Effects of Self-Care by Neuromuscular Electrical Stimulator on Subjective Fatigue in Collegiate Female Football Players

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This study examined self-care through neuromuscular electrical stimulation (NMES) and its efficacy on subjective fatigue in collegiate female football players. Fourteen females (age: 20.7±0.8 years) participated in a crossover experimental design. The participants were randomly allocated to group A (n=7, phase I: self-care, phase II: control) or B (n=7, phase I: control, phase II: self-care). The study was completed in two phases with a washout period of 21 days set between phases. NMES was used for five nights in self-care but not in the control phase. The subjective fatigue magnitude was measured using the visual analogue scale; Ogri, Shirakawa, Azumi sleep inventory MA version (OSA); and cortisol awakening response (CAR). Subjective fatigue was significantly different between the before self-care and next morning groups (p<0.02). However, the control group showed no significant differences between before sleep and next morning (p=0.113) in phase I. There were no significant differences between both groups (self-care: p=0.6943, control: p=0.1154) in phase II. OSA scored significantly higher by self-care in F4 (p<0.002) in phase I and F5 (p<0.004) in phase II. CAR showed no significant difference between phases I (p=0.2642) and II (p=0.2275). These results suggest that self-care with NMES has potential to improve fatigue and sleep quality. Further research with a sufficient sample size is required to confirm the efficacy of the present self-care procedure.

Keywords: female football player, self-care, Neuromuscular Electrical Stimulator, subjective fatigue

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1. Introduction

Football players are required to perform high-intensity movement such as sprinting, dashing, turning, kicking, and jumping during a 90-minute match. Compared with the first half of football matches, accident rates tend to increase toward the end of the last half (Hawkins and Fuller, 1999). The accumulation of action leads to physical and psychological fatigue, which is thought to be a cause of the increase in accident rates (Japan Football Association, 2007). Female football players tend to have injuries to their ankle and knee joints (Japan Football Association, 2007). It is thought that fatigue causes an increase in ankle joint dorsiflexion angle at the initial grounding of a single leg jump, and a decrease in ankle joint power and floor reaction force, which limits lower limb joint movement (Jayalath et al., 2018) and causes injury. Therefore, it is necessary to provide care for football players that relieves fatigue in lower limb muscles.

To relieve fatigue after exercise, a wide range of care, including active recovery, compression wear, massage, electrotherapy, and water baths is provided. Massage in particular is considered one of the most effective treatments because it shows improvement in inflammatory markers, delayed onset muscle soreness (DOMS), and subjective fatigue. The mechanism of massage is thought to increase muscle blood flow and decrease intramuscular pressure (Dupuy et al., 2018). Furthermore, previous studies have reported that massage is highly effective in reducing fatigue after exercise, and the usefulness of massage is clear and obvious; however, massage requires a third person such as a trainer. It is difficult for the individual player to perform self-massage, and massage is time consuming.

Electrotherapy has not been clearly proven to be effective compared with massage for fatigue; however, it has been reported to be effective in decreasing muscular pain and the feeling of fatigue, and in improving performance (Astokorki et al., 2017). This suggests that electrotherapy may be effective in reducing fatigue. Furthermore, electrical stimulation can be used for self-care at home, which allows players to control their health management and be ready to engage in training in good condition. This has the potential to reduce the accident rate and to be extremely beneficial.

Therefore, we conducted this study to clarify the usefulness of the Neuromuscular Electrical Stimulator (NMES) developed through application of the same stimulation patterns as hand-massage to reduce subjective fatigue targeting collegiate female football players.

2. Methods

2.1. Subjects

Subjects of this study were 14 collegiate female football players belonging to the Japan University Women Football Association (JUWFA)–Kansai Division 1. Subjects were dormitory students, had no injuries, and could participate in team practice. We excluded individuals who fall under contraindications for NMES. Before conducting the study, we explained to all subjects that (1) They were free to participate in this study and could leave the study at any time; (2) After leaving the study, they would not suffer any disadvantage; and (3) They are covered by medical insurance in case of adverse event or side effect during the period of this study, and obtained consent from all subjects. This study was conducted upon approval from the Human Research Ethics Committee.

