Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

Mani Izadi Sharifi

Neuromuscular efficiency in relation to muscle blood flow and oxygen consumption in isolated muscle work

is there any age-related effect?

Master's thesis in Physical Activity and Health - Exercise Physiology
Supervisor: Mireille van Beekvelt
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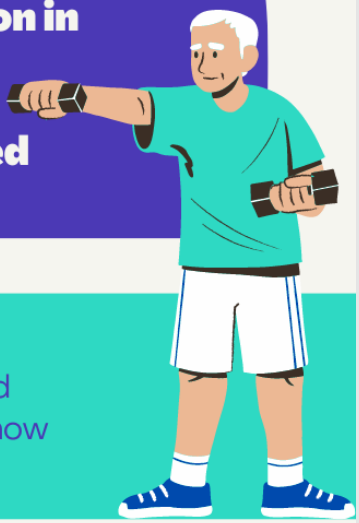

BACKGROUND

Unclear if aging causes declined neuromuscular efficiency and how its variability can be explained

PURPOSE

Test neuromuscular efficiency of forearm muscles in dynamic handgrip exercise

Its relationship with muscle blood flow and oxygen consumption

METHODS

- 11 young and 12 older healthy, recreationally active
- Neuromuscular efficiency as Force/EMG
- Muscle blood flow and oxygen consumption by NIRS
- FDS and BR muscles
- Five 1-min dynamic handgrip exercises

RESULTS

- Only BR showed some declines in neuromuscular efficiency and muscle blood flow with age

- Poor relationship between neuromuscular efficiency with muscle blood flow and oxygen consumption

CONCLUSION

Aging does not affect all muscles equally.

FDS muscle function is preserved with age, but there are losses in BR

Muscle blood flow and oxygen consumption does not affect neuromuscular efficiency in the forearm muscles of older adults.

Izadi Sharifi, M. (2022). Neuromuscular efficiency in relation to muscle blood flow and oxygen consumption in isolated muscle work: is there any age-related effect? (Master's thesis, NTNU).

Abstract

Background: It is well-established that aging is associated with declined muscle mass and force. However, the impacts of age on neuromuscular efficiency, muscle blood flow and oxygenation**,** and their association are less clear. **Objective:** The present study investigates whether advanced age affects neuromuscular efficiency, muscle blood flow, and $m\dot{V}O_2$ in isolated muscle work and if neuromuscular efficiency is associated with O_2 delivery and extraction. **Methodology:** 11 young (26.45±7.38 years) and 12 older (64.41±3.94 years) adults participated. All were healthy and recreationally active. An incremental handgrip test was conducted to determine maximal handgrip load. Bouts of dynamic handgrip exercise at work rates 10, 30, 50, 70, and 90% of maximal handgrip load were performed. Force/EMG_{RMS} was used as a measure of neuromuscular efficiency. Blood flow and $m\dot{V}O_2$ were evaluated using NIRS and venous occlusion. All measurements were done in two forearm muscles, flexor digitorum superfacialis and brachioradialis. **Results:** Young showed higher neuromuscular efficiency than the older group, only for brachioradialis (borderline significant effect, $F(1,21)=4.04$, $p=0.05$). There was also a significant group-by-WR interaction effect for blood flow in brachioradialis ($F(4,82)=3.27$, $p=0.01$). Except for three significant associations out of 40 tested ($p<0.05$), neuromuscular efficiency was poorly associated ($p>0.05$) with muscle blood flow and $m\dot{V}O_2$. **Conclusion:** The findings of this study demonstrate some differences in the rate of muscle aging within forearm musculature since flexor digitorum superfacialis function appears to be preserved with age while there were declines in brachioradialis. Moreover, muscle O_2 delivery and extraction do not seem to affect neuromuscular efficiency.

Keywords: muscle aging, forearm musculature, dynamic exercise

Acknowledgments

A thesis brings opportunities and challenges that are not accomplished and overcome only by one but also by support from others. I would therefore like to acknowledge those who helped me with this thesis.

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Abbreviations

ATT	adipose tissue thickness
BF	blood flow
BR	brachioradialis
DHT	dynamic handgrip exercise test
EMG	electromyography
FDS	flexor digitorum superficialis
Hb	hemoglobin
HG	handgrip
HG_{max}	maximal handgrip load
HHb	deoxyhemoglobin
IHT	incremental handgrip test
Mb	myoglobin
MVC	maximal voluntary contraction
$m\dot{V}O_2$	muscle oxygen consumption
NIRS	near-infrared spectroscopy
NME	neuromuscular efficiency
O_2	oxygen
O_2Hb	oxyhemoglobin
RMS	root mean square
tHb	total hemoglobin
VO	venous occlusion
$\dot{V}O_2$	oxygen consumption
WR	work rate

Introduction

There is a decline in muscle mass and force-generating capacity with age (1). This process, typically known as sarcopenia, causes several events, including poorer physical capabilities due to decreased muscle strength. Consequently, older adults become prone to disabilities, falls, and loss of independence (2). Although it is well established that old age is associated with losses in muscle mass and strength (1), the impacts of advancing age on muscle blood flow (BF) and bioenergetics**,** neuromuscular efficiency (NME), and muscle fatigability are less consistent. For instance, some authors have shown more significant muscle fatigue among older adults than their younger peers (3, 4). On the contrary, others have demonstrated increased fatigue resistance with advancing age (5-7) across different muscle groups.

Moreover, aging results in slowed contractile properties in skeletal muscle, represented by prolonged contraction and relaxation times. Selective loss of type II muscle fibers is an explanatory mechanism for the slowed contractile properties with old age, leading to a shift toward a slower muscle fiber profile (8, 9). Slowed muscle contractile properties have been suggested to cause fusion of muscle force at lower firing rates of motor units (8, 10). This medium may indicate a leftward shift in force-frequency relationships. Thus, at lower stimulation frequencies, a larger magnitude of the relative force is produced (5), leading to an increased NME (8) or a decrease in the central motor drive (10) necessary to create a required amount of voluntary force. Force to electromyographic activity (EMG) ratio (force/EMG) is typically used as a measure of NME. A leftward shift in the force-frequency relationship, which indicates force summation at lower stimulation frequencies, may result in enhanced NME among older adults compared to young individuals (11). However, one study has reported that slowed contractile properties with age do not enhance NME (11). The author noted that despite the older group exhibiting a slowing of contractile properties, they showed an increased EMG/force compared to the younger group.

Therefore, mechanisms other than neural control of contractions may also play a significant role in NME. Older adults' lower proportional muscle mass and strength can reduce intramuscular pressure and BF occlusion during contractions (12), promoting muscle perfusion, especially during high-intensity contractions (13). At the same time,

muscle perfusion might be a limiting factor for regulating force production at a given muscle activity. The paradox is that older adults tend to have a more significant proportion of type I and II_a muscle fibers than II_b, which are highly reliant on oxidative metabolism, requiring a continuous supply of O_2 and nutrients, and this is compromised by decreased BF (14). This notion is fascinating in the association of age-related changes in NME with BF and oxygenation of active muscles in voluntary contractions. Since aging typically causes changes in neural and cardiovascular control of BF to the working muscle, NME is also thought to be affected by advancing age, especially during dynamic muscle action which are more relevant to activities of daily living.

In addition to age-related declines in muscle mass and quality, a series of adaptations in the cardiovascular system caused by aging can compromise muscle BF and influence its regulation during dynamic exercise. These adaptations include decreased cardiac pump capacity, structural changes in the vasculature, increased muscle sympathetic neural outflow, and alterations in local vascular control mechanisms (15). Muscle BF increases via vasodilation, instantly following a single muscle contraction among young adults. However, this response is substantially blunted with old age (16). Evidence shows that muscle BF is reduced by 20-30% during steady-state dynamic exercise involving large muscles (17-19). This decline can contribute to an age-associated decrease in maximal oxygen consumption and physical functional capacity. Since it is conceivable that reduced BF in this type of exercise correlates with age-related alterations in central circulation factors (i.e., cardiac output) (17, 18), some researchers attempted to minimize this effect by studying isolated muscle work (20, 21).

