Journal of Asian Rehabilitation Science

ISSN 2434-0758
J.Asia.Reha.Sci.

Journal of Asian Rehabilitation Science

Vol.3 No.2 June 2020

The Society of Asian Rehabilitation Science

The Journal of Asia Rehabilitation Science (ISSN 2434-07058) is published for the Society of Asia Rehabilitation Science. The journal is published quarterly.

The editors welcome original papers with significant areas of physical therapy, occupational therapy and speech and language therapy.

Manuscripts should be submitted to:
http://rehaac.org/asiareha.html
For enquiries please contact:
JARS Editorial Office
acarehacenter@yahoo.co.jp

The Journal of Asian Rehabilitation Science
Vol.3 No.2, June
2020

Contents

ORIGINAL ARTICLES

J. Asi. Reha. Sci.3(2):10-16,2020

The Journal of Asian Rehabilitation Science

Original Article

Gender-corrected index characteristics of grip and endurance in healthy young people

AKIHIRO YAKABI, RPT, PhD [1)], MASAHIRO ISHIZAKA, RPT, PhD [1)]
TSUYOSHI HARA, RPT, PhD [1)], YOHEI SAWAYA, RPT, MS [1)], AKIRA KUBO, RPT, PhD [1)]

1) Department of Physical Therapy, school of Health Science, International University of Health and Welfare and Welfare (2600-1 Kitakanemaru, Ohotawara City, Tochigi Prefecture 324-8501, Japan)

Abstract. [Purpose] We aimed to examine the characteristics of an index that can correct for gender differences in grip strength and endurance by using muscle mass, such as skeletal muscle mass in healthy young individuals. [Subjects and Methods] Forty-one healthy, young males aged 19.2 ± 0.4 years old and 29 females aged 19.2 ± 0.4 years old (mean ± standard deviation) were enrolled. Grip and peakVO2 were adjusted according to body weight, fat-free mass, and skeletal muscle mass alone, and the values were compared between male and female. [Results] Only grip/skeletal muscle mass showed no significant differences between males and females. [Conclusion] Gender differences in mere muscular exertion, such as grip, could be corrected for using skeletal muscle mass.

Key Words: Grip strength, Skeletal muscle mass (SMM), Gender-corrected

(This article was submitted May.12, 2020, and was accepted June.11, 2020)

1. INTRODUCTION

At the 2020 Tokyo Olympics, due to changes in the event program, it is expected[1)] that approximately half of the participants will be females. It is also reported[1)] that the number of mixed-gender events will increase. In order to promote gender equality, the goals of the Olympics were “to achieve a female participation rate of 50%” and “to encourage the adoption of mixed-gender group events,” with the addition of mixed-gender events such as table tennis, judo, Athletics and swimming. This is being adopted and competition events for males and females are being promoted. On the other hand, it is necessary to pay attention to the physical difference when performing a mixed competition. It is known that compared to females, males generally have a larger amount of skeletal muscle mass (SMM)[2)], whereas females have comparatively large amounts of body fat[3)]. Therefore, it is considered difficult to play contact and power sports in a mixed-gender system, considering possible injuries. Previous studies[4, 5)] compared isometric muscle strength between males and females and reported that, in females, the force-generating capacity of the upper limb muscles was 50–60% that of males. In the lower limbs, females demonstrated a force-generating capacity that was 60–80% that of males. Since muscle strength is significantly higher in males than in females, it is necessary to carry out the competition based on gender. In addition, in previous studies on endurance, it was reported that females showed superior performance to males, and they showed similar performance during long-term exercise. Prior studies[6)] have found that females showed superior physical endurance compared to males, although the performance of males and females was equivalent during long-term exercise. In a previous study of males and females with similar full marathon times, females

*Corresponding author: AKIHIRO YAKABI (yakabi@iuhw.ac.jp)

