMG data were filtered by a band pass filter (10–500 Hz). The filtered EMG data were smoothed by 100 ms root mean square (RMS) and integrated values during the 2-second exercise were calculated as an index of the quantity of muscle activity. For the analysis of power spectrum, power spectral density during the 2-second exercise was calculated by fast Fourier transform after zero padding treatment. Median power frequency (MF) was investigated from each power spectral density using the following equation (eq.1) as an index of characteristics of the spectral power in the sEMG signals:

$$\int_0^{MDF} P(f)df = \int_{MDF}^{\infty} P(f)df, \quad (1)$$

### 4. Statistical analysis

Exerted force, RMS and MF during the exercise were calculated as means  $\pm$  standard deviation (SD) and coefficient of variance (CV) from 10-time repeated data. The Friedman test was used to compare the data measurements obtained in exercise each condition. Significance was set at  $p < 0.05$ .

## Results

The mean and standard deviation of exerted force,

RMS, and MF in each exercise condition are shown in fig3, fig4 and fig5, respectively. There were no significant differences of the exerted force, RMS or MF in each condition (all  $p \geq 0.05$ ). The CV of the exerted force, RMS and MF measurements are shown in table1. There were no significant differences in CV among the three

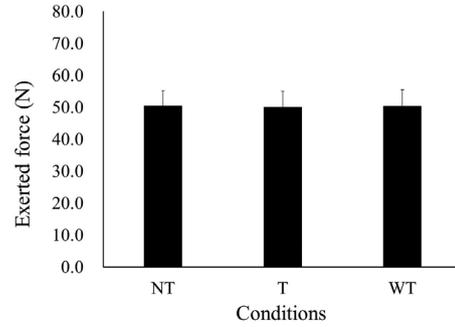


Fig 3 The mean and standard deviation of the exerted force in each condition. NT: in air without waterproofing treatment. T: in air with waterproofing treatment. WT: in water with waterproofing treatment.

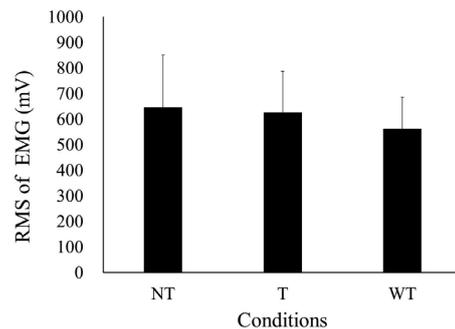


Fig 4 The mean and standard deviation of the root mean square (RMS) of the electromyography (EMG) signal in each condition. NT: in air without waterproofing treatment. T: in air with waterproofing treatment. WT: in water with waterproofing treatment.

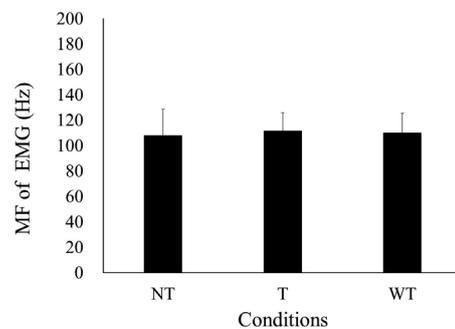


Fig 5 The mean and standard deviation of the median frequency (MF) of the electromyography (EMG) signal in each condition. NT: in air without waterproofing treatment. T: in air with waterproofing treatment. WT: in water with waterproofing treatment.

exercise conditions (all  $p \geq 0.05$ ). The changes of the normalized RMS and MF value which is normalized by

the individual mean value through the 10-time exercises in each condition shown in fig6 and fig7.

Table 1 The coefficient of variation of exerted force, root mean square (RMS) value, and median frequency (MF). NT: in air without waterproofing treatment. T: in air with waterproofing treatment. WT: in water with waterproofing treatment.

Variables		Experimental condition			Significance ( $p$ )
		No tape	Tape	Tape +Water	
CV of Exerted force	(%)	1.4±0.6	1.3±0.5	1.4±0.6	.89
CV of mean RMS	(%)	13.0±7.5	11.6±6.8	12.5±4.2	.72
CV of MF	(%)	6.0±1.6	6.7±2.0	6.0±1.7	.49