In these studies, a significant reduction in muscle BF was demonstrated for the older group during steady state isolated knee extension exercise, which was associated with a diminished vascular conductance (20, 21). However, it has been shown that forearm muscle BF during (20) and immediately after (22) steady-state dynamic handgrip exercise was preserved with age. This preserved muscle BF during handgrip exercise was contradicted by some other studies (23). While the majority of studies suggest an impaired BF during large muscle and leg muscle exercise and generally preserved BF (with some controversial findings) on forearm BF during handgrip exercise among older adults, they commonly used methods which are limited to more proximal arteries that supply the whole limb, providing less evidence on BF and oxygenation of

exercising muscle from a microcirculation point of view. Near Infrared Spectroscopy (NIRS) is a method that can be used to evaluate tissue oxygenation, local O_2 consumption, and BF in various tissues, including skeletal muscle (24, 25), thus providing an opportunity to assess muscle BF and oxygenation in microcirculation level. When combined with simple physiological interventions such as vascular occlusions, NIRS provides a non-invasive quantitative measurement of two significant determinants of skeletal muscle capacity to exercise, O_2 delivery, and O_2 utilization. The non-invasiveness of NIRS makes it an alluring method to be used for a dynamic environment and activities of daily living (26).

Our lab members recently experimented on the effect of submaximal whole-body (cycling) and isolated muscle (handgrip) exercises at various intensities on muscle oxyhemoglobin saturation (SmO_2) responses among young and older adults and demonstrated a similar muscle function between two groups (27). However, findings on the age-related differences in muscle BF and muscle oxygen consumption ($m\dot{V}O_2$) in responses to dynamic isolated muscle exercise are scarce. Moreover, little is known on the association of muscle BF and $m\dot{V}O_2$ with NME during dynamic exercises, while it can have significant implications for older adults. In other words, documenting the effect of old age on muscle BF and oxygen consumption ($\dot{V}O_2$) of skeletal muscle during dynamic exercise is essential for identifying exercise limiting factors, including reduced exercise tolerance and fatigue resistance and the possible alterations in NME. Furthermore, a better understanding of the relationships between muscle force-generating capacity, activity, and O_2 delivery and utilization would aid in recognizing primary causes (relevant to the normal aging process) versus secondary causes (e.g., diseases and inactivity) of limited muscle function.

It is conceivable that resting muscle BF (O_2 delivery) and $\dot{V}O_2$ (O_2 extraction) are not substantially impaired with age. However, they would be limited during dynamic exercise among older adults, which may affect force-EMG relationships and, thus, NME. To this end, the present study's first aim was to investigate if there is a difference in forearm muscle activity and force production, NME (as expressed by force/EMG), BF, and $m\dot{V}O_2$ between young and older adults. We hypothesize a trend toward less force production at a given EMG level with age that would result in diminished NME. The older group is thought to exhibit less muscle BF and $\dot{V}O_2$ compared to the younger group. As a

secondary aim, we seek to elucidate the association of NME with muscle BF and $\dot{V}O_2$. We assume that, with advancing age, decreased force/EMG is correlated with attenuated muscle BF and $\dot{V}O_2$, thus requiring augmentation of muscle activity to retain the same level of force generation. Accordingly, it is hypothesized that NME is associated with muscle BF and $\dot{V}O_2$ in the older group.

Methodology

This study is part of an ongoing project aiming to provide normative data on skeletal muscle microvascular function and markers of skeletal muscle aging through non-invasive measurements. Therefore, parts of the protocol that are irrelevant to this thesis will not be presented in detail in this section. However, figure 1 illustrates the whole protocol and the project components.

Participants

A total of 25 healthy participants were recruited through advertisements on social media, local gyms, and public places, including university and hospital buildings. Inclusion criteria were as follows: aged between 25 to 40 years for the young group and 60 years and older for the older group; BMI less than 30 $kg \cdot m^{-2}$. Exclusion criteria included smoking, any chronic condition, diseases, or medications that would affect neuromuscular function and/or hemodynamic responses to events in the protocol. All the participants were recreationally active, and all but one were right-hand dominant. Two participants were excluded from the study due to measurement errors and poor signal quality. Therefore, data from 23 participants underwent further analysis; the older group (OG, n = 12) and the young group (YG, n = 11).

The advertisements provided preliminary information on the project's aims, protocols, and methods. In case individuals were interested in participating in the study, follow-up phone calls or email conversations were made to explain further details of the project. Instructions on possible risks and discomforts, test procedures, and experiment preparations were given in written and oral forms. All participants gave informed written consent before the test procedures. The study was approved by the Regional Ethical Committee for Medical and Health Research Ethics, Midt-Norge.

Study design

Data collection activities took place in Trondheim, Norway, at a well-controlled laboratory condition with a temperature between 18-20°C, under the supervision of three master students. All participants visited the lab in three separate sessions. Tests were divided into two testing days and aimed to have one to three days between two occasions. However, it was impossible to meet this criterion for four participants due to Covid pandemic difficulties (one in old group and three in young group), and there were more days between two testing days. Plus, a part of the body composition measurements was done on the third day.

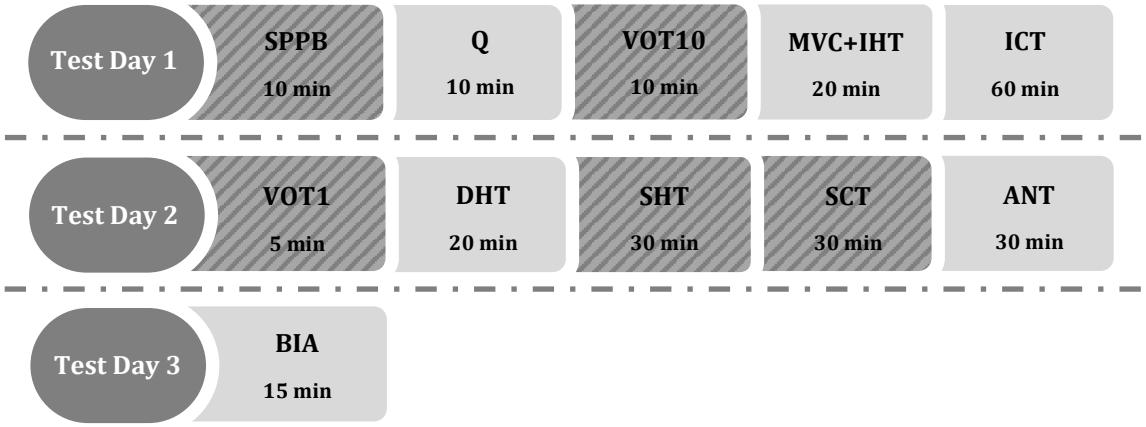


Figure 1. Day-by-day experimental protocol. SPPB, short physical performance battery; Q, questionnaire; VOT10, 10-min vascular occlusion test; MVC, maximal voluntary contraction test; IHT, incremental handgrip test; ICT, incremental cycling test; VOT1, 1-min vascular occlusion test; DHT, dynamic handgrip exercise test; SHT, submaximal handgrip exercise test; SCT, submaximal cycling exercise test; ANT, anthropometric measurements; BIA, bioelectric impedance analysis. Data from tests in striped boxes (SPPB, VOT10, VOT1, SHT, and SCT) was not used in this thesis.

Participants were instructed to refrain from alcohol use for 48 hours, vigorous physical activity 24 hours before testing days, and caffeine use on the day of tests. Testing protocols followed the same arrangement for all the participants, as shown in figure 1. On the first test day, participants underwent a maximal voluntary contraction (MVC) test of forearm muscles and an incremental handgrip test (IHT). On day two, a 1-min venous

occlusion test (VOT) and a dynamic handgrip exercise test (DHT) with multiple workloads (which were set based on values from IHT on day 1) were performed.