performed significantly higher than males during the 90 km marathon. Thus, there are reports that males have superior muscular strength, whereas females have superior endurance performance. Miller[7] examined knee extension and elbow flexion strength in males and females—including those with sports experience—and reported that sex-based differences were more likely to manifest in the upper limbs. Maughan[8] reported that the absolute value of knee extension muscle strength showed a significant difference between males and females, but the difference was reduced after adjusting for body weight and fat-free mass (FFM). In addition, there were no significant between-sex differences in knee extension muscle strength and quadriceps cross-sectional area. In other words, it has been pointed out that the difference in muscle strength between males and females is more affected by the difference in muscle cross-sectional area than by the effect of body weight or FFM. In addition, in a previous study[9], the cross-sectional area of the pectoralis muscles on single axial CT images showed a moderate correlation with total body SMM, as determined by bioelectrical impedance analysis (BIA) in healthy subjects. From this result, it is hypothesized that the difference in SMM greatly affects the gender difference in muscular exertion. In previous research for the evaluation index of SMM and FFM, there are how to correcting SMM with body weight and converting it to 100%[10], dividing limb SMM by the square of height[11], and extremity removal in which the fat mass is divided by the square of the height exist[12]. In Japan, Sanada[13] et al. calculated the cutoff values of SMM, which were 6.87 kg/m2 for males and 5.46 kg/m2 for females. In addition, FFM was sometimes regarded as SMM, but it is difficult to treat it as pure SMM because FFM contains water in tissues other than fat. Therefore, it may be possible to correct the gender difference by evaluating the simple muscle force exertion value obtained by dividing the muscle force by the SMM. In this study, we used the measurements of healthy, young individuals to measure grip and peakVO2. Grip is the important outcomes and indicator of overall strength[14]. In addition, peakVO2 is main outcome of endurance. By dividing the two outcomes of grip and peakVO2 by weight, FMM, SMM and comparing these indexes between males and females.

This study aimed to examine an index that can correct gender differences and it may be possible to compare uniform data between males and females.

2. SUBJECTS AND METHODS

Ninety participants (41 males, aged 19.2 ± 0.4 years old, height 171.9 ± 5.6 cm, weight 65.7 ± 7.1 kg, body mass index [BMI] 22.3 ± 2.6 kg/m2; 29 females, aged 19.2 ± 0.4 years old, height 159.9 ± 5.0 cm, body weight 55.4 ± 5.8 kg, BMI 21.7 ± 1.9 kg/m2 [mean ± standard deviation]) were included in the study. Those with a history of respiratory or heart diseases, those who did not undergo measurement due to physical and mental conditions on the day of measurement, and those who had pacemakers or metals inserted into the body were excluded. To measure body composition components (BCCs) the bioelectrical impedance analysis (BIA) method was used.

This study complied with the ethical standards of the Declaration of Helsinki and was approved by the Ethics Committee of the International University of Health and Welfare (approval number: 19-Io-190). After the ethical examination was approved for the retrospective study, the participants were informed in writing about the purpose of the study and the handling of the measurement data, and consent was obtained.

This study measured BCCs, maximum oxygen intake (peakVO2), and grip of healthy, young males and females. The order of measurement was randomly assigned. The BCCs were measured by first removing the sebum from the limb surfaces with alcoholized cotton, then measuring the weight using In-Body 520 (In-Body, Japan), and inputting the height and ID. For BCCs, we extracted the weight, BMI, SMM, body fat percentage (BFP), and FFM values. To measure endurance, a dedicated mask was attached by a breath-by-breath method using an exhalation gas analyzer (AERO MONITOR 300S manufactured by MINATO), and ramp load was applied on a treadmill (GAIT TRAINER manufactured by BIODEX). In the measurement protocol, the patient stayed in a sitting position for 3 min, then assumed a standing position, and started exercising 1 km/h with a tilt of 0°. Later, the speed was increased by 1 km/h every 1 min. In addition, inclination angle was increased by 1° every minute from 4 km/h. The participants were explained on how to use the stop button and instructed to stop if they felt uncomfortable or unwell. The exercise termination conditions were 15 km/h, completion of an exercise task with a tilt angle of 10°, or the subject's complaining of discontinuation at the limit. For risk management, a physical therapist, with a license for more than 10 years, performed abnormal waveform and heart rate (HR) management using an electrocardiogram monitor (NIHON KOHDEN, BSSM-2401). The endurance was not confirmed in all participants owing to the peaking phenomenon, so the peakVO2 value was adopted and calculated. Weight index, obtained by dividing the calculated peakVO2 value by body weight (peakVO2/W); FFM index, obtained by dividing the calculated peakVO2 value by FFM (peakVO2/FFM); and SMM index, obtained by dividing the calculated peakVO2 value by skeletal muscle (peakVO2/SMM) were calculated. Grip measurement was performed using the Smedley type digital grip force meter (manufactured by Takei Kiki Kogyo) and the grip meter was grasped in an upright position; the second joint of the index finger was adjusted to 90°. The participants were instructed not to wear a grip dynamometer on the body during the measurement. The measurements were taken twice, right and left, and the maximum value was used as the representative value.

