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[Title] Effects of acute arm-cranking exercise with electrical muscle stimulation at different intensities on the vascular endothelial function

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Abstract

Arm-cranking exercises combined with electrical muscle stimulation (EMS) of the lower limbs at maximum intensity enhance vascular endothelial function. To bring this procedure into clinical application, we examined the effects of acute arm-cranking exercise combined with lower-extremity EMS at different intensities on vascular endothelial function. The study included eight healthy adult males. After resting in the supine position, arm-cranking exercises were performed at an intensity of 50% $\dot{V}O_2$ max for 20 min, and the lower limb received EMS under three trials: maximum intensity trial (A+100%EMS trial), 50% intensity trial (A+50%EMS trial), and 25% intensity trial (A+25%EMS trial). Flow-mediated dilation (FMD), which reflects vascular endothelial function, was measured before and after the procedure, and the normalized FMD (nFMD) was calculated. The mean nFMD before and 30 min after the exercise was 0.8±0.3 and 2.3±1.8, respectively, in the A+100%EMS trial and 0.9±0.4 and 1.4±1.0, respectively, in the A+50%EMS trial, indicating a significant increase after exercise under both trials. No changes were observed in the A+25%EMS trial. The combination of arm-cranking exercise and 50% intensity EMS appears to be a clinically applicable program for improving vascular endothelial function, even with reduced exercise intensity.

[Keywords] vasodilatation; electrical stimulation; aerobic exercise; upper extremity

Article title

一過性の上肢の有酸素性運動と異なる強度の骨格筋電気刺激が血管内皮機能に及ぼす影響

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Abstract

上肢の有酸素性運動と最大耐性強度の下肢への骨格筋電気刺激(EMS)の併用運動は血管内皮機能を向上させる．このプログラムを臨床応用させるためには，運動プログラムの低強度化が求められるが低強度化した運動プログラムが血管内皮機能に及ぼす影響については，十分に検討されていない．本研究では，一過性の上肢の有酸素性運動と異なる強度の下肢EMSの併用が上腕動脈の血管内皮機能に及ぼす影響について検討した．被験者は，健康な成人男性 8 名であり仰臥位安静後，50% $\dot{V}O_2max$ 強度で20分間の上肢クランク運動と下肢へのEMSを最大耐性強度 (A+100%EMS) 条件，50%強度 (A+50%EMS) 条件，25%強度 (A+25%EMS) 条件の3条件を実施させた．運動前後に血管内皮機能を反映するFMDを測定し，標準化 FMD (nFMD)を算出した． 運動前および運動終了 30 分後のnFMD は，A+100%EMS 条件で 0.8±0.3，2.3±1.8 であり，A+50%EMS 条件で 0.9±0.4，1.4±1.0 であり，両条件ともに運動前と比較して運動終了 30 分後に有意な増加を示した．A+25%EMS 条件では，運動前後に変化は認められなかった．50%強度のEMSにおいても，他動的な筋収縮による血流量の増加，一酸化窒素などの血管拡張物質の産生促進などにより，nFMD が増加したことが考えられる．上肢の有酸素性運動と50%強度の下肢EMSの併用運動は，血管内皮機能の改善を目的とした臨床応用可能な運動プログラムとなる可能性が示唆された．

Introduction

Walking and bicycle pedaling are used as exercise therapies for cardiovascular diseases (CVDs) and metabolic diseases. The effects of such lower-limb aerobic exercises on arterial function include improved arterial compliance 1), improved flow-mediated dilation (FMD) 2), and decreased pulse wave velocity (PWV) 3). The mechanism for this is that increased blood flow due to exercise increases shear stress, a mechanical stress on the vessel wall that causes vasodilation due to the release of nitric oxide from vascular endothelial cells 4). Thus, aerobic exercise of the lower extremities has been shown to reduce the risk of developing CVDs.

However, patients with spinal cord injury (SCI) and paralysis of the lower extremities and orthopedic patients with joint pain and deformity have difficulty performing the recommended aerobic exercises, limiting daily physical activity and rehabilitation. Patients with SCI have higher resting femoral artery PWV 5) and lower arterial compliance than healthy patients 6). Moreover, they are associated with increased mortality from CVD due to atherosclerosis and hypertension 7). Aerobic exercise of the upper extremities may be considered when aerobic exercise of the lower extremities is difficult. Miura et al. reported no significant change in the brachial-ankle PWV before and after 30 min of moderate-intensity arm crank exercise in healthy adult men 8). These results suggest that aerobic exercise of the upper extremities does not alter arterial function; however, electric muscle stimulation (EMS), which is effective in increasing muscle strength 9), energy metabolism 10), and blood flow 11), has attracted attention as a possible solution. Rappelt et al. reported that a hybrid exercise involving arm-cranking (35.9±8.4 W, 50% of body mass) combined with EMS (4 Hz, 350 μs) at the maximum tolerated intensity increased oxygen uptake compared to arm-cranking exercise alone (hand cycle: approximately 13.5 ml/min/kg vs. hand cycle with EMS: approximately 19.0 ml/min/kg) 12). In addition, arm-cranking exercise at 50% $\dot{V}O_2$ max combined with EMS of the lower extremities at maximal tolerable intensity has been reported to improve brachial artery (BA) endothelial function 13), suggesting the possibility of improving endurance and cardiovascular performance in patients with SCI and those that are wheelchair-dependent. However, in both studies, the stimulation intensity of EMS was at the maximum tolerable intensity. In clinical physical therapy, it is difficult to actively perform high-intensity exercise because many patients have a combination of various diseases associated with poor physical function and various risks associated with exercise. In addition, discomfort and pain caused by high-intensity electrical stimulation (ES) may affect withdrawal from therapy 14). Therefore, identification of more clinically appropriate stimulus intensities for ES conditions is important to implement physical therapy. A new program combining low-intensity aerobic exercise for the upper extremities and EMS for the lower extremities should be developed. If the beneficial effects of combined arm-cranking exercise and low-intensity EMS on vascular endothelial function are demonstrated, this could be a new exercise therapy that could be applicable to more patients; however, this point has not been adequately investigated and may be a factor preventing the widespread use of this hybrid exercise.