Experimental protocol

Anthropometric measurements

Body height and weight were measured to the nearest 0.1 cm and 0.1 kg using a stadiometer and a weighing scale, respectively. Skinfold thickness was measured at the sites of NIRS optode placement on flexor digitorum superficialis (FDS), and brachioradialis (BR) muscles using a skinfold caliper (Holtain, Crymych, UK). Adipose tissue thickness (ATT) was calculated as the average of two skinfold measurements at each site divided by 2. Body composition measurements, including body fat percentage, fat mass, fat-free mass, skeletal muscle mass, and right arm muscle mass, were done using bioelectrical impedance analysis. Forearm length and circumference were measured using a flexible tape, and forearm volume was evaluated using arm volumetry. Participants were sitting on a laboratory bed for all other measurements.

Physical activity and physical fitness level

Subjective assessment of physical activity level was obtained through a questionnaire. An incremental cycling test (ICT) was used to determine $\dot{V}O_{2max}$, as an indicator of physical fitness. First, a multi-stage lactate threshold test was run to reach a lactate level of four $mmol \cdot L^{-1}$, and the work rate (WR) at this lactate level was used as the starting WR in ICT.

Incremental handgrip test (IHT) and maximal voluntary contraction test (MVC)

The maximal workload for handgrip exercise was determined through an incremental handgrip test. The participant was positioned on the bed. The test was performed on a custom-made handgrip dynamometer, with the elbow and wrist support, the forearm placed at an upward angle (around 25 degrees), and the upper arm at the level of the heart. Before running the actual test, one examiner explained the procedure, and the participant was allowed to have a short practice. The range of motion was guided by a fixed handle and a marker with blue tape on the dynamometer's plank. That means the starting point was set over the tape (an approximately 90-degree angle on the index finger) and the end of the range of motion was where the moving handle touched the fixed

handle. However, the starting point was adjusted when the length/proportions of fingers did not match this pre-defined length.

The pace in contraction and relaxation phases during exercise was guided using a metronome signaling one beep per second; one beep for contraction, and one beep for relaxation, resulting in a frequency of 30 contractions per minute with a duty cycle of 1:1. The workload was set at 2.5 kg for the initial 30 seconds of IHT test and increased by 0.25 kg every 15 seconds (figure 2). The test was terminated when the participant reached volitional exhaustion or could not follow the proper pace, range of motion, and/or drifted from initial positioning to probably use other muscle groups due to fatigue in exercising muscles. Maximal dynamic handgrip load (HG_{max}) was defined as the final load that could be maintained for at least 15 seconds. HG_{max} was used to determine the work rates (WRs), as the percentages of HG_{max}, for the DHT on day 2.

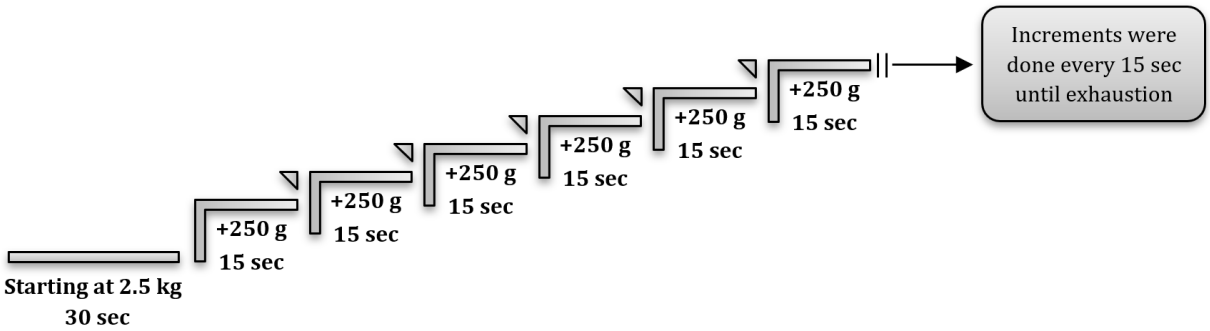


Figure 2. Illustration of IHT protocol.

An MVC test preceded the IHT test. The MVC of the handgrip was assessed via a handgrip dynamometer (Lafayette Instruments Model 5030L1, Indiana, USA). All participants performed the test using their right arm with an approximately 90-degree position at the elbow, and the dynamometer was squeezed maximally for 2 seconds. Three trials were conducted with 1-minute rest between them, and the best MVC score (measured in kg) across three trials was considered.

Dynamic handgrip exercise test (DHT)

A dynamic handgrip exercise test was employed to perform isolated muscle work. Five submaximal WRs with constant load were set based on 10 (WR_{10}), 30 (WR_{30}), 50 (WR_{50}), 70 (WR_{70}), and 90 (WR_{90}) percent of individual's HG_{max}. All instructions on positioning and range of motion during handgrip exercise were the same as IHT. Although the duty cycle was kept the same as 1:1, contraction frequency was double that of the IHT test (two beeps per second), executing one complete contraction-relaxation cycle every second and 60 contractions per minute again audibly guided by the metronome. The exercise included five 1-min bouts of dynamic handgrip (at WRs described above) interspersed with 1-min rest intervals. At the onset of stopping each WR, a 30-sec venous occlusion (VO) was applied to the upper arm. The participants were instructed to completely relax, minimize movement in fingers and wrist, and avoid making any voluntary contractions. The second 30-sec phase within 1-min rest intervals was allowed with no VO (figures 3 and 4).

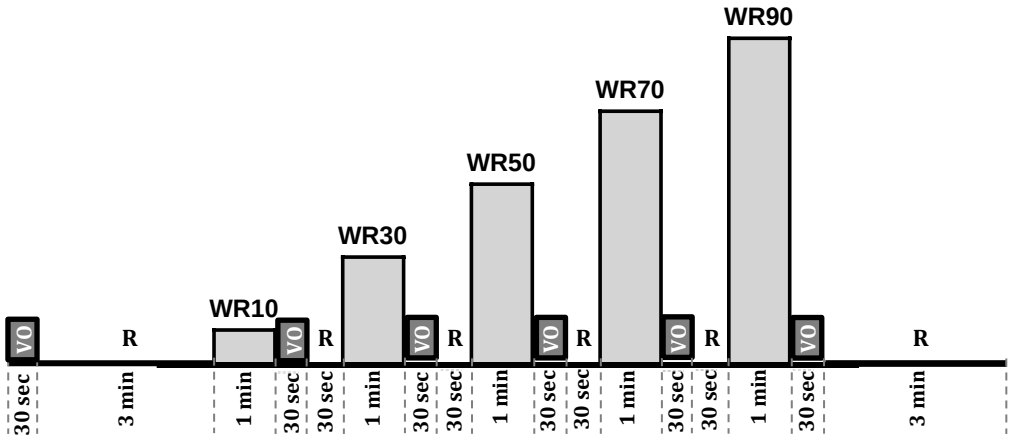


Figure 3. Illustration of DHT protocol with details on events. VO, venous occlusion; R, rest.