IBM SPSS Statistics version 25 was used for statistical analysis. The calculation software G*power was used to calculate the number of participants. Attribute comparison between males and females, age, height, weight, BMI, BFP, FFM, SMM, peakVO2, and grip were compared using the unpaired t-test. Also, 95% confidence intervals (95% CI) were calculated for each index in grip and peakVO2. The level of significance was 5%.

3. RESULTS

As shown in Table 1, which demonstrates subject characteristics, there was no significant difference in age and BMI between the males and females. Only BFP was higher in females, whereas other values were higher in males.

table 1 Subjects of subjects

		Male (n=41)		Female (n=29)
Age	(years)	19.2 ± 0.4 (19.0 — 20.0)		19.2 ± 0.4 (19.0 — 20.0)
Height	(cm)	171.9 ± 5.6 (160.5 — 188.3)	*	159.9 ± 5.0 (152.8 — 171.0)
Weight	(kg)	65.7 ± 7.1 (53.9 — 80.2)	*	55.4 ± 5.8 (45.1 — 71.3)
BMI	(kg/m^2)	22.3 ± 2.6 (18.6 — 29.1)		21.7 ± 1.9 (19.0 — 28.2)
SMM	(kg)	30.7 ± 2.8 (24.9 — 35.4)	*	22.3 ± 2.2 (18.4 — 27.2)
BFP	(%)	16.8 ± 5.9 (6.7 — 36.9)	*	26.4 ± 3.9 (18.3 — 34.5)
FFM	(kg)	54.4 ± 4.6 (45.2 — 62.1)	*	40.7 ± 3.7 (34.0 — 48.7)
Peak VO2	(ml/kg/min)	46.4 ± 6.7 (30.2 — 66.3)	*	36.2 ± 3.7 (29.7 — 44.2)
Grip	(kg)	42.3 ± 6.5 (30.4 — 55.3)	*	28.9 ± 3.5 (23.2 — 36.7)

*****: $p < 0.05$(vs: Female). **Mean ± standard deviation(range)**. Statistics was independent Student t-test.
BMI: body mass index, **FFM**: Fat free mass, **BFP**: Body fat percentage, **SMM**: Skeletal Muscle Mss.

As shown in Table 2, which demonstrates the comparison of the indexes of grip and peakVO2, only grip/skeletal muscle mass showed no significant differences between males and females.

table 2. Comparison of Index in Peak VO2 and Grip

		Male (n = 41)		Female (n = 29)	95%CI
Peak VO2 / Weight	(ml/kg/min)	46.4 ± 6.7 (30.2 — 66.3)	*	36.2 ± 3.7 (29.7 — 44.2)	(7.7 — 12.7)
Peak VO2 / FFM	(ml/kg/min)	55.8 ± 7.2 (36.5 — 76.2)	*	49.3 ± 5.4 (36.6 — 63.7)	(3.4 — 9.7)
Peak VO2 / SMM	(ml/kg/min)	99.0 ± 12.5 (65.4 — 135.7)	*	90.2 ± 10.1 (66.3 — 117.0)	(3.3 — 14.5)
Grip / Weight	(kg/kg)	0.6 ± 0.1 (0.4 — 0.9)	*	0.5 ± 0.1 (0.4 — 0.7)	(0.1 — 0.2)
Grip / FFM	(kg/kg)	0.8 ± 0.1 (0.6 — 1.0)	*	0.7 ± 0.1 (0.6 — 0.9)	(0.0 — 0.1)
Grip / SMM	(kg/kg)	1.4 ± 0.2 (1.0 — 1.9)		1.3 ± 0.1 (1.1 — 1.6)	(0.0 — 0.2)

*****: $p < 0.05$(vs: Female). **Mean ± standard deviation(range)**. Statistics was independent Student t-test.
BMI: body mass index, **FFM**: Fat free mass, **BFP**: Body fat percentage, **SMM**: Skeletal Muscle Mass, **Map**: Maximum anaerobic power, **95%CI**: 95 %confidence interval.

4. DISCUSSION

In this study, grip and peakVO2 values were divided by body weight, FFM, and SMM, respectively, in healthy, young males and females to compare the indexes.