Data are expressed as Mean±SD

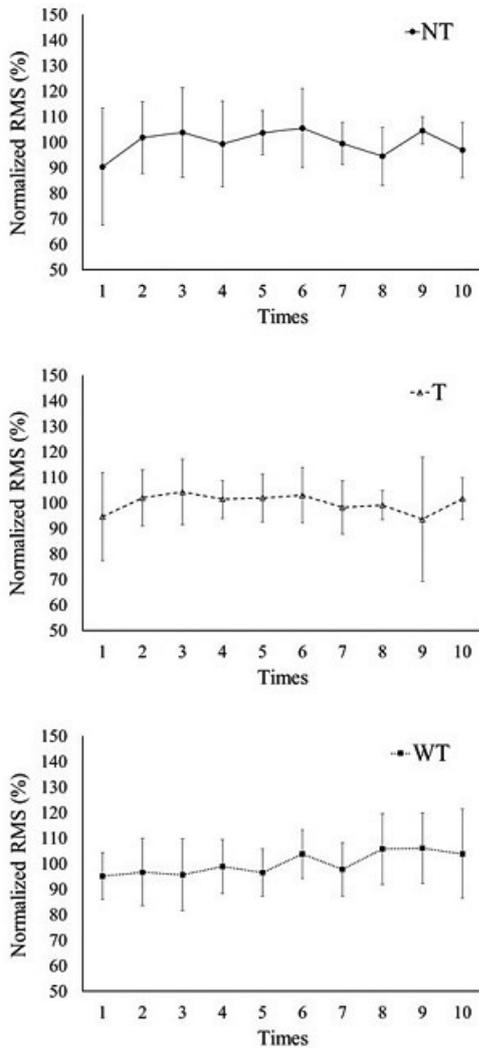


Fig 6 The mean and standard deviation of the normalized root mean square (RMS) value in each time of the 3 experimental conditions (NT, T, and WT). The normalized value was calculated as the RMS value normalized by the mean value through the 10 times. NT: in air without waterproofing treatment. T: in air with waterproofing treatment. WT: in water with waterproofing treatment.

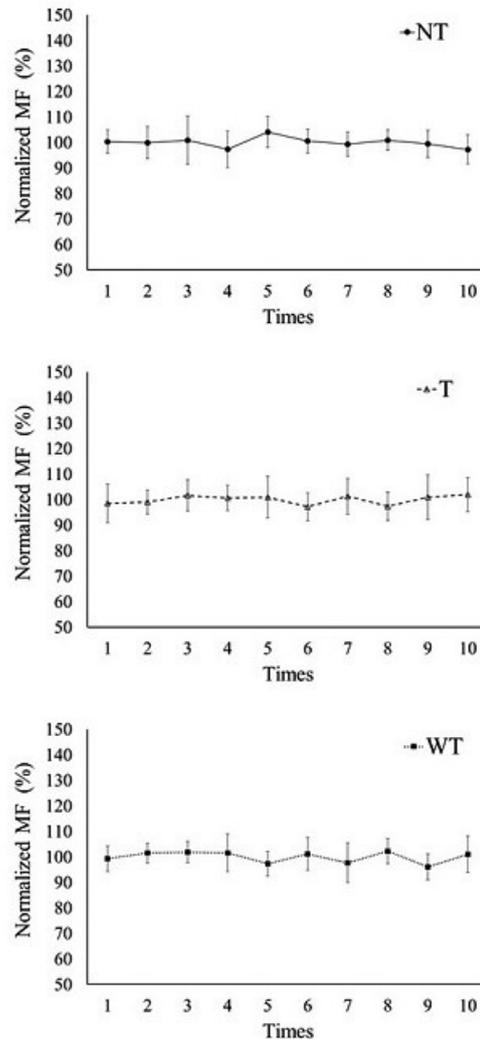


Fig 7 The mean and standard deviation of the normalized median frequency (MF) value in each time of the 3 experimental conditions (NT, T, and WT). The normalized value was calculated as the MF value normalized by the mean value through the 10 times. NT: in air without waterproofing treatment. T: in air with waterproofing treatment. WT: in water with waterproofing treatment.

## Discussion

The purpose of this study was to investigate the suitability of the electrodes waterproofing treatment on the amplitude and spectral characteristics of the sEMG signals. We compared the RMS and MF values of sEMG signals measured during the same isometric exercise performed in air without waterproofing treatment (NT), in air with waterproofing treatment (T) and in water with waterproofing treatment (WT). We observed no significant differences between the 3 conditions in the RMS and MF values.

From the results of the exerted force (fig3), we confirmed that the our participants achieved the experimental task correctly. Furthermore, the MF value was stable through the 10-time exercises in the 3 conditions as demonstrated in fig7. It is known that a decrement of MF value in the power spectrum density is associated with muscular fatigue<sup>4</sup>). Therefore, we considered that the muscle fatigue did not affect the measured sEMG signals in this study.

As fig4, there was no significant difference in the RMS value in this study. Rainoldi et al.<sup>13</sup>) suggested that the amplitude and spectral characteristics of the sEMG signals measured in water with waterproofing treatment were similar to the data measured in air without waterproofing treatment when the participants performed same isometric exercise in air and water. The RMS results in the present study supported the previous study. In addition, there were no significant differences between the 3 conditions in the MF value (fig5). In general, power spectrum analysis of the EMG signal is used to evaluate the signal form which is consisted of various frequency component. Therefore, it was considered that our waterproofing treatment did not affect the amplitude and signal form of the sEMG and was suitable to measure the sEMG in water. Furthermore, there was no significant difference in the CV values of the RMS and MF. Therefore, it was clarified that our waterproofing treatment also did not affect the variability of the sEMG data.

Regarding the effect of the electrodes waterproofing treatment on the EMG signal, there were no significant differences of the RMS and MF values between the NT and T conditions in this study (fig4 and fig5). Veneziane et al.<sup>17</sup>) indicated that the pressure of the tapes covering the electrodes could change an area of muscle fibres under the electrode and thus influence the sEMG signals. However, we did not observe any differences in the amplitude and spectral characteristics of sEMG signals in the air with and without waterproofing. Therefore, it was considered

that the pressure of the water-resistant adhesive tapes did not influence the sEMG data in this study.