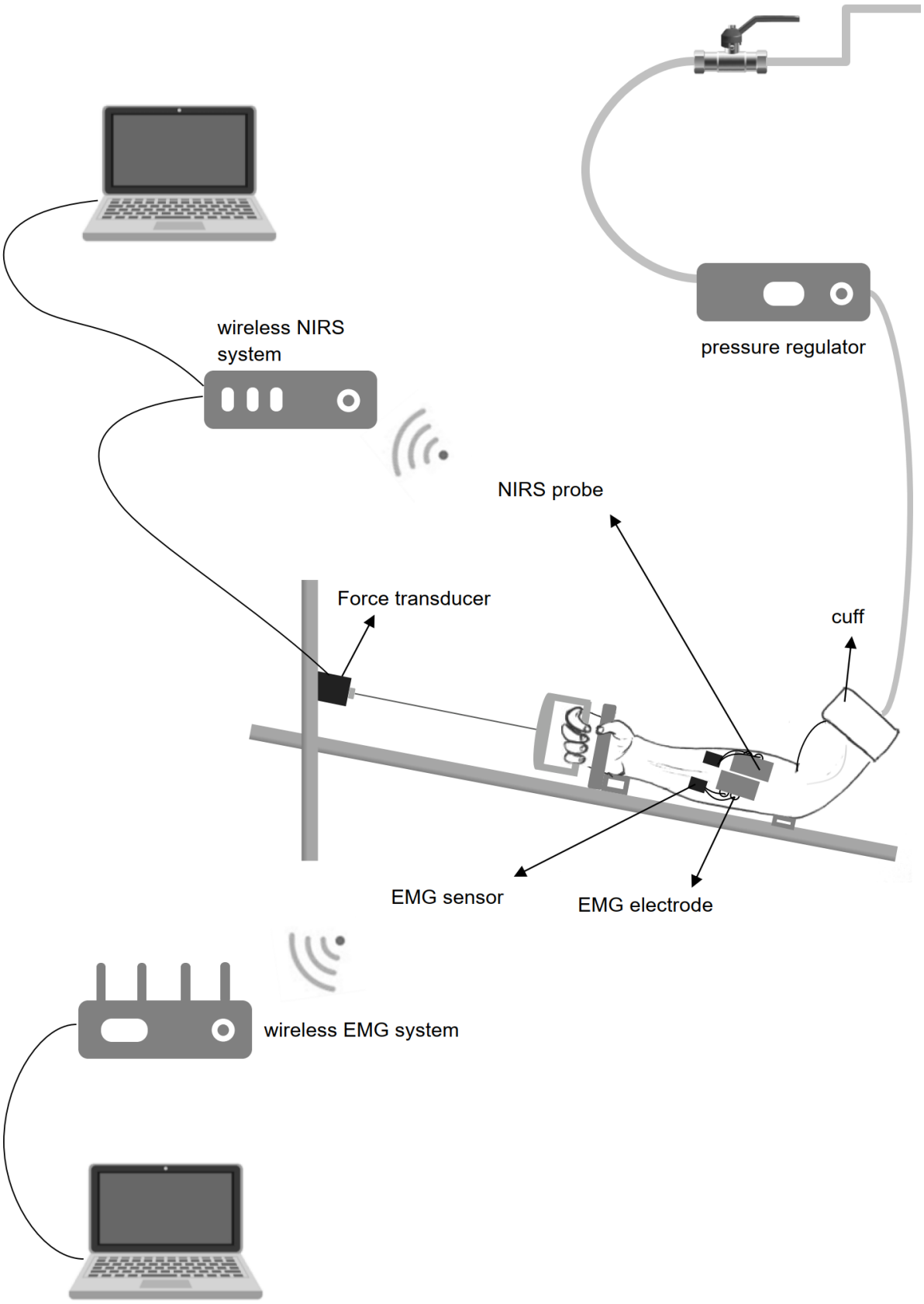


Figure 4. Experimental setting in DHT

Force, electromyographic activity (EMG), and neuromuscular efficiency (NME)

During IHT and DHT, the force was measured continuously via a force transducer (Model 9363, 50 kg capacity, Revere Transducers, CA, USA). Electrical activity of FDS and BR muscles was obtained through surface EMG using a wireless EMG system (Noraxon TeleMyo Desktop DTS, AZ, USA). First, the skin was carefully shaved and cleaned with alcohol wipes to ensure suitable skin impedance. Before placing EMG electrodes, the location of the NIRS probe and its light transmitters and receiver was marked on the belly of FDS and BR. To measure EMG at the nearest location of NIRS measurement, pairs of adhesive electrodes (Ambu BlueSensor NF, Copenhagen, Denmark) were placed close to the sites of NIRS measurement. However, care was taken to ensure no interference in NIRS measurement by EMG electrodes. EMG sensors (DTS Lossless EMG Sensor) were attached to the electrodes through a DTS EMG lead set and were secured on the skin using surgical tapes. EMG signals were recorded at a sampling frequency of 1500 Hz, amplified, and bandpass filtered at 20-300 Hz. Signals were rectified, and low pass filtered off-line. Root mean square (RMS) of the EMG amplitudes (μV) were calculated with 0.1-second window width. Force and EMG data were calculated as the average value for the whole period of each exercise bout. NME was expressed as the force/EMG_{RMS} ($kg \cdot \mu V^{-1}$).

Muscle BF and $\dot{V}O_2$

The present study used continuous-wave NIRS (CW NIRS) system (Portamon, Artinis Medical Systems, Netherlands) to measure muscle BF and $\dot{V}O_2$. NIRS utilizes near-infrared light, which is absorbed by oxy- and deoxyhemoglobin (Hb)/myoglobin (Mb) in the tissue. Due to the identical spectral properties of Hb and Mb, it is not possible to distinguish them using NIRS. However, since the light absorption of oxy-Hb (+ oxy-Mb) and deoxy-Hb (+ deoxy-Mb) differs, NIRS can distinguish them. CW NIRS uses the modified Beer-Lambert Law to calculate the relative oxy- and deoxy-Hb/Mb concentrations (26). After finding the location of FDS and BR through palpation, EMG electrodes were attached, and then NIRS probes were placed longitudinally on the muscle belly, close to EMG electrodes. A piece of black fabric was placed on NIRS probes to prevent contamination by ambient light. All probes, sensors, and fabrics were secured using soft cloth surgical tapes and self-adhesive bandage wraps. The NIRS probes used wavelengths 845 nm and 761 nm with a sampling frequency of 10 Hz.

Data from DHT was used to calculate muscle BF and $\dot{V}O_2$. More specifically, a 30-sec venous occlusion at rest was applied before DHT, followed by a 3-min baseline measurement. Afterward, DHT started, and immediately following completion of each 1-min at the pre-defined WR, a 30-sec venous occlusion at rest was implemented. Concentration changes for total hemoglobin (tHb = oxy-Hb + deoxy-Hb) and deoxy-Hb (HHb) were measured during the entire DHT protocol. Muscle BF ($ml \cdot min^{-1} \cdot 100ml^{-1}$) and $\dot{V}O_2$ ($mlO_2 \cdot min^{-1} \cdot 100g^{-1}$) were determined by the linear regression of the rate of increase in tHb and HHb concentration, respectively, calculated for three seconds and starting 0.5 seconds after the cuff inflation. All venous occlusions were conducted via a pneumatic cuff (Hokanson SC5L, Marcom Medical ApS, Denmark) wrapped proximally around the upper arm. The cuff was rapidly inflated by a pressure regulator (Hokanson E20 Rapid Cuff Inflator, Marcom Medical ApS, Denmark) to a pressure of 50 mmHg. When venous occlusion is applied, the venous outflow is expected to be stopped while arterial inflow is allowed, causing an increase in all signals (oxy-Hb (O_2Hb), HHb, and tHb) in regions distal to the inflated cuff.

Statistical Analysis

Data were processed in Matlab version R2021b. All statistical analyses and plottings were conducted using SPSS 27 software (SPSS Inc., Chicago, IL, USA), GraphPad Prism v. 9 (GraphPad Software, San Diego, CA, USA), and Microsoft Excel (Microsoft Excel for Office 365 MSO, Microsoft COP., Redmond, WA, USA). Descriptive statistics were presented as means ± standard deviations. Body composition and physical fitness factors were compared between two groups using an independent sample t-test. For $m\dot{V}O_2$ and BF values, those corresponding to negative regression values were excluded from further analysis since signals are expected to increase during the first seconds of venous occlusion. Therefore, those numbers were likely due to measurement errors (including participants' movements) and/or poor signal quality. Normality of data and homogeneity of variances were checked using Shapiro–Wilk and Levene's tests, respectively.