Therefore, this study aimed to investigate the effects of acute arm-cranking exercise combined with EMS of the lower extremities at different intensities on BA vascular endothelial function.

Methods

Participants

The study participants were eight healthy adult men (age: 21.6±0.5 years, height: 169.4±5.8 cm, weight: 67.1±9.1 kg, body mass index: 23.6±3.0 kg/m^2) who had never smoked, did not take regular medications or supplements, and exercised for 1–2 times/week. This study was approved by the Research Ethics Committee of the Department of Physical Therapy, Faculty of Health Science, Osaka Yukioka College of Health Science (#33-0005), Japan. Additionally, the participants were provided with an oral explanation of the content and purpose of the study, including refusal, withdrawal, and interruption of participation, and written informed consent was obtained.

Study Design

The protocol used in this study and the picture of the experiment are shown in Figures 1 and 2. All participants visited the laboratory four times for measurements. On the first day, a maximal exercise test with arm-cranking exercise was performed, and at least 1 week after the test, the participants were randomly assigned to a trial combining EMS with maximum tolerable intensity for pain and moderate-intensity arm-cranking exercise (A+100% EMS trial), a trial combining moderate-intensity EMS (A+50%EMS trial), or a trial combining low-intensity EMS (A+25%EMS trial). For the maximal exercise tolerance test and arm-cranking exercise for each trial, the participants sat in a chair and grasped the pedals of a bicycle ergometer (AEROBIKE 75XL Ⅲ; Combi Co., Tokyo, Japan) fixed on a platform with both hands. The bicycle ergometer was grounded such that the crankshaft and the participants' acromion were level, and the participants sat with their knee joints flexed at 90˚. The rotation rate of the arm-cranking exercise in the maximal exercise tolerance test and each condition was defined as 60 rotations per minute. All the participants were instructed to limit their alcohol consumption, caffeine intake, and strenuous exercise from the day before to the end of the experiment. Measurements were taken simultaneously in a room with controlled room temperature (23–25°C) and humidity (50–70%) at least 4 hours after eating.

Figure 1

Figure 2

Maximal Exercise Tolerance Test

To determine the intensity of the arm-cranking exercise, a multistage exercise tolerance test was performed on a bicycle ergometer to measure the maximal oxygen uptake ($\dot{V}O_2$ max). After resting in a chair for 3 min, a maximal exercise tolerance test was performed, starting at 6W and increasing the load in 6 W/min steps.

Flow-Mediated Vasodilation

In this study, the endothelial function of the BA was assessed. The endothelial function of the BA is an indicator of systemic endothelial function. Moreover, the FMD of the BA is highly significant because it is a predictor of CVDs 15, 16). The participants were asked to rest in the supine position for at least 15 min to obtain the resting arm systolic blood pressure (SBP) and diastolic blood pressure (DBP) using a standard sphygmomanometer on their left arm. An occlusion cuff was placed around the right forearm, and two electrocardiogram leads were attached to the wrists to measure the heart rate (HR). The FMD was quantified using high-resolution ultrasonography (UNEXEF 38G; UNEX Co., Nagoya, Japan) to measure endothelial function. The BA was scanned longitudinally 5–10 cm proximal to the elbow joint. To occlude the blood flow, the cuff was inflated to 50 mmHg above the SBP for 5 min. Upon cuff deflation, the blood flow velocity and arterial diameter were measured for an additional 3 min, and the change in the BA diameter was immediately expressed as a percentage change relative to the vessel diameter before cuff inflation. The FMD was calculated as the baseline value (Di base) before the cuff was released to the peak value after cuff release (Di peak). The FMD was calculated using the following equation: FMD (%) = {(Di peak–Di base)/Di base} × 100. A detailed description of the measurements was provided in a previous study 17).