2.2. Research Protocol

Fourteen subjects were randomly separated into Group A (seven subjects) and Group B (seven subjects) by computer. The research period was between October 12 and November 13, 2020, when the limitations on practice due to COVID-19 were relaxed. With the application of crossover design, the research was conducted during the phase I (self-care period: October 12–16), washout period (21 days), and the phase II (self-care period: November 9–13). During phase I, we set Group A as the Self-care Group, and Group B as the Control Group while we set Group A as the Control Group, and Group B as the Self-care Group during phase II. Self-care period was the period in which subjects used NMES while control period was the period without stimulation.

We also asked subjects to thoroughly observe the following rules: (1) Participate in team training; (2) Refrain from using other care and conditioning; (3) Measure predetermined items at five o'clock in the morning and before bed; (4) Note the location of fatigue they felt in the questionnaire before self-care and bed; (5) Check subjective fatigue before and after self-care during the self-care period; and (6) Perform self-care before bed.

2.3. Measurement Items

In order to examine subjective fatigue, we applied the Visual Analogue Scale (VAS) established by the Japanese Society of Fatigue Science and included in the Anti-fatigue Clinical Evaluation Guidelines, considered a noninvasive and highly safe and convenient evaluation method with small burden, referring to the method developed by the Japanese Society of Fatigue Science (2011), Dunbar et al. (2015), Yamamoto et al. (1999), and Uchida et al. (2020). In regard to other factors related to fatigue, we also measured subjective sleep quality using the Ogri, Shirakawa, Azumi sleep inventory MA version (OSA) and cortisol awaking response (CAR) using a SOMA Cube Reader made by SOMA Bioscience Limited in England.

In regard to VAS, subjects were required to write "I don't feel any fatigue" at 0mm and "I am exhausted" at 100mm on a 100mm scale, and check their subjective fatigue when awaking, before bed, before and after self-care during the self-care period. OSA is a statistical scale for changing sleep quality, and is used to evaluate the sleep habits and the condition of each subject. OSA consists of 16 items categorized by five factors; namely, sleepiness at awaking (first factor), induction and maintenance of sleep (second factor), dream frequency (third factor), refreshment (fourth factor), and sleeping hours (fifth factor). The average of each factor is set at 50 points, and it was deemed that the higher the score becomes, the better the subject's sleep quality is.

For CAR collection, subjects rinsed their mouths with running water after waking up at five o'clock every morning, inserted a swab into their mouths until it turned blue, placed the swab into a buffer solution and shook it gently for two minutes. After receiving the sample from each subject each day, a research companion who had mastered the measurement method placed three drops on a plate and waited for 10 minutes to measure salivary cortisol concentration.

2.4. Self-care Method

Subjects used HV-F080 (made by OMRON HEALTHCARE Co., Ltd.), which contains stimulation patterns similar to hand-massage stimulation using muscle contraction in its Recovery Mode. Use of the device was explained to subjects in advance, and the manual was read by each subject.

As shown in **Figure 1**, subjects laced the pad of the device onto both lower limbs (front or back of femoral regions, or front or back of lower thighs) where they felt the greatest degree of fatigue. The pad (HV-SPAD-MU) used for the device in this study has a 2470mm^2 area per electrode, and two electrodes per pad. Then, subjects were asked to choose one mode from Mode 1 (repeat of tetanic contraction and relaxation), Mode 2 (repeat of contraction and relaxation), and Mode 3 (repeat of short contraction and relaxation) in the Recovery Mode (frequency: 0.2–99Hz; maximum pulse width: 100μsec; output voltage: 10mA or lower; level of stimulation: 20 stages). They applied electrical stimulation at a comfortable level on both leges simultaneously for 30 minutes before bed. The locations of the pads were recorded each time and reported by subjects.

2.5. Statistical Processing

Measurements were recorded by physical characteristic, training time, and location of subjective fatigue. Frequency of mode use was shown in mean value±standard deviation, and VAS, OSA, and CAR were shown in boxplots.