In summary, the results of this study showed that our electrodes waterproofing treatment was suitable and did not affect the amplitude and spectral characteristics of the sEMG signals. In this study, the waterproofing treatment was designed referring to the methodology in previous studies<sup>5),16</sup>). Therefore, it was considered that the results of this study contributed to validate the accuracy of the EMG data obtained in these previous EMG studies<sup>5),16</sup>) and our previous studies<sup>7),8</sup>).

A limitation of this study is that a static isometric exercise was used to perform the same exercise in air and static water. When humans perform dynamic exercise in water, buoyancy decreases muscular power output, which reduces exercise loads<sup>1),6),12</sup>). Therefore, if researchers compare the sEMG data during a dynamic movement measured in air and water, they must consider about the effect of the buoyancy on the exercise load. Furthermore, Rainoldi et al.<sup>13</sup>) suggested that the water movement influenced the spectral characteristics of the sEMG signals measured without waterproofing treatment. Hence, future study should focus on the effect of the water flow on the sEMG signals measured in water with our waterproofing treatment.

## References

- 1) Bresseel E, Dolny DG, and Gibbons M (2011): Trunk muscle activity during exercises performed on land and in water. *Med Sci Sports Exerc* 43(10): 1927-1932.
- 2) Caty V, Aujouannet Y, Hintzy F, Bonifazi M, Clarys JP and Rouard AH (2007): Wrist stabilisation and forearm muscle coactivation during freestyle swimming. *J Electromyogr Kinesiol* 17(3): 285-291.
- 3) Cram JR, Kasman GS and Holtz J (1998): Introduction to surface electromyography. Gaithersburg, Aspen Publishers.
- 4) Figueiredo P, Rouard A, Vilas-Boas J and Fernandes RJ (2013): Upper- and lower-limb muscular fatigue during the 200-m front crawl. *Appl Physiol Nutr Metab* 38(7): 716-724.
- 5) Kaneda K, Sato D, Wakabayashi H and Nomura T (2009): EMG activity of hip and trunk muscles during deep-water running. *J Electromyogr Kinesiol* 19(6): 1064-1070.
- 6) Kelly BT, Roskin LA, Kirkendall DT and Speer KP (2000): Shoulder muscle activation during aquatic

- and dry land exercises in nonimpaired subjects. *J Orthop Sports Phys Ther* 30(4): 204-210.
- 7) Kobayashi K, Kaneoka K, Takagi H, Sengoku Y and Takemura M (2015): Lumbar alignment and trunk muscle activity during the underwater streamline position in collegiate swimmers. *Journal of Swimming Research* 23(1): 33-43.
  - 8) Kobayashi K, Takagi H, Tsubakimoto S and Sengoku Y (2016): Activation pattern of trunk, thigh and lower leg muscles during underwater dolphin kick in skilled female swimmers. *ISBS-Conference Proceedings Archive*.
  - 9) Martens J, Figueiredo P and Daly D (2015): Electromyography in the four competitive swimming strokes: A systematic review. *J Electromyogr Kinesiol* 25(2): 273-291.
  - 10) Panek D, Pavlu D and Cemusova J (2012): *Water Surface Electromyography*. (Ed.) Schwartz M (In) *EMG Methods for Evaluating Muscle and Nerve Function*. InTech. Rijeka, 456-470.
  - 11) Petrofsky J and Laymon M (2005): Muscle temperature and EMG amplitude and frequency during isometric exercise. *Aviat Space Environ Med* 76(11): 1024-1030.
  - 12) Poyhonen T, Keskinen KL, Hautala A, Savolainen J and Malkia E (1999): Human isometric force production and electromyogram activity of knee extensor muscles in water and on dry land. *Eur J Appl Physiol Occup Physiol* 80(1): 52-56.
  - 13) Rainoldi A, Cescon C, Bottin A, Casale R and Caruso I (2004): Surface EMG alterations induced by underwater recording. *J Electromyogr Kinesiol* 14(3): 325-331.
  - 14) Rouard AH and Clarys JP (1995): Cocontraction in the elbow and shoulder muscles during rapid cyclic movements in an aquatic environment. *J Electromyogr Kinesiol* 5(3): 177-183.
  - 15) Rouard AH, Billat RP, Deschodt V and Clarys JP (1997): Muscular activations during repetitions of sculling movements up to exhaustion in swimming. *Arch Physiol Biochem* 105(7): 655-662.
  - 16) Silvers WM and Dolny DG (2011): Comparison and reproducibility of sEMG during manual muscle testing on land and in water. *J Electromyogr Kinesiol* 21(1): 95-101.
  - 17) Veneziano WH, Da Rocha AF, Gonçalves CA, Pena AG, Carmo JC, Nascimento FAO and Rainoldi A (2006): Confounding factors in water EMG recordings: An approach to a definitive standard. *Med Biol Eng Comput* 44(4): 348-351.