In this study, peak shear rate (PSR) was calculated from the vessel diameter and blood flow velocity to compare the FMD in different trials. The blood flow velocity was calculated from the color Doppler data and displayed as a waveform in real-time. The PSR was calculated using the formula: PSR = [difference in flow velocity between the hyperemic response (peak after cuff deflation; FV peak) – baseline (FV base)] / baseline BA diameter. Subsequently, the normalized FMD (nFMD) was calculated as follows 18):

nFMD (a. u.) =FMD/PSR

All measurements were performed after 15 min of supine rest and 30 min after each trial. FMD was measured by all participants with the right hand. The HR was measured every 5 min during each trial using thoracic bipolar induction (POLAR H-10; Polar Co., Ltd., Tokyo, Japan).

Electrical Muscle Stimulation

In the EMS trial, belt electrode-skeletal muscle electrical stimulation (G-TES; Homer Ion Co., Ltd., Tokyo, Japan) was performed at a frequency of 4 Hz, pulse width of 250 μs [19)], and exponentially increasing waves. EMS was applied to the calf and thigh muscles, including the quadriceps femoris, hamstrings, gastrocnemius, and hip adductor muscles, using a stimulator. A value of 4 Hz was selected because this study aimed to promote peripheral circulation through aerobic exercises [20)]. One silicon-rubber electrode band (5.3×93.3 cm) was wrapped around the lumbar region, two bands (5.3×69.6 cm) were wrapped around both distal parts of the thighs, and two bands (5.3×54.6 cm) were wrapped around both ankles. As the stimulation cycles of the bilateral thighs and lower legs were synchronized, the bilateral lower-extremity muscle groups were simultaneously stimulated. The average stimulus intensity was approximately 3.0±0.6 mA in the thighs and 0.8±0.2mA in the ankle in the A+100%EMS trial, 1.6±0.3 mA in the thighs and 0.4±0.1 mA in the ankle in A+50%EMS trial, and 0.8±0.1 mA in the thighs and 0.3±0.1 mA in the ankle in the A+25%EMS trial.

Statistical Analysis

The results of this study were analyzed for normality using the Shapiro–Wilk test to confirm distribution of the data. The measurements for each trial were compared using a two-way repeated-measures analysis of variance to test for the presence or absence of an interaction. Moreover, the Bonferroni test was performed for posterior analysis. All measurements are expressed as means and standard deviations and were considered statistically significant at a significance level of <5%.

Results

HR and $\dot{V}O_2$ during each trial

The changes in HR and $\dot{V}O_2$ during the three trials are shown in Figures 3 and 4. There was a significant difference in the HR at 5 and 20 min during exercise in the A+100%EMS trial. Moreover, the HR in the A+100%EMS trial was significantly higher than that in the A+25%EMS trial at 5 and 10 min during exercise. From the 5 to 20 min timepoints, the

$\dot{V}O_2$ during exercise was significantly higher in the A+100%EMS trial than in the A+25%EMS trial. $\dot{V}O_2$ during exercise was also higher in the A+100%EMS trial than in the A+50%EMS trial at 5 and 20 min. Moreover, in the A+100%EMS trial, there was a significant increase in $\dot{V}O_2$ at 20 min of exercise compared with that at 5 min. The average $\dot{V}O_2$ from 5 to 15 min of exercise was as follows: 19.1±1.02 ml/kg/min (85% $\dot{V}O_2$ max) in the A+100%EMS trial, 15.75±0.65 ml/kg/min (70% $\dot{V}O_2$ max) in the A+50%EMS trial, and 13.7±0.20 ml/kg/min (60% $\dot{V}O_2$ max) in the A+25%EMS trial.

Brachial artery function before and after each trial

The changes in SBP, DBP, HR, Di base, Di peak, FV base, FV peak, PSR, and FMD before and after each trial are shown in Table 1. No interactions were observed for all measurements. In the A+50%EMS and A+25%EMS trials, a significant decrease was observed in the DBP 30 min after exercise compared to before ($p<0.05$). In addition, a significant increase was observed in the HR 30 min after exercise compared to before in the A+100%EMS trial ($p<0.05$). In all trials, there was a significant increase in the Di base and Di peak 30 min after exercise compared to before exercise ($p<0.05$ and $p<0.001$, respectively). There was no significant main effect or interaction among the SBP, FV base, FV peak, FMD, and PSR before and 30 min after exercise completion in each trial. The changes in nFMD before and 30 min after exercise completion are shown in Figure 5 (0.8±0.3 and 2.3±1.8 in the A+100%EMS trial, 0.9±0.4 and 1.4±1.0 in the A+50%EMS trial, and 0.8±0.2 and 1.1±0.5 in the A+25%EMS trial, respectively). In the A+100%EMS and A+50%EMS trials, a significant increase in the nFMD was observed 30 min after exercise completion compared with that before ($p<0.05$).

Table 1

Figures 3, 4, and 5

Discussion

In this study, we investigated the effects of moderate-intensity arm-cranking exercises with different EMS intensities on vascular endothelial function in healthy adult men. The results showed that the BA nFMD increased 30 min after exercise completion compared to that before in the maximum tolerable intensity EMS trial (A+100%EMS trial) and moderate-intensity EMS trial (A+50%EMS trial). It even showed a higher trend in the A+100%EMS trial than in the A+50%EMS trial. These results suggest that moderate-intensity arm-cranking exercise with 100%EMS enhances vascular endothelial function, similar to the results of previous studies (13). However, a lower intensity of 50%EMS also enhances vascular function.