To test the between- and within-group differences in NME, BF, and $m\dot{V}O_2$, a two-way mixed model analysis of variance (ANOVA) with repeated measures and a Bonferroni post-hoc test was conducted. Specifications of the model are as followings; the main effect of group: the difference between the two groups averaged across all WRs; the main effect

of time: the difference from one WR to the next WR averaged across two groups; Group-by-WR interaction effect: the difference in between-group differences in different WRs. The ANOVA statistics were adjusted by Greenhouse-Geisser epsilon (ε) corrections to remedy any violations of the assumption of sphericity on Mauchly's test. A Pearson correlation coefficient test was used to examine the relationship between $m\dot{V}O_2$ and BF with NME. Statistical significance was set at $p \leq 0.05$.

Results

Table 1 presents participants' characteristics, including body composition and physical fitness variables. Height ($p<0.01$), skeletal muscle mass ($p=0.03$), and $\dot{V}O_{2max}$ ($p<0.01$) were significantly different between groups. There was no significant difference ($p>0.05$) for other variables.

Table 1. Characteristics of participants

	YG		OG		
	Mean (± SD)	Range	Mean (± SD)	Range	t
n (male:female)	11 (6:5)		12 (6:6)		
Age (years)	26.45 (± 7.38)	18.0 – 37	64.41 (± 3.94)	60 – 73	
Weight (kg)	71.86 (± 7.52)	62.0 – 84	67.69 (± 9.51)	54 – 88.5	1.15
Height (cm)	176.5 (± 7.69)	166 – 193.5	168.69 (± 5.21)	160 – 178.5	2.87**
BMI ($kg \cdot m^{-2}$)	23.04 (± 1.57)	20.40 – 25.15	23.72 (± 2.41)	19.96 – 28.64	- 0.79
BF%	18.28 (± 5.67)	9.2 – 27.8	23.42 (± 6.37)	12.6 – 32.3	- 2.03
FM (kg)	12.81 (± 3.69)	7.6 – 21.2	15.73 (± 5.49)	8.3 – 26.3	- 1.47
FFM (kg)	59.04 (± 9.18)	46 – 76.4	51.95 (± 7.66)	42.6 – 67.9	2.01

SMM (kg)	32.99 (± 5.61)	25.2 – 43.2	28.26 (± 4.50)	22.8 – 37.2	2.23*
ATT_{FDS} (mm)	4.38 (± 1.39)	2.5 – 7.1	3.87 (± 1.68)	1.6 – 6.4	0.77
ATT_{BR} (mm)	5.21 (± 1.51)	3.05 – 7.95	4.65 (± 1.66)	2.35 – 7.5	0.84
RAMM (kg)	3.17 (± 0.63)	2.25 – 4.25	2.82 (± 0.66)	2.05 – 4.08	1.29
FAV (mL)	1036.18 (± 142.78)	835 – 1261	972.58 (± 198.27)	692 – 1292	0.87
FAL (cm)	27.86 (± 1.67)	25.5 – 31	27.12 (± 1.55)	25 – 30	1.09
FAC (cm)	24.4 (± 1.61)	22 – 27	23.67 (± 2.58)	20 – 28	0.79
MVC (kg)	46.55 (± 8.67)	36 – 61	39.83 (± 10.86)	26 – 56	1.62
HG_{max} (kg)	12.97 (± 1.35)	10.5 – 15	12.33 (± 1.79)	10.25 – 16.5	0.96
$\dot{V}O_{2max}$ ($mlO_2 \cdot kg^{-1} \cdot min^{-1}$)	52.82 (± 9.8)	42.22 – 67.54	41.84 (± 7.29)	31.26 – 53.84	3.06**
PA ($min \cdot week^{-1}$ (n)) MM MV	 180 (2) 226.36 (11)	 120-360	 120 (1) 236.66 (12)	 120-420	 -0.24

YG, young group; OG, older group; BMI, body mass index; BF%, body fat percentage; FM, fat mass; FFM, fat-free mass; SMM, skeletal muscle mass; ATT_{FDS}, adipose tissue thickness of flexor digitorum superficialis; ATT_{BR}, adipose tissue thickness of brachioradialis; RAMM, right arm muscle mass; FAV, forearm volume; FAL, forearm length; FAC, forearm circumference; MVC, maximum voluntary contraction; HG_{max}, maximal handgrip load; PA, physical activity; MM, mild to moderate intensity; MV, moderate to vigorous intensity; * significant difference between groups.

Resting muscle BF and mV̇O2

Results on resting BF and mV̇O2 for two muscles are present in figure 5. Despite that YG showed slightly higher values for BF and mV̇O2 than OG in FDS (1.5 ± 1.45 vs. 1.05 ± 1.37 and 0.14 ± 0.1 vs. 0.08 ± 0.07) and BR (1.72 ± 1.25 vs. 1.65 ± 1.88 and 0.19 ± 0.13 vs. 0.13 ± 0.08), there was no significant difference in either muscle (p>0.05).

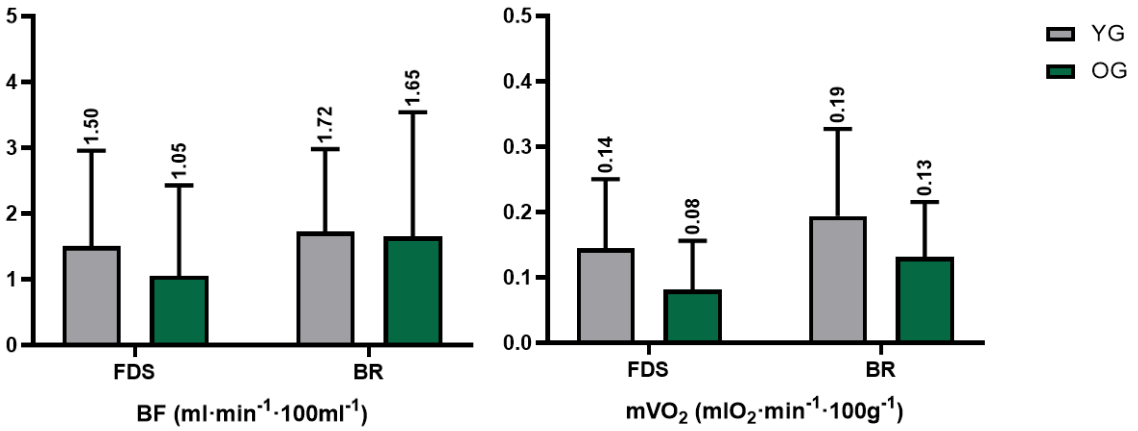


Figure 5. Resting muscle blood flow and oxygen consumption. Values over the bars are means.

Force

A 2-way mixed ANOVA using Greenhouse-Geisser correction (ε=0.23) revealed a significant main effect of WR on force (F(0.95,19.80)=1028, p<0.01; figure 6). There was also a significant group-by-WR interaction effect (F(4,83)=2.51, p=0.04; figure 6). However, the main effect of group on force was not significant (p>0.05). Post-hoc analysis with Bonferroni adjustments showed a significant difference in force for all within-group pairwise comparisons between WRs (p<0.01) for both groups.

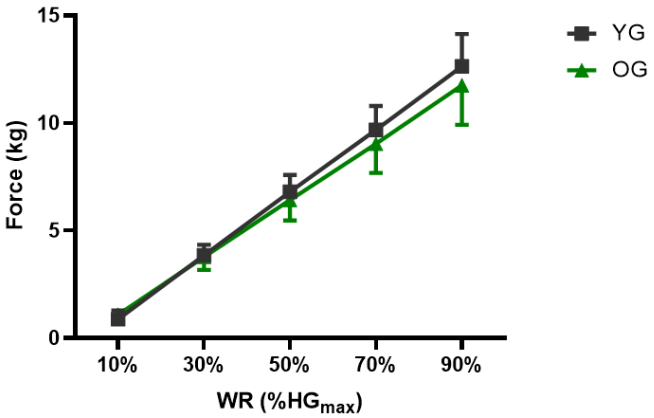


Figure 6. Force produced over five exercise workrates.