From the results in Table 1, there is no significant difference in age and BMI for the age and body type since the participants were university students who were healthy adults. In addition, only FFM was significantly higher in females, and the indexes excluding age and BMI were significantly higher in males. According to a report by Abe[15)], the amount of SMM was clearly different between males and females, and this study also supports the results. Furthermore, since SMM was significantly higher in males, it is considered that the grip and peakVO2 were higher. Moreover, since peakVO2 affects not only muscle strength but also respiratory function, it is necessary to study the effects such as respiratory function in the future.

From the results in Table 2, the values obtained by dividing peakVO2 and grip by body weight, FFM, and SMM were compared between males and females. The grip three indexes were significantly different between males and females, and the value divided by body weight and FFM was higher in males; however, the value divided by SMM was not significantly different between them (95% CI 0.0–0.2). In a previous study[16)], in which the knee extension strength of males and females was adjusted with absolute value, body weight, and FFM, respectively, the difference between the values corrected with body weight was smaller than the absolute value, and the values corrected with FFM were different and was reported to be smaller. The reason why there was no significant difference in this study was that it was pointed out that the difference in muscle strength between males and females was more influenced by the difference in the cross-sectional area of muscles than by the effects of body weight and FFM, as is the case in previous studies[17)]. Therefore, it is considered that the difference in SMM affects the exertion of muscle strength between males and females. In other words, it is considered that there is no significant difference between males and females in muscular exertion when dividing by SMM than when dividing by body weight or FFM. From these results, it was possible to correct the gender difference by using the value obtained by dividing the SMM as an index for simple muscle exertion, such as grip.

The first limitation of this study is that the number of participants is small and it is a study at a single institution; therefore, it is necessary to increase the number of participants and study at multiple institutions. Second, there was a significant difference between males and females in peakVO2 even if it was divided by body weight, FFM, and SMM. Consequently, SMM alone could not correct the gender difference. The influencing factors of peakVO2 could not be clarified in this study. peakVO2 may affect not only SMM but also respiratory and cardiopulmonary functions, so it is necessary to study these factors in the future. Third, the participants of this study were only healthy, young individuals. The effects of aging on muscle exertion and SMM should also be considered, and therefore studies on middle-aged to elderly people are necessary. These results indication that correction using SMM might allow for direct comparisons of muscle strength between males and females.

In conclusion, from the results of this study, there was a significant difference between males and females in peakVO2 even if it was divided by body weight, FFM, and SMM. But there was no gender difference in Grip divided by SMM. In other words, Grip divided by SMM has no gender difference and can compare the muscle strength divided by muscle volume of male and female. It was possible to correct the gender difference between healthy, young males and females by dividing the grip strength by SMM.

Funding and Conflict of interest

No funding was provided for this study. The author declares no conflict of interest.

Acknowledgement

The author is grateful to the subjects and co-author for assistance with data acquisition.