Acute responses after EMS include increases in oxygen uptake and HR $^{21)}$, which have been reported to rise with increasing intensity of ES $^{22)}$ and combined upper- and lower-extremity exercise rather than with upper- and lower-extremity exercise alone. Rappelt et al. found that exercise with EMS to the lower-extremity (4 Hz, 250 μs, maximal tolerance) combined with a hand cycling resulted in higher $\dot{V}O_2$ and vasodilatory blood lactate levels than using the hand cycling alone or EMS to the lower-extremity alone $^{12)}$. Moreover, increases in stimulus intensity and pulse width have also been reported to increase blood flow $^{23).}$ This finding indicates that the combination of active exercise and ES has beneficial effects on cardiac dynamics and metabolism. In the A+50%EMS and A+25%EMS trials, DBP decreased significantly 30 min after exercise compared to before. This may be due to an increase in circulating blood flow caused by the muscle pumping action of EMS to the lower limbs at low to moderate intensities. However, no change in blood pressure was observed before and after exercise in the A+100%EMS trial, possibly due to the effects of high-intensity ES and high-intensity aerobic exercise on the autonomic nervous system. Painful ES, such as in the A+100%EMS trial, may be perceived as a nociceptive stimulus, which increases sympathetic nerve activity, resulting in the inhibition of peripheral vasodilation, and high-intensity aerobic exercise may increase the level of protein carbonyl, an oxidative stress marker, and contribute to inactivation of nitric oxide [24]. Thus, A+100%EMS trial had no effect on blood pressure before or after exercise, suggesting that the A+50%EMS and A+25%EMS trials are not overloading exercises for blood pressure.

Most importantly, the nFMD increased significantly in the A+100%EMS and A+50%EMS trials after exercise completion compared to that before exercise, with the degree of increase being greater in the A+100%EMS trial but not significantly different between trials. Regarding the stimulation intensity of EMS, Karavidas et al. found that after 6 weeks of functional ES training (25 Hz; stimulus intensity was a visible, painless muscle contraction) in 16 patients with chronic heart failure, the BA FMD improved compared to before the training (5.77±2.58%, before; 7.56±2.63%, after) [25]. It has also been reported that acute low-intensity EMS (10.7±4.7% of HR reserve, approximately 2 metabolic equivalent during EMS exercise) improves brachial-ankle PWV and cardio-ankle vascular index, which reflect arterial function [26]. This was attributed to increased local blood flow due to EMS-induced muscle pumping in the lower-extremity muscles. However, no effect on arterial function in the upper extremity was observed. In the present study, it was suggested that blood flow in the lower extremities, the site of stimulation, may have increased; however, the increase in nFMD in the BA may have been due to a greater effect of EMS-induced metabolites. Muscle contraction induced by ES partially reverses the order of motor units to be mobilized [27)]. Moreover, when more type II fibers are mobilized (type II fiber preferential recruitment) during ES, the release of vasodilators, such as hydrogen ions and phosphate, increases, which may affect vasodilation [28)]. Since these vasodilators increase depending on the ES intensity, a similar vasodilatory response to stimulation intensity may have been observed in the present study [29)]. In addition, EMS stimulation releases vasodilator P and calcitonin gene-related peptides from nociceptive C fibers, which causes dilation of the skin vessels. The dilation of cutaneous vessels requires an increase in cardiac output, which may be involved in the increase in blood flow in the conduit arteries. These factors suggest that EMS can promote peripheral circulation and vasodilation even without the maximum intensity that can be tolerated, and the nFMD may have been improved by medium-intensity EMS in this study.

It has been reported that individuals with SCI (especially those with high lesions) have lower aerobic capacity than normal and healthy individuals due to reduced physical activity (due to wheelchair-dependent living) and that aerobic capacity decreases linearly with increasing injury levels [30)]. To address this issue, previous studies have examined the effects of hybrid exercise combining active exercise and ES on cardiorespiratory function. These studies have reported that combined exercise of the upper extremities and ES of the lower extremities improves aerobic capacity in wheelchair-dependent individuals with

SCI [12)]. In the present study, the oxygen uptake during the hybrid exercise was approximately 85%$\dot{V}O_2$ max in the A+100%EMS trial and 70%$\dot{V}O_2$ max in the A+50%EMS trial, suggesting the possibility of improving endurance capacity with habitual continuation. These results suggest that EMS at 50% of the maximum tolerable intensity may be a new exercise program that can improve vascular function and endurance at a lower intensity than that used in the A+100%EMS trial.

The clinical implications of the present study are that the combined use of arm-cranking exercises with EMS at a lower intensity may be indicated for more patients with the goal of improving vascular endothelial function. Previous studies have reported that the stronger the intensity of ES, the greater the effect on circulatory dynamics; however, in clinical practice, the appropriate exercise intensity should be set while assessing the respiratory-circulatory response to exercise due to the reduced physical activity and exercise tolerance caused by paralysis of the lower extremities, such as in patients with SCI. Furthermore, ES therapy often requires a gradual increase in exercise intensity because patients may discontinue treatment due to discomfort caused by stimulation. Therefore, combining arm-cranking exercise with moderate-intensity lower-extremity EMS may be a more clinically suitable exercise program compared to combining it with ES of maximum tolerable intensity.