EMG_{RMS}

Figure 7 illustrates an example EMG on one muscle from one participant. EMG_{RMS} increased at higher exercise WRs, which was confirmed by a significant main effect of WR on EMG_{RMS} both for FDS ($F(1.91,39.21)=61.57$, $p<0.01$, figure 8) and BR ($F(1.57,32.61)=85.42$, $p<0.01$, figure 8) in the 2-way mixed ANOVA using Greenhouse-Geiser correction ($\varepsilon=0.47$ and $\varepsilon=0.39$, respectively). Post-hoc analysis with Bonferroni adjustments showed, except for pairs WR_{50}-WR_{90} and WR_{70}-WR_{90} in YG and WR_{70}-WR_{90} in OG for FDS and pair WR_{70}-WR_{90} in OG for BR, a significant difference was found for all other within-group pairwise comparisons between WRs ($p<0.01$) for both groups and both muscles. Nevertheless, there was no significant main effect of group or group-by-WR interaction effect on EMG_{RMS} of either muscle ($p>0.05$).

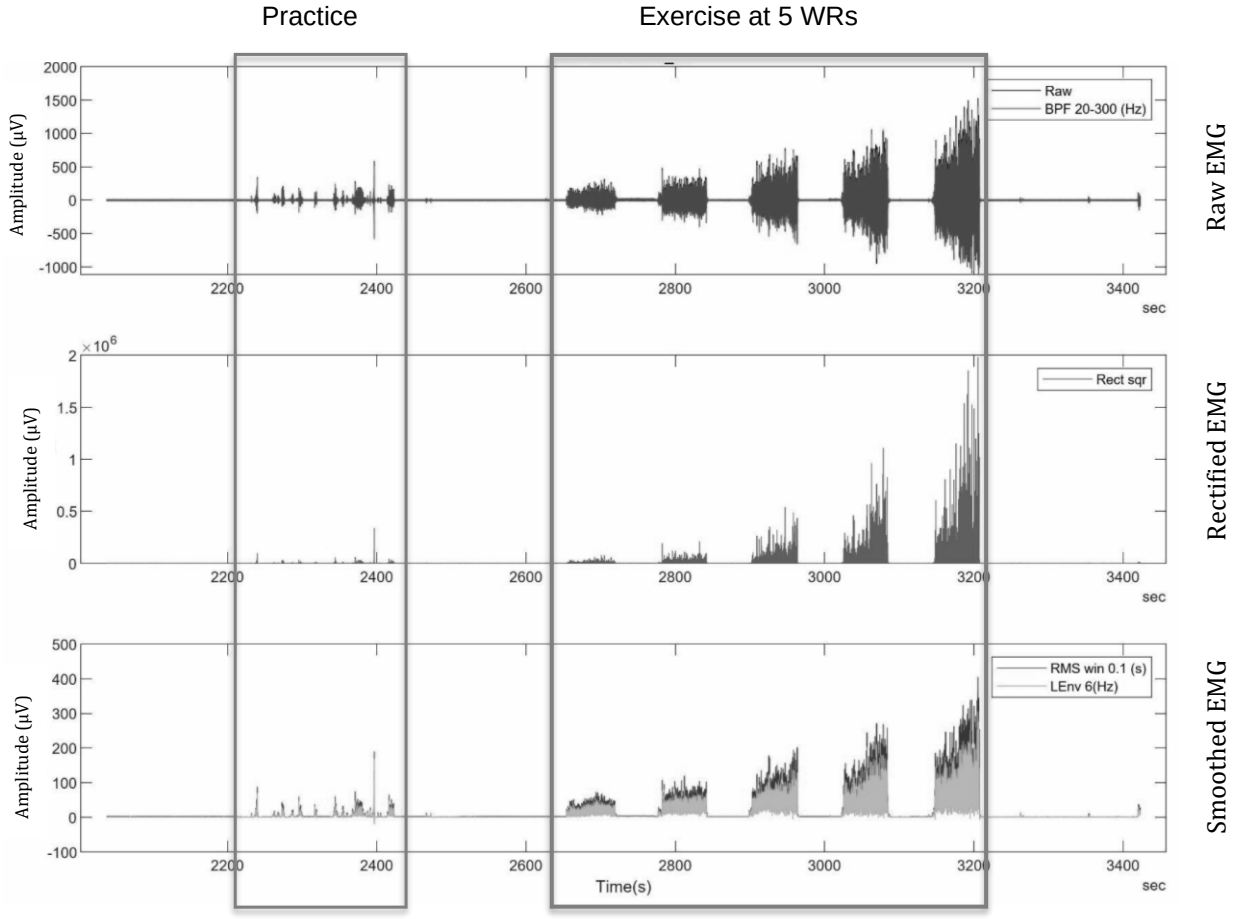


Figure 7. An example raw and processed EMG signals of BR muscle from one participant

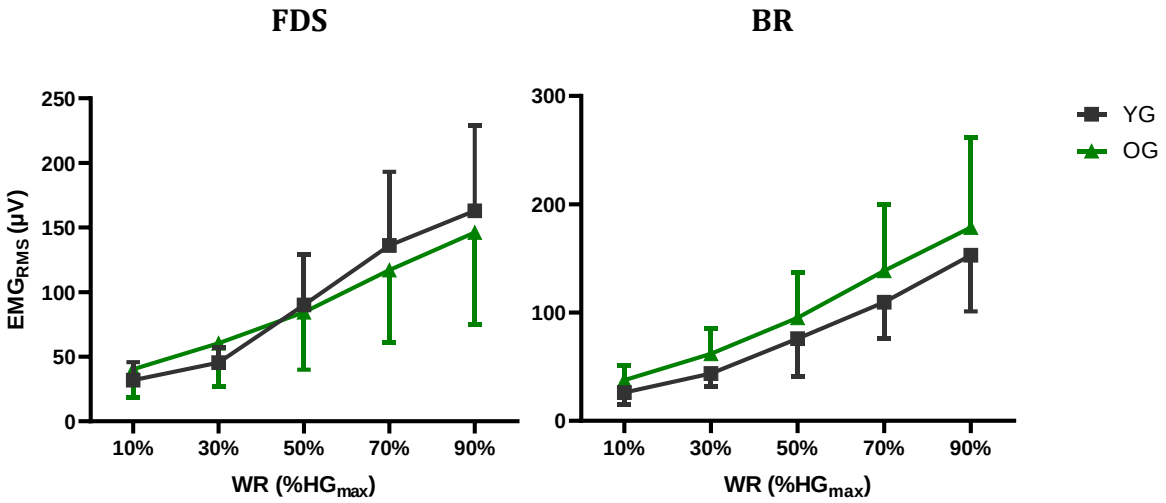


Figure 8. EMG_{RMS} over five exercise work rates.

NME

No significant main effect of group for FDS or group-by-WR interaction effect for both muscles on NME was found ($p>0.05$). However, there was a borderline significant main effect of group for BR ($F(1,21)=4.04$, $p=0.05$, figure 9). There was also a main effect of WR on NME for FDS ($\varepsilon=0.3$, $F(1.2,24.46)=6.61$, $p=0.01$, figure 9) and BR ($\varepsilon=0.72$, $F(2.9,59.44)=56.94$, $p<0.01$, figure 9).

Within-group pairwise comparisons using post-hoc Bonferroni adjustments for FDS showed that there were significant differences only between WR_{30}, WR_{50}, and WR_{70} with WR_{10} ($p<0.01$) for YG and WR_{30}, WR_{50}, WR_{70}, and WR_{90} with WR_{10} ($p<0.01$), and between WR_{30} and WR_{50} ($p=0.04$) for OG. Post-hoc analysis with Bonferroni adjustments for BR showed significant differences only between WR_{30}, WR_{50}, WR_{70}, and WR_{90} with WR_{10} ($p<0.01$) for both groups.