REFERENCES

1) THE INTERNATIONAL OLYMPIC COMMITTEE. PROMOTION OF WOMEN IN SPORT THROUGH TIME. https://www.olympic.org/women-in-sport/background (Accessed April. 23, 2020)
2) I Janssen, SB Heymsfield, ZM Wang, et al.:Skeletal Muscle Mass and Distribution in 468 Men and Women Aged 18-88 Yr. J Appl Physiol(1985). 2000, 89:81-88.
3) Bredella MA:Sex Differences in Body Composition. Adv Exp Med Biol.2017,1043:9-27.
4) Abe T, De Hoyos DV, Pollock ML, et at：Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. Eur J Apple Physiol.2000,81:174-180.
5) Heyward VH, Johannes -Ellis SM, Romer JF:Gender differences in strength. 1986, Res Quart,57:154-159.
6) Speechly DP, Taylor SR, Rogers GG：Differences in ultra-endurance exercise in performance-matched male and female runners. Medicine＆Science in Sports＆Exercise(Med Sce Spoorts Exerc), 1996,28:359-365.
7) Miller AE, MacDougall JD, Tarnaopolsky MA, et al.: Gender differences in strength and muscle fiber characteristics. Eur J Appl Physiol Occup Physiol. 1993, 66: 254-262.
8) Maughan RJ, Watson JS: Strength and cross-sectional area of human skeletal muscle. J Physiol. 1983, 338:37-49.
9) Young SK, Eun YK, Shin MK, et al.:Single Cross-Sectional Area of Pectoralis Muscle by Computed Tomography - Correlation With Bioelectrical Impedance Based Skeletal Muscle Mass in Healthy Subjects. Clin Physiol Funct Imaging. 2017.37:507-511.
10) Janssen I, Heymsfield SB, Ross R.: Low relative skeletal muscle mass(sarcopenia) in older persons is associated with functional impairment and physical disability. J Am Geriatr Soc. 2002, 50: 889-896.
11) Baumgartner RN, Koehler KM, Gallagher D, et al.: Epidemiology of sarcopenia among the elderly in New Mexico. Am J Epidemiol, 1998, 147: 755-763.
12) Newman AB, Kupelian V, Visser M, et al. Health ABC Study Investigators: Sarcopenia: Alternative definitions and associations with lower extremity function. J Am Geriatr Soc, 2003, 51: 1602-1609.
13) Sanada K, Miyachi M, Tanimoto M, et al.: A cross-sectional study of sarcopenia in Japanese men and women: Reference values and association with cardiovascular risk factors. Eur J Appl Physiol, 2010, 110: 57-65.
14) Ying-Chih W, Richard WB, Xiaoyan L, et al.: Hand-Grip Strength: Normative Reference Values and Equations for Individuals 18 to 85 Years of Age Residing in the United States. J Orthop Sports Phys Ther, 2018, 48:685-693.
15) Abe T. Kearns C. Fukunaga T.: Sex differences in whole body skeletal muscle mass measured by magnetic resonance imaging and its distribution in young Japanese adults. Br j. Sports Med.2003, 37：436-440.
16) Janssen I, Heymsfield SB, Ross R.: Low relative skeletal muscle mass(sarcopenia) in older persons is associated with functional impairment and physical disability. J Am Geriatr Soc. 2002, 50: 889-896

17) Abe T, De Hoyos DV, Pollock ML, et at：Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. Eur J Apple Physiol.2000,81:174-180.

J. Asi. Reha. Sci.3(2):17-22,2020

The Journal of Asian Rehabilitation Science

Original Article

Brain Regions Activated During Visual Motor Illusion of The Ankle Joint Movement

KATSUYA SAKAI, RPT, MS[1, 2], YUMI IKEDA, RPT, PhD[2], KAZU AMIMOTO, RPT, PhD[2]
KEISUKE GOTO, RPT, MS[2], KENJI MORIKAWA, RPT, MS[2], KEN KUMAI, RPT, MS[2]

1) Faculty of Healthcare Sciences, Chiba Prefectural University of Health Sciences (645-1, Nitonacho, Chuo-ku, Chiba-city, Chiba,116-8551, Japan)
2) Graduate School of Human Health Sciences, Tokyo Metropolitan University, Japan

Abstract. [Purpose] This study sought to localize the brain activity prompted by visual motor illusion (VMI) of the ankle joint movement. [Participants and Methods] We randomly applied VMI condition to the left and right lower limbs of 13 healthy subjects. The VMI condition required watching a video to induce VMI; the recording featured an ankle dorsiflexion movement on the non-measuring side in the first-person perspective. The left and right VMI conditions were measured three sets using a rest-task-rest block design using functional near-infrared spectroscopy. Oxygenated hemoglobin (oxy - Hb) during rest and task was measured under two conditions. Oxy - Hb of the two conditions were calculated average values of three sets and compared left and right VMI condition. During the VMI condition, a visual analog scale (VAS) was evaluated the degree of kinesthetic illusion. VAS of both VMI condition was compared using t test. [Results] VAS of the left VMI condition was higher compared with the right VMI condition. In both conditions, oxy - Hb in the premotor area was significantly increased during the VMI condition. [Conclusion] VMI of the ankle movement induces increased oxy - Hb in the premotor area of healthy subjects.

Key words: Visual motor illusion, functional near-infrared spectroscopy, ankle joint movement

(This article was submitted May.13, 2020, and was accepted June.11, 2020)

1. INTRODUCTION

Visual motor illusion (VMI) is to evoke a kinesthetic sensation by viewing images of oneself performing physical exercise while the body is at rest[1]. Previous research has explored the clinical applications of VMI. It has been reported that VMI was improved range of motion and muscle activity of upper limb in stroke hemiparesis[2]. We have explored whether VMI can be applied to the lower limbs. An investigation conducted by the authors of the present study found that VMI improved the range of ankle dorsiflexion and walking speed of patients with stroke hemiparesis improved following VMI[3]. VMI improves the motor function of stroke patients by inducing an illusion while a body is at rest.