This study had several limitations. In clinical applications, it is necessary to consider paralysis accompanied by sensory disturbances, such as SCI. In this study, low-strength conditions were set from the maximum tolerable strength; however, it is necessary that the examiner objectively evaluates muscle contraction because it may be difficult to report the maximum tolerance due to sensory impairment. In addition, it has been shown that the percentage of type II fibers is higher in paralyzed muscles than in non-paralyzed muscles 31); therefore, whether the results of that study will be similar to those of the present study remains unclear. Furthermore, since the present study was conducted in the acute phase, changes in vascular function and aerobic capacity due to the intervention were unknown. The vasoactive substances produced by exercise, such as nitric oxide, were also unknown, as no biochemical tests were performed. The FMD is usually normalized using the area under the curve of the shear rate. However, in the present study, it was normalized using PSR only. Furthermore, since the stimulation intensity of EMS was determined subjectively, the possibility of individual differences in muscle contraction and body composition (lean body mass, subcutaneous fat thickness, and circumference) cannot be ignored. Muscle contraction and body composition should be measured in future studies.

Conclusion

The beneficial effects of ES on the body have been shown in various studies, making it an important therapeutic option in rehabilitation. However, patients' disability profiles vary widely, and rehabilitation needs to be tailored to their unique severity and symptoms. In the present study, the combination of moderate-intensity arm rotation exercise and 50% intensity EMS suggests that vascular endothelial function can be improved even at reduced exercise intensity. Therefore, this may be a new exercise program option for patients who are harmed by the intensity and stimulation of ES and high exercise intensity.

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Conflict of Interests

There is no conflict of interests for this study.

Contributions

All authors contributed to the study conception and design. MN collected the data and drafted the manuscript. HM, AM, and YT revised the manuscript. All authors approved the final version of the manuscript.

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Table 1. Changes in brachial artery function before and after each trial

	A+100%EMS trial			A+50%EMS trial			A+25%EMS trial			
	before	after 30 minutes	time effect within-group p-value	before	after 30 minutes	time effect within-group p-value	before	after 30 minutes	time effect within-group p-value	group × time interaction p-value
SBP (mmHg)	118.9 ± 11.6	118.0 ± 6.6	0.80	119.8 ± 10.5	120.3 ± 10.1	0.81	119.4 ± 15.4	121.0 ± 16.8	0.35	0.50
DBP (mmHg)	66.3 ± 6.9	62.0 ± 5.1	0.18	67.0 ± 6.4	61.1 ± 6.5	0.04*	67.4 ± 5.5	62.3 ± 6.0	0.01*	0.72
HR (bpm)	63.8 ± 10.0	74.4 ± 8.4	0.03*	63.5 ± 10.0	70.5 ± 6.8	0.06	64.3 ± 10.0	72.3 ± 7.7	0.12	0.60
Di $_{\text{base}}$ (mm)	3.8 ± 0.2	4.3 ± 0.3	0.002*	3.7 ± 0.2	4.15 ± 0.4	0.003*	3.8 ± 0.2	4.1 ± 0.5	0.03*	0.47
Di $_{\text{peak}}$ (mm)	4.1 ± 0.3	4.6 ± 0.3	0.001**	4.0 ± 0.2	4.5 ± 0.4	0.002*	4.0 ± 0.2	4.4 ± 0.5	0.03*	0.14
FV $_{\text{base}}$(cm/sec)	10.4 ± 5.2	11.4 ± 6.6	0.33	11.8 ± 8.7	10.3 ± 3.1	0.53	11.0 ± 5.5	12.6 ± 8.8	0.48	0.65
FV $_{\text{peak}}$ (cm/sec)	48.1 ± 12.8	40.8 ± 6.6	0.33	47.4 ± 17.8	43.8 ± 19.0	0.51	46.1 ± 5.5	44.2 ± 21.0	0.83	0.83
FMD (%)	7.3 ± 1.0	8.3 ± 2.3	0.31	7.4 ± 0.8	8.3 ± 0.9	0.13	7.3 ± 1.0	6.7 ± 0.8	0.29	0.15
PSR (s^{-1})	10.0 ± 3.6	7.1 ± 5.7	0.08	9.7 ± 4.4	8.2 ± 4.4	0.26	9.4 ± 3.2	7.7 ± 3.6	0.42	0.14

SBP: systolic blood pressure, DBP: diastolic blood pressure, HR: heart rate, Di base: diameter baseline, Di peak: diameter peak line, FV base: flow volume base, FV peak: flow volume peak, FMD: flow-mediated dilation, PSR: peak shear rate. *$p<0.05$, **$p<0.01$ vs. before.