We conducted a statistical comparison of VAS in the morning between the Self-care and Control Groups using the Wilcoxon signed rank test. Then, we compared VAS between Self-care and Control (non-stimulation) Groups in phase I and II using the Wilcoxon signed rank test. Finally, we compared VAS, OSA, and CAR between two groups in phase I and II using the Wilcoxon rank sum test. Statistical significance was set less than 5%.

3. Results

3.1. Basic Characteristics of Subjects

Characteristics of subjects are shown in **Tables 1** to **5**.

In regard to the physical characteristics and presence or absence of chronic fatigue of the subjects, because the subjects were collegiate female football players, weight against height was standard in both groups. Performance history showed no differences, while six out of seven members of Group A, and three out of seven members of Group B felt chronic fatigue (**Table 1**). Team training was performed for approximately two hours per week on average in the early morning (**Table 2**). In addition, the highest number of subjects had subjective fatigue in the gastrocnemius due to the characteristics of football (**Table 3**). In regard to the number of times Recovery

Gastrocnemius Quadriceps Hamstrings

Figure 1 Location of the pad attached

Appearance of the subjective fatigue in the leg muscles.

Table 1 Characteristics of the subject

Characteristics of the subject	Group A (n=7)	Group B (n=7)
Age (years)	20.4 ± 0.7	21 ± 0.8
Height (cm)	159.6 ± 3.6	158.9 ± 2.0
Weight (kg)	50.4 ± 3.8	52.0 ± 2.8
Competition history (years)	13.7 ± 1.7	15.1 ± 1.6
Chronic fatigue	6	3

Values show mean ± SD.

Table 2 Program of training menu and performed time in each phase

Phase	Day	Time (hours)	Menu
I	Day1	0.5 ± 0.6	Strength&Agility
	Day2	2.3 ± 0.7	Interpersonal practice
	Day3	2.0 ± 1.9	Formation
	Day4	2.6 ± 1.9	Game
	Day5	2.4 ± 0.8	
II	Day1	0.3 ± 0.4	Strength&Agility
	Day2	2.0 ± 0.5	Interpersonal practice
	Day3	1.9 ± 1.9	Formation
	Day4	1.8 ± 1.8	Game
	Day5	2.1 ± 0.5	

Phase I conducted during Oct 12-16, 2020. Phase II conducted during Nov 9-13, 2020.
Washout period was 21 days. Values show mean ± SD (n=14)

Table 3 Appearance of the subjective fatigue in the leg muscles

Result of fatigue body parts	number of body parts (n=70)
Gastrocnemius (%)	67 (43%)
Quadriceps (%)	53 (34%)
Hamstrings (%)	33 (21%)
Tibialis anteiror (%)	2 (1%)

Values show mean ± SD.

Mode for electrical stimulation was used during the self-care period, in phase I, Mode 1 was used 17 times, Mode 2 was used 10 times, and Mode 3 was used eight times while in phase II, Mode 1 was used 16 times, Mode 2 was used seven times, and Mode 3 was used 11 times (**Table 4, 5**).

3.2. Changes in Subjective Fatigue (VAS)

Figure 2 shows the changes in VAS in the Self-care and Control Groups. While the Self-care Group median is 40mm, the Control Group is 52mm, indicating a greater decrease in VAS in the Self-care Group; however, there was no statistically significant difference (p=0.3483).

Table 4 The number of times of uses by type of recovery mode (phase I)

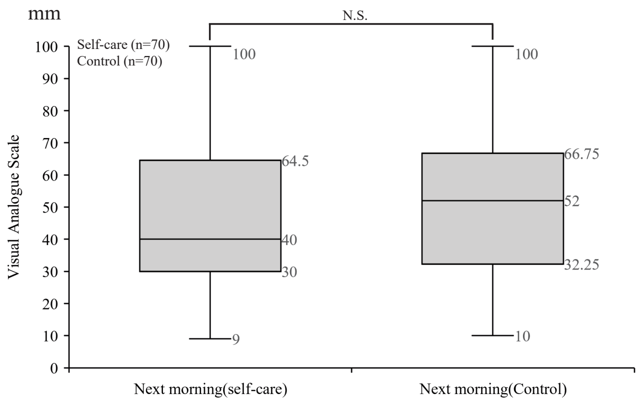
Phase I	**Number of uses (times)**		
12~16/Oct/2020	**mode1**	**mode 2**	**mode 3**
Day1	6	1	0
Day2	3	3	1
Day3	4	2	1
Day4	2	2	3
Day5	2	2	3
Total	17	10	8

mode1 :Repeat of Tetanic contraction & Relaxation (like massage stimulation)
mode2 :Repeat of Contraction & Relaxation (like push stimulation)
mode3 :Repeat of Short contraction & Relaxation (like hit stimulation)