Previous research has explored the mechanism of VMI. Motor evoked potential obtained from the anterior tibial muscle increased by VMI of the ankle joint movement and revealed that the excitability of the primary motor area (M1) increased using transcranial magnetic stimulation[4].

Based upon these reports indicating that VMI involving ankle joint movement increases the excitability of the M1 and improves the motor function, we hypothesize that brain regions typically associated with

*Corresponding author: YUMI IKEDA (ikedayum@tmu.ac.jp)

movement will be observed during VMI. The purpose of this study was to identify specific regions of brain activity area during VMI of ankle joint movement.

2. SUBJECTS AND METHODS

The subjects recruited for this study were 13 healthy adults (mean age, 25.3 ± 5.8 years; 10 men, 3 women). None of the subjects had any history of orthopedic or neurological disease. The purpose of the study was explained to the subjects, and written consent was obtained in compliance with the Declaration of Helsinki. This study was conducted with the approval of the institutional ethics committee of Tokyo metropolitan university (approval number: 17045).

The subjects were randomly assigned to one of two experimental conditions: left or right VMI. The video was recorded prior to the experiment with the camera of a tablet (iPad Pro, Apple). The individual in the video was seated during filming to allow for a first-person perspective. The recording was then transposed, rotated, and flipped horizontally with video reversal software to permit subject participants to view the ankle dorsiflexion as if it were performed on the subject's measuring side (Figure 1). The side being measured was positioned so that the ankle joint overlapped with the image of the ankle joint of the non-measuring side shown on the video.

Outcomes were brain activity during VMI and visual analog scale (VAS) scores. Brain activity was measured using functional near-infrared spectroscopy (fNIRS, LABNIRS, Shimadzu Co., Ltd). VAS was used as an index of the degree of kinesthetic illusion.

Figure 1. Set of VMI condition

This figure is the right VMI condition. The tablet was placed in front of the foot, and the tablet was set so that the actual foot could not be seen. The video is a reverse image of the left ankle joint movement.

Functional near-infrared spectroscopy

fNIRS was measured using a rest-task-rest block design. Each set of a block was performed with a rest of 15 seconds followed by a 30-seconds task and another break of 15 seconds, respectively. A block consisted of three sets. Oxygenated hemoglobin (oxy - Hb) during rest and task were recorded using fNIRS. The sampling rate of fNIRS was 10Hz. The regions of interest (ROI) for the fNIRS measurement were informed by motor association area; they included the bilateral prefrontal cortex (PFC), premotor cortex (PMC), M1, and supplementary motor area (SMA). The ROIs were measured using a total of 50 channels. The position of the probe was determined using the international 10-20 methods to maintain the consistency of measurement positions across participants[5]. The channels were arranged vertically in a 7 × 4 grid so as to cover from the front right corner to the center groove. An additional three channels were arranged in front of the grid such that the channels were in a convex configuration (Figure 2). The channels used NIRTRAC software (3 SPACE®, FASTRAK®, Polhemus Co., Ltd.) to ascertain which brain region corresponded to its respective channel. The channels then converted these coordinates into the location each of the 50 channels in an estimated MNI space by NIRS-SPM[6]. Figure 2 shows the results of the channels. In this study of the left VMI condition, the right hemisphere was target, and in the case of the right VMI condition, the left hemisphere was target.

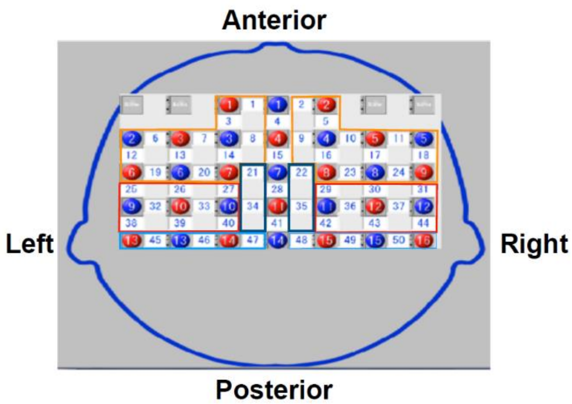

Figure 2. The measurement channels of fNIRS

The orange line indicates channels corresponding to the prefrontal cortex: 1-3, 5-8, 9-14, 16-20, 23, 24. The red line indicates channels corresponding to the premotor cortex: 25-27, 29-31, 32, 33, 36, 37, 38-40, 42-44. The blue line indicates the primary motor area is 45-47, 48-50. The green line indicates that supplementary motor area is 21, 22, 34, 35.