Figure 1

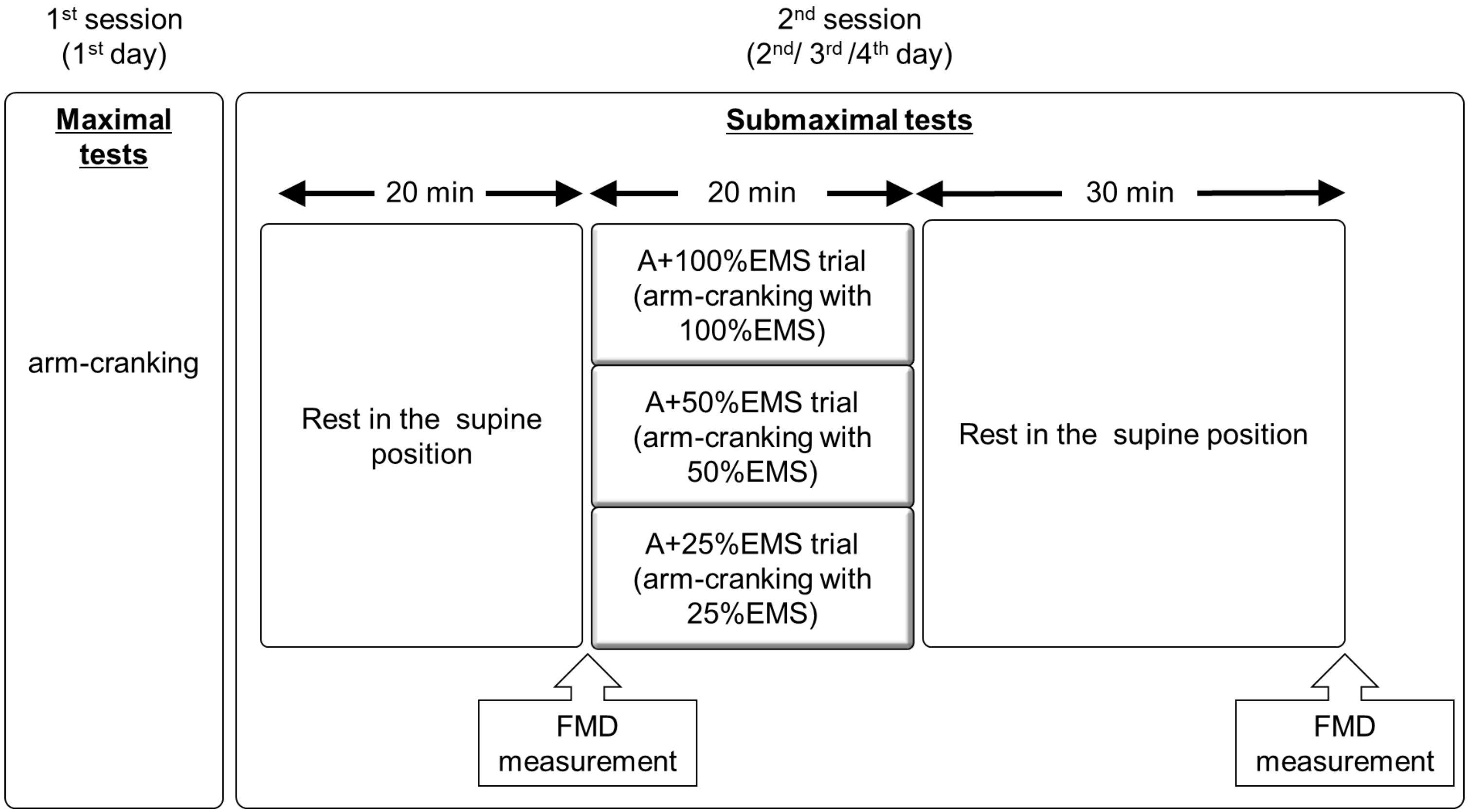
1st session
(1st day)
2nd session
(2nd/ 3rd /4th day)
Maximal tests
arm-cranking
Submaximal tests
20 min
20 min
30 min
Rest in the supine position
A+100%EMS trial (arm-cranking with 100%EMS)
A+50%EMS trial (arm-cranking with 50%EMS)
A+25%EMS trial (arm-cranking with 25%EMS)
Rest in the supine position
FMD measurement
FMD measurement