Table 5 The number of times of uses by type of recovery mode (phase II)

Phase II	**Number of uses (times)**		
9~13/Nov/2020	**mode1**	**mode 2**	**mode 3**
Day1	4	1	2
Day2	2	4	0
Day3	4	0	3
Day4	4	1	2
Day5	2	1	4
Total	16	7	11

mode1 :Repeat of Tetanic contraction & Relaxation (like massage stimulation)
mode2 :Repeat of Contraction & Relaxation (like push stimulation)
mode3 :Repeat of Short contraction & Relaxation (like hit stimulation)



Asymptotic Wilcoxon rank sum test
data: vx and vy
W = 2225, p-value = 0.3483
alternative hypothesis: true mu is not equal to 0

Figure 2 Difference of VAS between the self-care groups and control groups

The boxplot shows the subjective fatigue in the self-care group and the control (non-stimulation) group.
Both ends of the box indicate 25% and 75% points, the horizontal line in the box indicates the median, and the error bar indicates ± 1.5 × (interquartile range).
There was no significant difference in the subjective of fatigue before and after in both groups.

Meanwhile, **Figures 3** and **4** show changes in VAS in the Self-care (before stimulation and the following morning) and Control Groups (before bed and the following morning) in phase I and II. In phase I (**Figure 3**), the Self-care Group median is 57mm before self-care, and 40mm the following morning, indicating a decrease in VAS the following morning, and a statistically significant difference ($p<0.02$) was noted. The Control Group median before bed is 58mm, and 51mm the following morning, indicating a lack of change in VAS, and no statistically significant difference ($p=0.113$). In phase II (**Figure 4**), the Self-care Group median is 49mm before self-care, and 42mm the following morning while the Control Group median is 60mm before bed, and 54mm the following morning. Therefore, neither group showed a statistically significant difference (Self-care Group: $p=0.6943$, Control Group: $p=0.1154$).

3.3. Changes in Subjective Sleep Quality (OSA) when Awaking

Figures 5 and **6** show changes in OSA factors (F1 to 5) in the Self-care and Control Groups in phase I and II. In phase I (**Figure 5**), the median F4 factor (refreshment) was 47.2 points in the Self-care Group, and 42.4 points in the Control Group, indicating a statistically significant difference ($p<0.002$). In phase II (**Figure 6**), the median F5 factor (sleeping hours) was 42.5 points in the Self-care Group, and 34.2 points in the Control Group, indicating a statistically significant difference ($p<0.004$). Other factors showed no change.

3.4. Changes in Cortisol Awaking Response (CAR)

Figures 7 and **8** show the changes in CAR in the Self-care and Control Groups in phase I and II. In phase I (**Figure 7**), median CAR was 5.8nM in the Self-care Group, and 4.5nM in the Control Group, showing no change in either group ($p=0.2642$). In addition, in phase 2 (**Figure 8**), median CAR was 27.7nM in the Self-care Group, and 36.2nM in the Control Group, indicating no statistically significant difference, although CAR in Self-care Group decreased ($p=0.2275$).

3.5. Self-care Safety

We asked subjects to report to the research manager if any adverse event or side effect arose during the research period due to the use of the mobile electrotherapeutic device HV-F080 (made by OMRON HEALTHCARE). However, there were no reports from subjects.