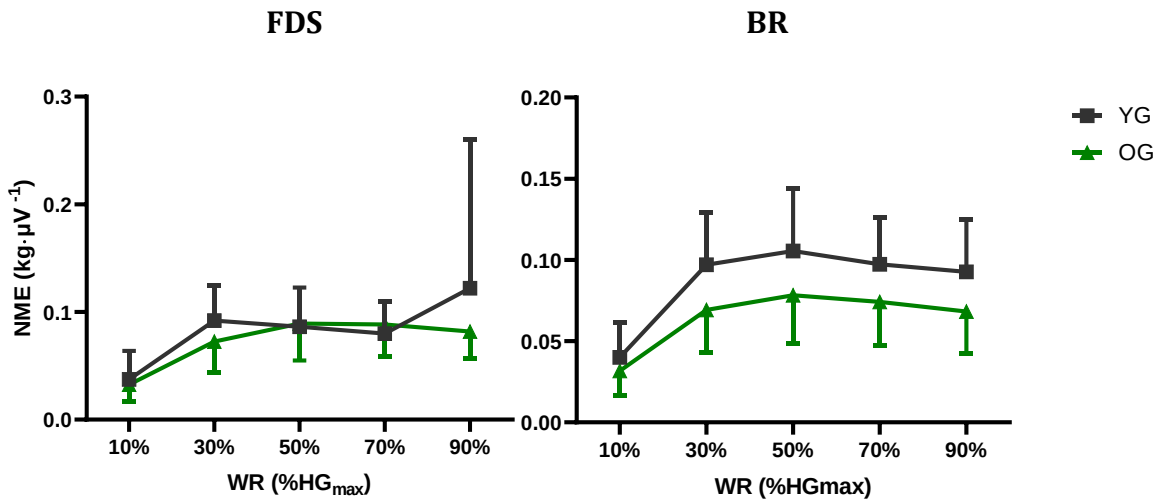


Figure 9. Neuromuscular efficiency over five exercise work rates.

BF

Figure 10 illustrates an example NIRS recording on one muscle from one participant. A 2-way mixed ANOVA using Greenhouse-Geiser correction revealed a main effect of WR on FDS_{BF} (ε=0.55, F(2.23,46.34)=30.39, p<0.01; figure 11) and BR_{BF} (ε=0.46, F(1.86,38.22)=20.64, p<0.01; Fig.). However, a non-significant main effect of group for BF result was found (p>0.05). Group-by-WR interaction effect was significant for BR (F(4,82)=3.27, p=0.01) and non-significant for FDS (p>0.05).

Post-hoc analysis with Bonferroni adjustments showed a significant difference in FDS_{BF} between WR_{50}, WR_{70}, and WR_{90} with WR_{10} (p=0.03, p=0.02, and p<0.01, respectively) and between WR_{30} and WR_{70} (p=0.04) for YG, and between WR_{30}, WR_{50}, WR_{70}, and WR_{90} with WR_{10} (p=0.02, p=0.01, p<0.01, and p<0.01, respectively) and between WR_{30} and WR_{70} (p=0.01) for OG. The post-hoc analysis also demonstrated a significant difference in BR_{BF} for pairs WR_{10}-WR_{30} (p=0.03), WR_{10}-WR_{90} (p=0.01), WR_{30}-WR_{90} (p=0.02), and WR_{50}-WR_{90} (p=0.02) in YG, while only for pair WR_{10}-WR_{90} (p<0.01) in OG.

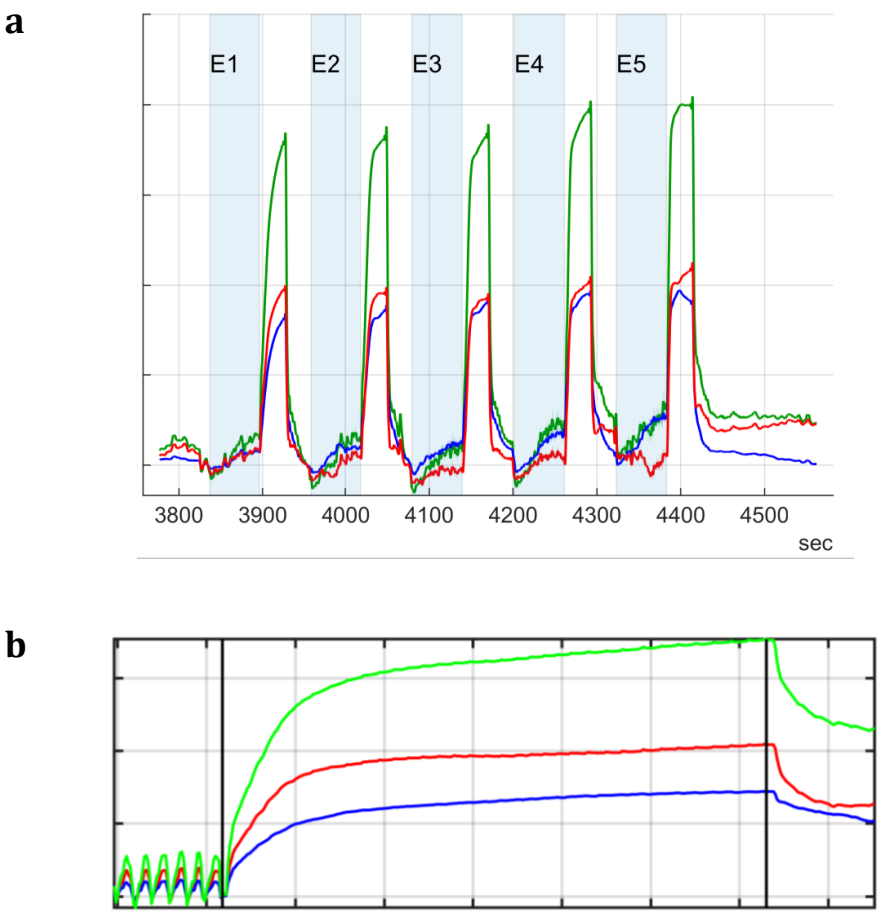


Figure 10. An example of NIRS recording with concentration changes shown by lines: green, tHb; red, O_2Hb; and blue, HHb. Panel a: the dynamic handgrip exercise test with five WRs (showed by E1-5). Panel b: a venous occlusion period.

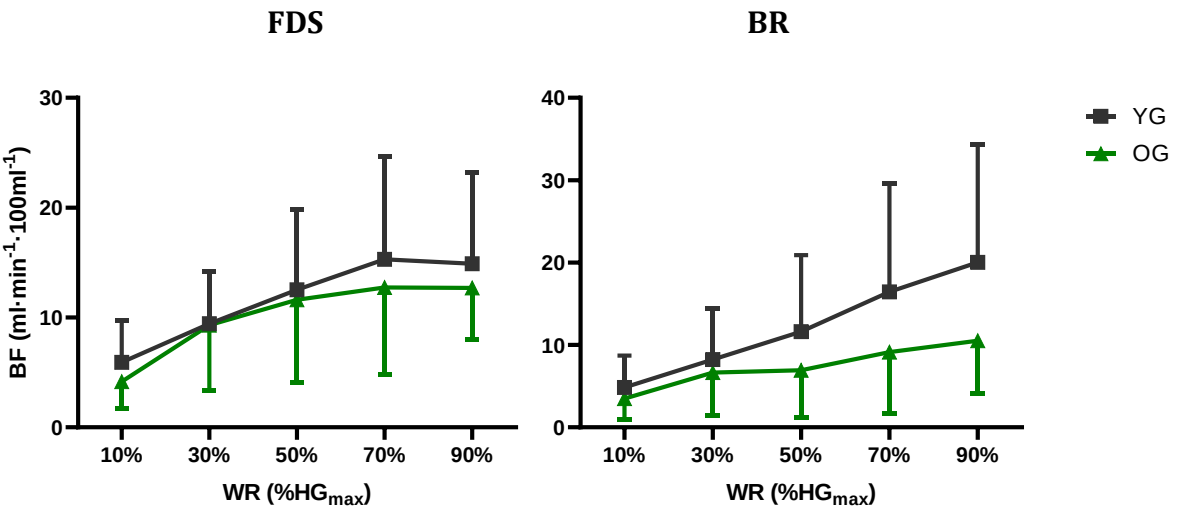


Figure 11. Blood flow over five exercise work rates.