Figure 2

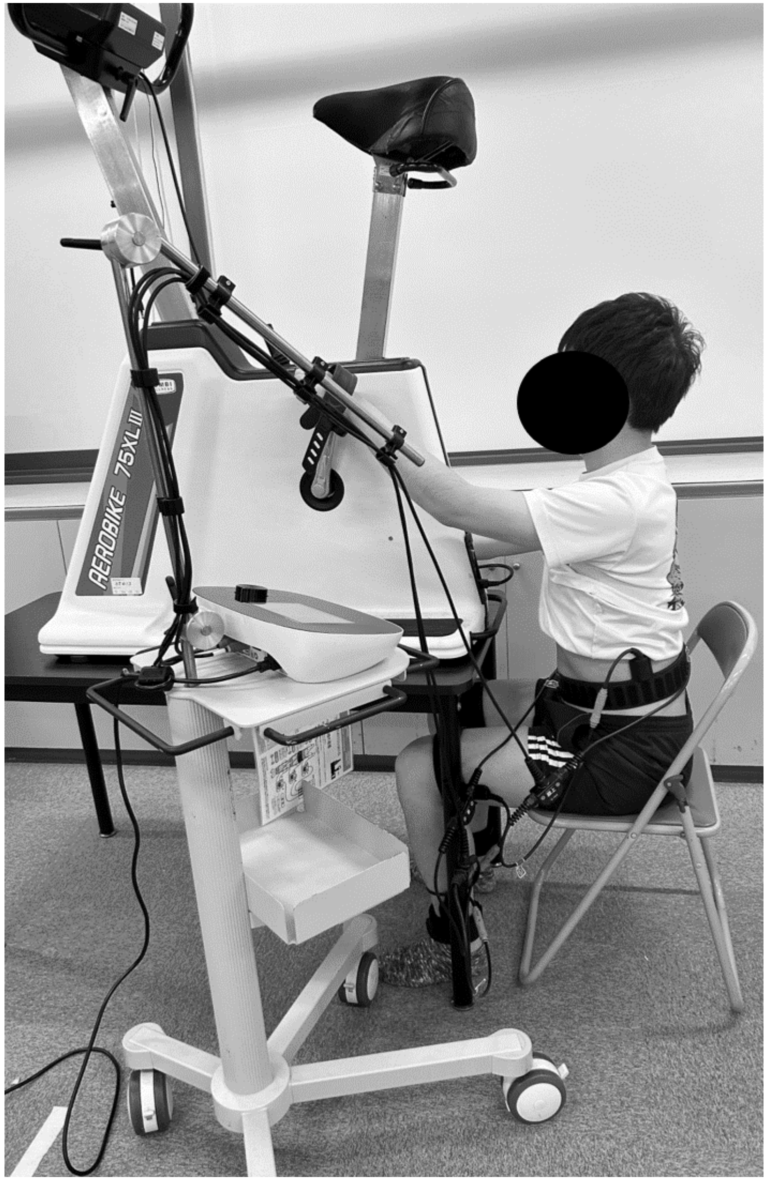

Figure 3

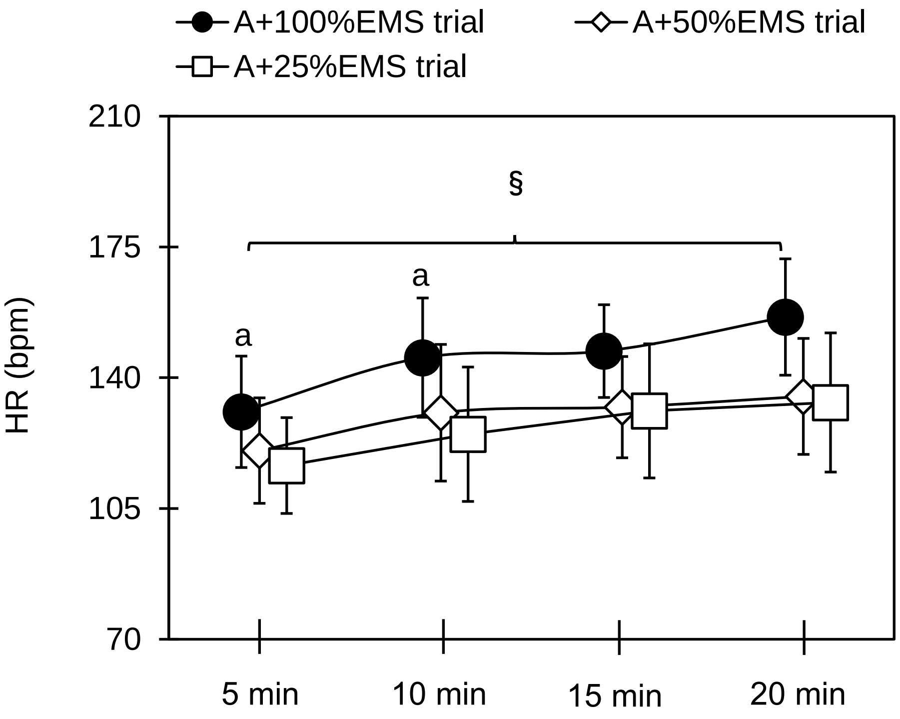
A+100%EMS trial
A+50%EMS trial
A+25%EMS trial
HR (bpm)
210
175
140
105
70
§
a
a
5 min
10 min
15 min
20 min