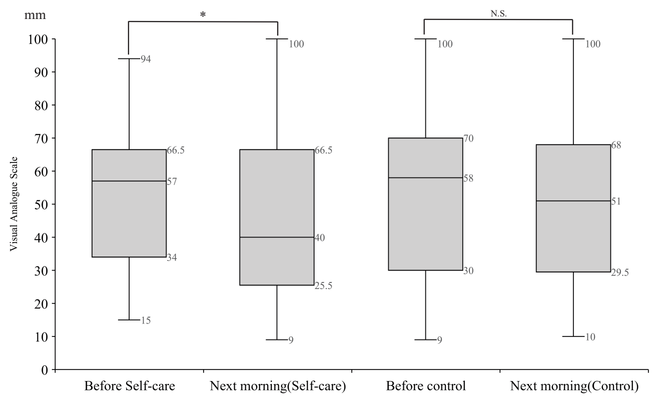


Figure 3 Difference of VAS between the self-care and control groups (phase I)

The boxplot shows the subjective fatigue in the self-care group and the control (non-stimulation) group in phaseI.
Before and after self-care, the subjective of fatigue was significantly reduced ($p<0.05$).

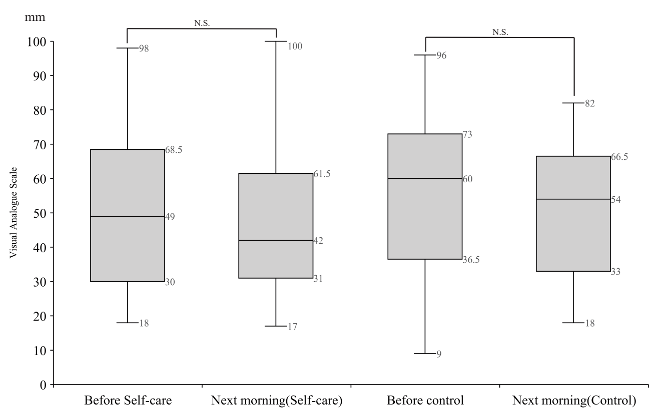
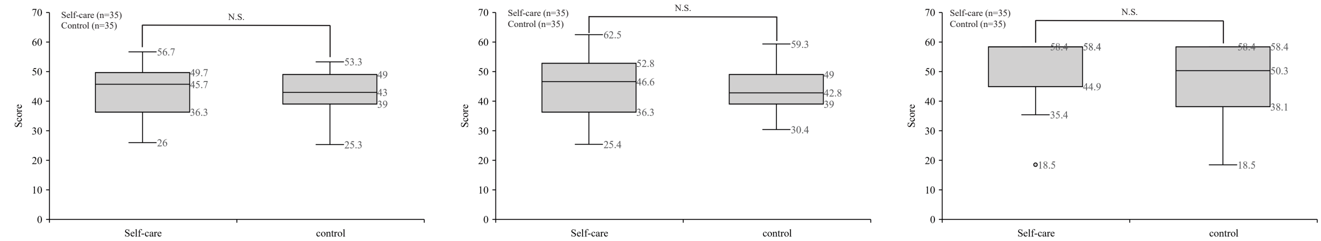
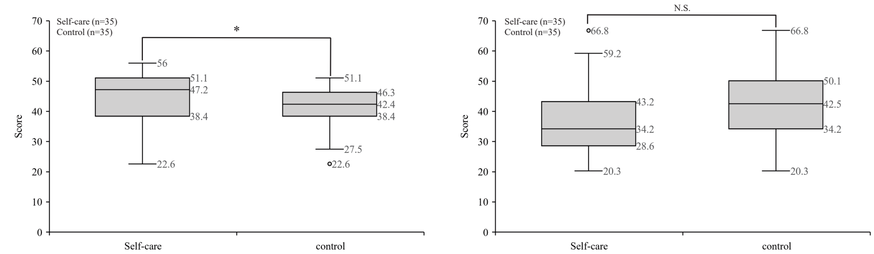


Figure 4 Difference of VAS between the self-care and control groups (phase II)

The boxplot shows the subjective fatigue in the self-care group and the control (non-stimulation) group in phaseII.
There was no significant difference in the subjective of fatigue before and after in both groups.