In analyses, the oxy - Hb was filtered and smoothed to remove noise. The band pass filter was set to 0.1 - 1.0 Hz and three sets were averaged. For brain activity using fNIRS, the oxy-Hb for each ROI was calculated as the mean value of activity at rest and then during each task. As fNIRS features an approximate delay of 5 seconds before recording the oxy - Hb value[7], recording and analysis during rest and task began 5 seconds after its start.

Visual analog scale

The subjects were asked to point to a position on a 100 mm line that represented the level of illusory movement; 0 mm indicated that the subject did not experience an illusion, while 100 mm indicated that the subject experienced a kinesthetic illusion and felt as though his or her leg was moving.

Statistical analyses

In statistical analyses, for oxy - Hb values, the two-way analysis of variance of two condition (left VMI condition, right VMI condition) and block (rest, task) was conducted in each ROI (PFC, PMC, M1, SMA). A t-test was used to compare whether there was a difference in VAS under the right and left VMI conditions. Spearman's correlation analysis was conducted to examine the relationship between the VAS and oxy – Hb value of target ROI.

3. RESULTS

Indicating the degree of kinesthetic illusion experienced during VMI, the mean VAS score of the left VMI condition was 67.2 ± 13.5 mm, while that of the right VMI condition was 56.9 ± 11.3 mm. The left VMI condition was significantly higher compared to the right VMI condition ($t(12) = 2.72$, $p = 0.019$, Table 1).

Table 1. The oxy - Hb of left and right VMI condition and VAS score

Condition	Block	PFC	PMC	SMA	M1	VAS
Right VMI condition	Rest	0.013 ± 0.058	0.014 ± 0.044	0.002 ± 0.020	-0.002 ± 0.014	67.2 ± 13.5 †
	Task	0.034 ± 0.081	0.033 ± 0.026 *	0.008 ± 0.018	-0.004 ± 0.013	
Left VMI condition	Rest	-0.001 ± 0.054	0.014 ± 0.068	-0.005 ± 0.016	0.001 ± 0.008	56.9 ± 11.3
	Task	0.037 ± 0.090	0.037 ± 0.090 *	-0.002 ± 0.008	-0.001 ± 0.008	

Unit: oxy-Hb : mm・Mm. VAS: mm. *p<0.05 (vs Rest). †p<0.05 (vs left VMI condition).
Prefrontal cortex: PFC, Premotor cortex: PMC, Supplementary motor area: SMA, Primary motor area: M1

A significant main effect was observed in both sides of the PMC between conditions (Table 1, left VMI condition: $F(1, 25) = 8.09$, $p = 0.009$, right VMI condition: $F(1, 33) = 4.93$, $p = 0.034$). However, no significant interaction was observed. In other ROIs, no significant main effects and interactions were observed ($p > 0.05$). The mapping image using fusion software is shown (Figure 3).

Weak, but not significant correlations were observed between the VAS and PMC (left VMI condition: $p = 0.378$, $r = 0.27$, right VMI condition, $p = 0.420$, $r = 0.25$).

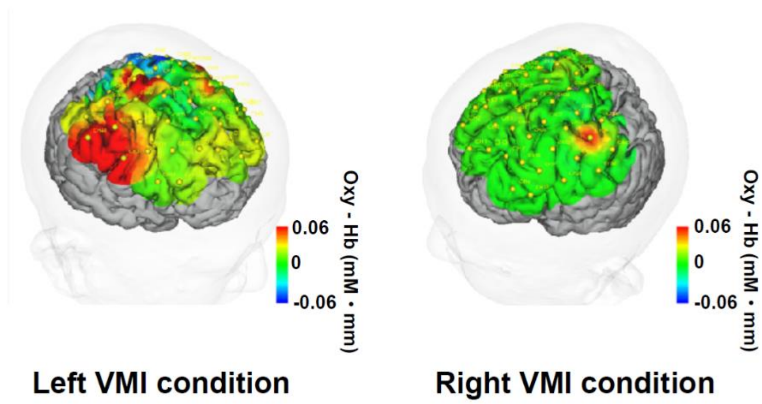

Figure 3. The mapping of left and right VMI condition
The left VMI condition was widely active compared with the right VMI condition.