Figure.4

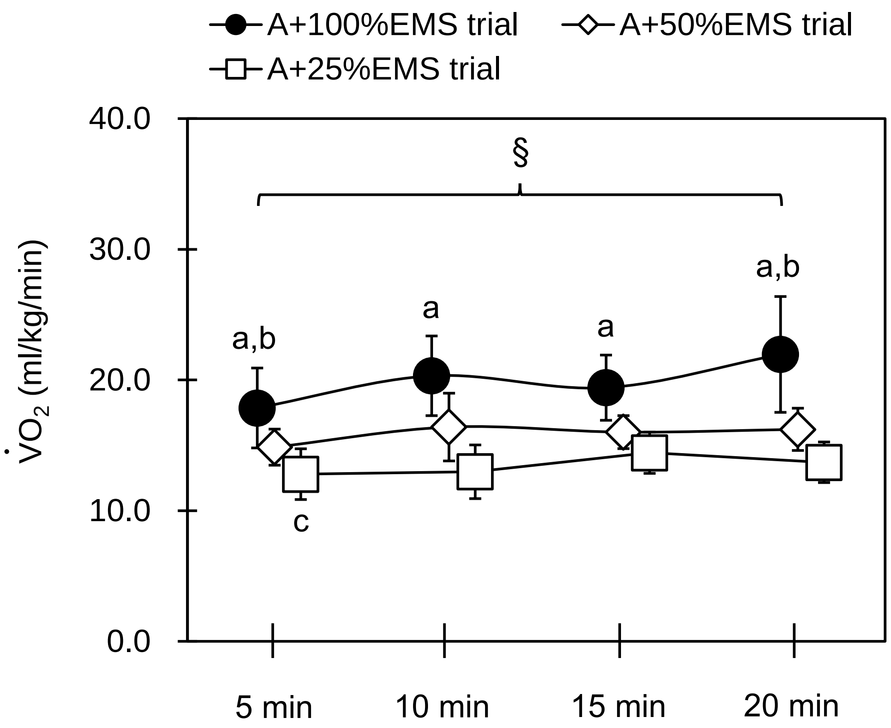
A+100%EMS trial
A+50%EMS trial
A+25%EMS trial
$\dot{V}O_2$ (ml/kg/min)
40.0
30.0
20.0
10.0
0.0
§
a,b
a
a
a,b
c
5 min
10 min
15 min
20 min

Figure 5

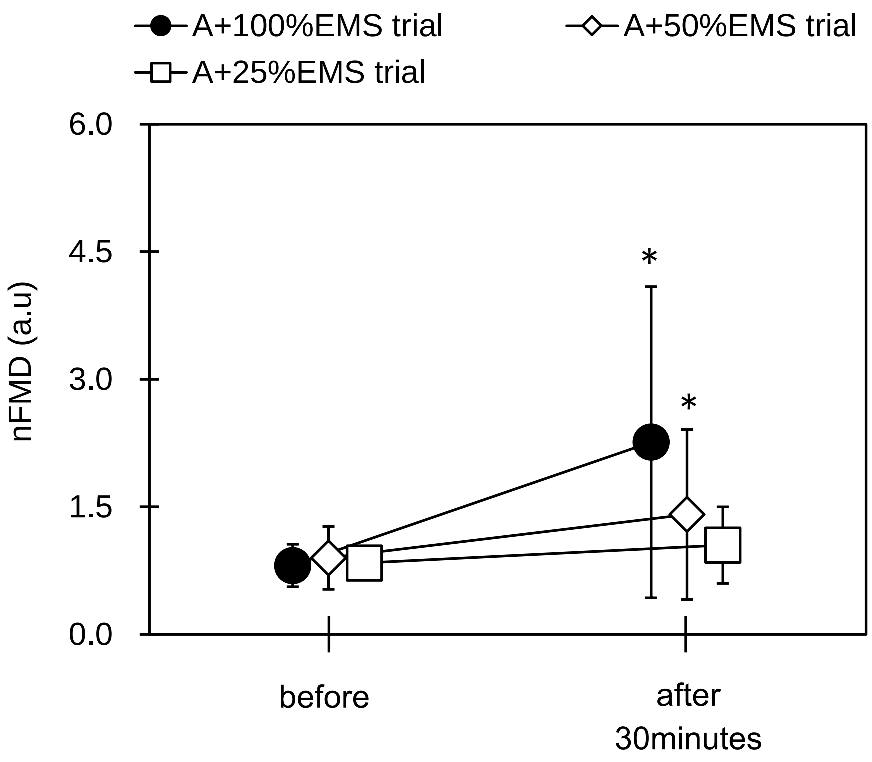
A+100%EMS trial
A+50%EMS trial
A+25%EMS trial
nFMD (a.u)
6.0
4.5
3.0
1.5
0.0
*
*
before
after
30minutes

Figure Legends

Figure 1. Experimental protocol of test sessions. All subjects performed each test in random order. EMS: electrical muscle stimulation, FMD: flow-mediated dilation

Figure 2. A picture of the experiment.

Figure 3. Changes in heart rate (HR) during each trial.

Values are presented as mean ± standard deviation (SD).

$^{a}p<0.05$ vs. A+25%EMS trial, $^{\S}p<0.05$ vs. 5min.

A: arm-cranking exercise

EMS: electrical muscle stimulation

Figure 4. Changes in oxygen uptake ($\dot{V}O_2$) during each trial.

Values are presented as mean ± standard deviation (SD).

$^{a}p<0.05$ vs. A+25%EMS trial, $^{b}p<0.05$ vs. A+50%EMS trial, $^{c}p<0.05$ vs. A+50%EMS trial, $^{\S}p<0.05$ vs. 5min.

Figure 5. Changes in normalized flow-mediated dilation (nFMD) before and after each trial.

$^{*}p<0.05$ vs. before.