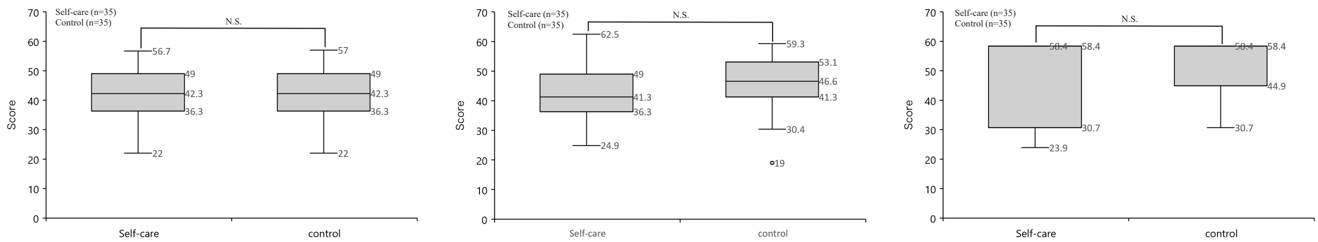
F1: sleepiness at awaking F2: induction and maintenance of sleep F3: dream frequency



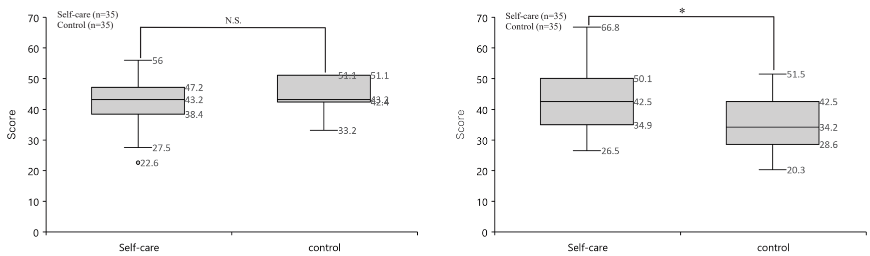
F4: refreshment F5: sleeping hours

The boxplot shows the OSA in the self-care group and the control (non-stimulation) group in phase I.
In F4, the self-care group showed a significantly higher score than the control group (p<0.002).

Figure 5 Differences in OSA sleep inventory MA version between Self-care and Control groups (phase I)



F1: sleepiness at awaking F2: induction and maintenance of sleep F3: dream frequency



F4: refreshment F5: sleeping hours

The boxplot shows the OSA in the self-care group and the control (non-stimulation) group in phase II.
In F5, the self-care group showed a significantly higher score than the control group (p<0.004).

Figure 6 Differences in OSA sleep inventory MA version between Self-care and Control groups (phase II)

4. Discussion

Targeting 14 collegiate female football players, this study examined the effects of self-care using NMES with subjective fatigue (VAS), subjective sleep quality (OSA), and cortisol awaking response (CAR) as evaluation indicators.

4.1. Subjective Fatigue (VAS)

In phase I, VAS in the Self-care Group decreased and there was a statistically significant difference while in phase II, there were no changes in VAS in either group. This suggested that self-care using NMES is potentially effective in reducing fatigue; however, we could not confirm reproducibility of the effects. Reasons for this may be the setting of stimulation levels and the environment for different phases.

The subjects were free to choose from the stimulation levels, and chose “moderate,” which may have influenced the effects of self-care using

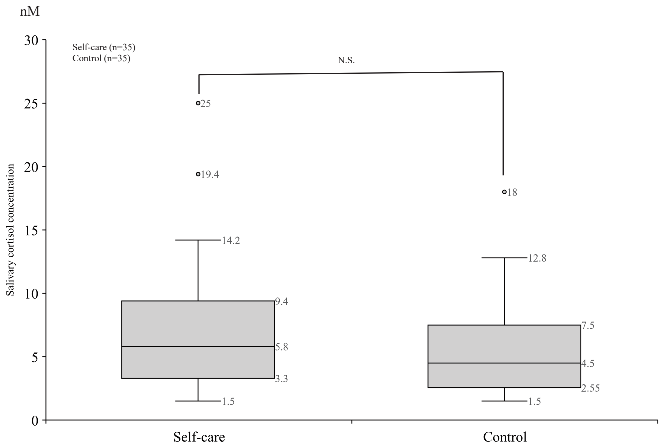


Figure 7 Difference of salivary cortisol concentration between the self-care and control groups (phase I)

The boxplot shows the cortisol awaking response in the self-care group and the control (non-stimulation) group in phase I.
There was no change in salivary cortisol levels in both groups (p=0.2642).