4. DISCUSSION

This study sought to localize the brain activity prompted by VMI of the ankle joint movement. The VAS of the left VMI condition was significantly higher compared with right VMI condition. On both VMI condition, the PMC was activated on the side contralateral to the measurement side.

Previous research on the upper limb VMI was reported PMC, SMA, parietal area[8)]. Christensen et al. reported that applying repetitive transcranial magnetic stimulation to the PMC induced the perception of motion, reportedly recruiting a top-down process that involves sensory-motor integration[9)]. The tendon vibration stimulation study reported that a kinesthetic-illusion-induced increase in the cerebral blood flow rate in the PMC[10)]. In this study, the PMC was activated during both conditions, similar to findings of previous studies. In the mapping image, the left VMI condition was wildly actived than the right VMI condition. The frontal-parietal network of the right hemisphere has also been reported to be involved[11)]. Therefore, the right hemisphere thought that cerebral blood flow increased widely.

The intensity of the illusion was significantly higher under the left VMI condition compared with right VMI condition. The frontal-parietal network of the right hemisphere has also been reported to be involve[11]. Therefore, we can conclude that the illusion intensity in the left VMI condition may have been high. The VAS scores in this study indicated similar degrees of kinesthetic illusion as previously reports[4,5], and this degree of kinesthetic illusion is considered sufficient to induce kinesthetic illusion.

Our study features several limitations. As found in previous investigations, brain activity during kinesthetic illusion was observed both in the PMC and the parietal area. In this study, the limited number of channels prevented our measurement of the parietal region.

In conclusion, we used fNIRS to identify brain activity elicited by VMI of the ankle joint movement. We found that oxy - Hb in the PMC increases during kinesthetic illusion.

Funding and Conflict of interest

The authors have no conflicts of interest to declare for this research.

Acknowledgement

The authors would like to thank research members of Tokyo Metropolitan University for their help in the study.

REFERENCES

1) Kaneko F, Yasojima T, Kizuka T.: Kinesthetic illusory feeling induced by a finger movement movie effects on corticomotor excitability. Neuroscience, 2007, 49: 976-984.
2) Kaneko F, Inada T, Matsuda N.: Acute effect of visually induced kinesthetic illusion in patients with stroke: a preliminary report. Inter. J. Neurorehabilitation, 2016, 3: 212.
3) Sakai K, Ikeda Y, Amimoto K.: Effect of kinesthetic illusion induced by visual stimulation on ankle dorsiflexion dysfunction in a stroke patient: ABAB single-case design. Neurocase, 2018, 24: 245-249.
4) Aoyama T, Kaneko F, Hayami K, Shibata E.: The effects of kinesthetic illusory sensation induced by a visual stimulus on the corticomotor excitability of the leg muscles. Neurosci. Lett, 2012, 514: 106-109.
5) Towle V. L, Bolanos J, D. Suarez K, et al.: The spatial location of EEG electrodes ： locating the best-fitting sphere relative to cortical anatomy. Electroencephalogr Clin Neurophysiol, 1993, 86: 1-6.
6) Tsuzuki D, Jurcak V, Singh A. K, et al.: Virtual spatial registration of stand-alone fNIRS data to MNI space. NeuroImage, 2006, 34: 1506-1518.
7) Jasdzewski G, Strangman G, Wagner J, et al.: Differences in the hemodynamic response to event-related motor and visual paradigms as measured by near-infrared spectroscopy. NeuroImage, 2003, 20: 479-488.
8) Kaneko F, Blanchard C, Lebar N, et al.: Brain regions associated to a kinesthetic illusion evoked by watching a video of one’s own moving hand. PLoS One, 2015, 10, e0131970.
9) Christensen M. S, Lundbye-jensen J, Geertsen S.S, et al.: Premotor cortex modulates somatosensory cortex during voluntary movements without proprioceptive feedback. Nat. Neurosci, 2007, 10: 417-419.
10) Imai R, Hayashida K, Nakano H.: Brain activity associated with the illusion of motion evoked by different vibration stimulation devices: an NIRS study. J. Phys. Ther. Sci, 2014, 26: 1115-1119.
11) Naito E, Morita T, Amemiya K.: Body representations in the human brain revealed by kinesthetic illusions and their essential contributions to motor control and corporeal awareness. Neurosci. Res, 2016, 104: 16-30.