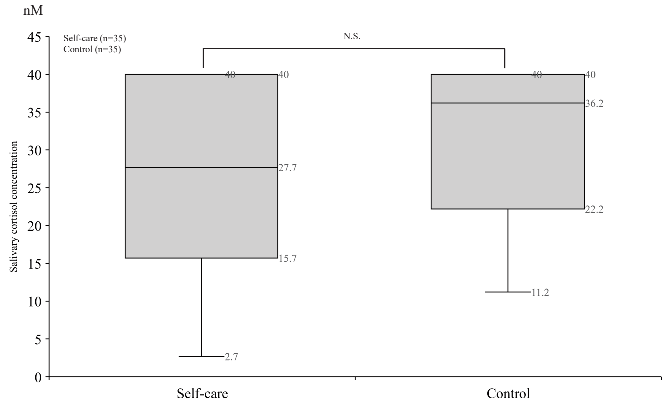


Figure 8 Difference of salivary cortisol concentration between the self-care and control groups (phase II)

The boxplot shows the cortisol awaking response in the self-care group and the control (non-stimulation) group in phase II.
There was no change in salivary cortisol levels in both groups (p=0.2275).

NMES rather than the number of times of use by type of mode shown in **Tables 4** and **5**. Characteristics of NMES are as follows: (1) The stronger the stimulation (current value) is, the stronger the muscle contraction becomes; however, the stronger current value also stimulates sensory nerves and causes pain; (2) NMES tends to stimulate thinner nerve fibers (fast muscle: Type II muscle fibers); and (3) Repetition of stimulation contracts the same muscle group (motor unit) only and this tends to cause muscle fatigue (Ogata, 2017). Repeated contraction with NMES may have influenced subjective fatigue. This suggested that when using NMES for self-care, it is necessary to consider the stimulation level to obtain certain effects.

In regard to the difference in the environment for phases, phase I was conducted immediately after the easing of limitations on practice due to COVID-19, and salivary cortisol concentration was low in both groups, as shown in **Figure 7**, which shows that subjects had less stress physically and psychologically. However, phase II conducted about one month after easing of limitations on practice indicated higher salivary cortisol concentration in both groups, as shown in **Figure 8**, which indicates that subjects had more stress physically and psychologically. As described above, NMES was effective in reducing subjective fatigue in phase I, in which subjects had less physical and psychological stress, while it was ineffective in phase II, in which subjects had more physical and psychological stress. This suggested that the use of NMES for reducing subjective fatigue may be influenced by stress level.

NMES has been used to enhance muscle strength, improve metabolism, and to support extremity functions as physical therapy in rehabilitation (Ogata, 2017). Recently, the use of NMES has been expanded, and use to improve cardiopulmonary function and exercise tolerability (Miyamoto, 2019) has also been reported. NMES used in this study can provide stimulation similar to hand-massage, and has the potential to contribute to conditioning for players as a way to achieve active recovery; however, the effects must be validated further due to the influence of stimulation and stress levels.

4.2. Subjective Sleep Quality (OSA)

Sleep in general is known to be closely associated with subjective fatigue (Onoue, 2009). In particular, because muscle tone is controlled via autonomic nerves, sleep loss may change the state of muscle tone and increase subjective fatigue. Therefore, in this study, we measured subjective sleep quality using OSA. As a result, F4 (refreshment) factor in phase I and F5 (sleeping hours) factor in phase II indicated higher scores using electrical stimulation and showed a statistically significant difference compared with Control Group. This suggested that self-care for lower limbs using NMES may improve both the quality and quantity of sleep.

The reasons for improved sleep with electrical stimulation cannot be clarified by the results of this study alone. However, it has been suggested that NMES tends to stimulate nerve fibers (fast muscle: Type II muscle fibers) (Ogata, 2017), and small-diameter nerve fibers are known to control autonomic nerves via polymodal receptors. Foot massage activates parasympathetic nerves, which reduces blood pressure and heart rate, and promotes sleepiness (Kito et al., 2014). This suggests the high likelihood that the electrical stimulation given in this study influences sleep via autonomic nerves. However, because factors influenced by electrical stimulation differed in phase I and II, it is necessary to further clarify which factor is effectively influenced by electrical stimulation.

4.3. Cortisol Awaking Response (CAR)

Salivary cortisol concentration has attracted attention as a means of evaluating stress physiologically. Cortisol is a steroid hormone released from the adrenal cortex, and has been investigated most frequently in relation to stress. Cortisol has a wide range of physiological functions for the immune, vascular, and central nervous systems, and is an important hormone to consider for physically and psychologically healthy conditions. In addition, salivary cortisol is highly correlated with blood cortisol. Salivary cortisol concentration rapidly increases 30 to 60 minutes after awaking, and then gradually decreases thereafter (circadian rhythm) (Izawa et al., 2010). It is also reported that cortisol secretion increases via the hypothalamic-pituitary-adrenal axis (HPA axis) due to acute and chronic physical and psychological stress, which causes the increase of salivary cortisol concentration (Schulz et al., 1998).

Salivary cortisol concentration is easier to measure than blood cortisol is, as described above, and has been used as a stress indicator. We were unable to observe the effects of NMES in decreasing CAR in this study. One reason for this is that stimulation by NMES to lower limbs with fatigue did not directly decrease physical and psychological stress. It has also been reported that the effect of massage on cortisol is insignificant (Christopher et al., 2011). These are reasons that our study showed results similar to previous studies. On the other hand, it has also been reported that massage decreased salivary and urinary cortisol (Field et al., 2005). Therefore, the effects of massage on cortisol have not yet been clarified. It is known that tactile stimulation leads to activation of autonomic nerve reactions in the brain stem reticular formation and activation of parasympathetic nerves. This along with the results of a previous study reporting that foot massage decreased plasma noradrenalin, blood pressure, and heart rate (Yoneyama et al., 2009) suggests that cortisol may influence the sympathetic-adrenal-medullary axis (SAM axis), not the HPA axis. Future studies should examine autonomic nerve functions, including blood pressure and heart rate, using the SAM axis as an indicator, massage locations, stimulation level and frequency to clarify the effects of NMES.

4.4. Effects of Self-care Using NMES

In this study, we examined the effects of self-care using NMES for subjective fatigue targeting 14 collegiate female football players. The results suggested that performing self-care after practice may improve subjective fatigue, sleeping time, and sleep quality. Although subjective fatigue tended to decrease, examination using crossover design could not clarify reproducibility of the effects; and salivary cortisol concentration, which is a stress indicator, was not influenced by the use of NMES. Therefore, it is necessary to consider how NMES can be used most effectively.

Although jogging, massage, and other activities are effective for recovery from fatigue after practice, NMES is easier and safer to use, does not require any specialized knowledge, and can provide therapy in a shorter amount of time. Therefore, it would be beneficial for athletes if NMES is shown to be effective for use in self-care. In the future, we would like to reexamine the effective use of NMES in different settings to establish self-care methods using NMES.

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Brief Biographical History:

1998 Bachelor of acupuncture, Practitioner in acupuncture and moxibustion.
1998-2015 Teacher in Meiji School of Oriental Medicine.
2015 Master's Program in Faculty of Health and Sports Science, University of Doshisha.
2015-2018 Fisio (Acupuncturist), SL Benfica, Lisbon, Portugal.
2018-2019 Fisio (Acupuncturist), CF Belenenses, Lisbon, Portugal.
2019- Assistant Professor, MAT/ASC Coordinator, Director of Football in Meiji University of Integrative Medicine.

Main Publications:

- Taniguchi, T. (2017). Global Communication on Acupuncture "Sports Acupuncture"-An introduction to the "Acupuncture in the Portugal". JJSAM,67 (4): 379-386.
- Taniguchi, T. (2018). Taping Therapy Front Line. Ido-No-Nippon-Sha,112-119.

Membership in Learned Societies:

- Japanese Society of Science and Football
- Japan Mibyou Association
- The Japanese Society Of Physical Fitness And Sports Medicine