$m\dot{V}O_2$

A 2-way mixed ANOVA using Greenhouse-Geisser correction revealed a main effect of WR on $m\dot{V}O_2$ for FDS (ε=0.55, F(2.22,38.97)=7.58, p<0.01; figure 12) and BR (ε=0.39, F(1.57,31.59)=15.45, p<0.01; figure 12). However, there was no significant main effect of group or group-by-WR interaction effect for $m\dot{V}O_2$ result (p>0.05). Post-hoc analysis with Bonferroni adjustments showed no within-group pairwise significant difference in $FDS_{m\dot{V}O2}$ in YG and OG. The post-hoc analysis also demonstrated a significant difference in $BR_{m\dot{V}O2}$ between WR_{10}, WR_{30}, and WR_{50} with WR_{90} (p<0.05) for YG, while only for pair WR_{10}-WR_{90} (p<0.05) in OG.

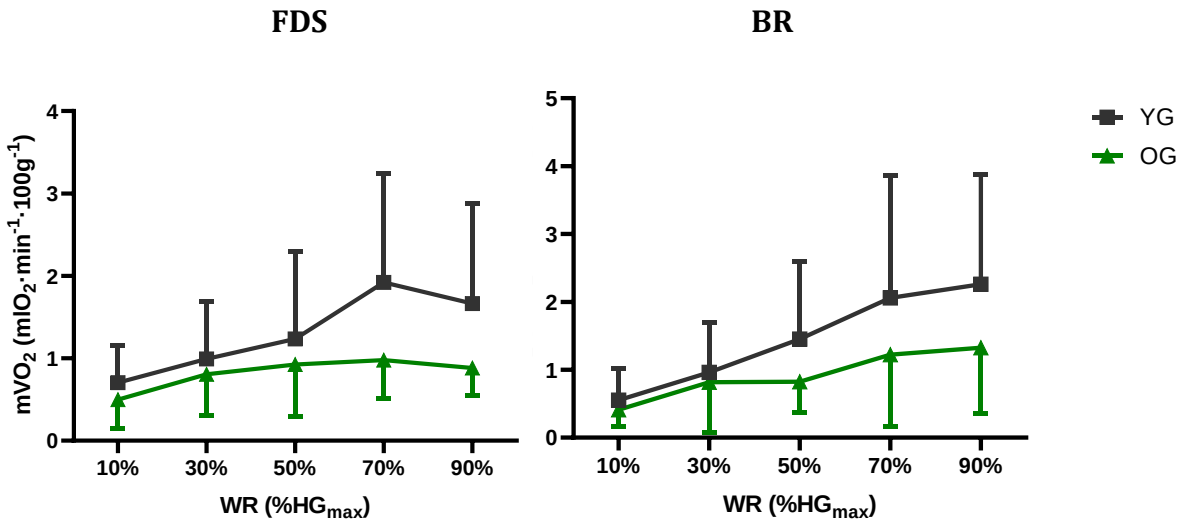


Figure 12. muscle oxygen consumption over five exercise work rates.

Association of NME with BF and $m\dot{V}O_2$

Pearson correlation coefficient analysis demonstrated non-significant associations (p<0.05) between NME and BF in FDS across WRs for both groups, but only one in OG. There was a significant positive correlation (r=0.74, p<0.01, figure 13) between FDS_{NME} and FDS_{BF} in OG at WR_{10}. Regarding BR, results showed only one significant correlation across WRs. At WR_{30}, BR_{NME} was significantly and negatively correlated (r=-0.7, p=0.01, figure 14) with BR_{BF} in OG. Pearson correlation coefficient analysis also revealed a significant negative association (r=-0.71, p=0.03, figure 15) between FDS_{NME} and $FDS_{m\dot{V}O2}$ in WR_{70} for YG. All other associations between NME and $m\dot{V}O_2$ for two muscles across WRs were non-significant (p>0.05) for both groups.

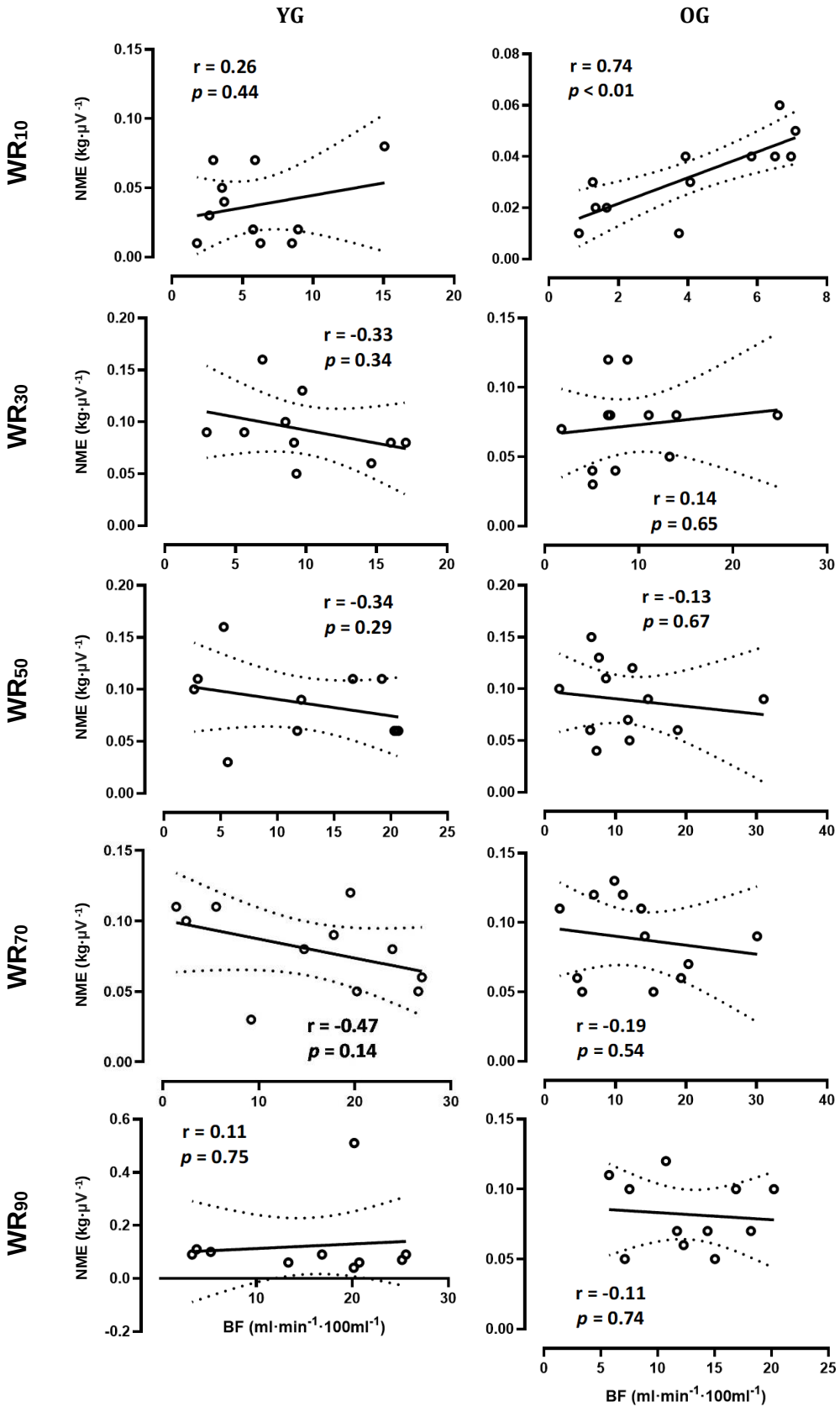


Figure 13. Association of neuromuscular efficiency and blood flow for flexor digitorum superficialis.

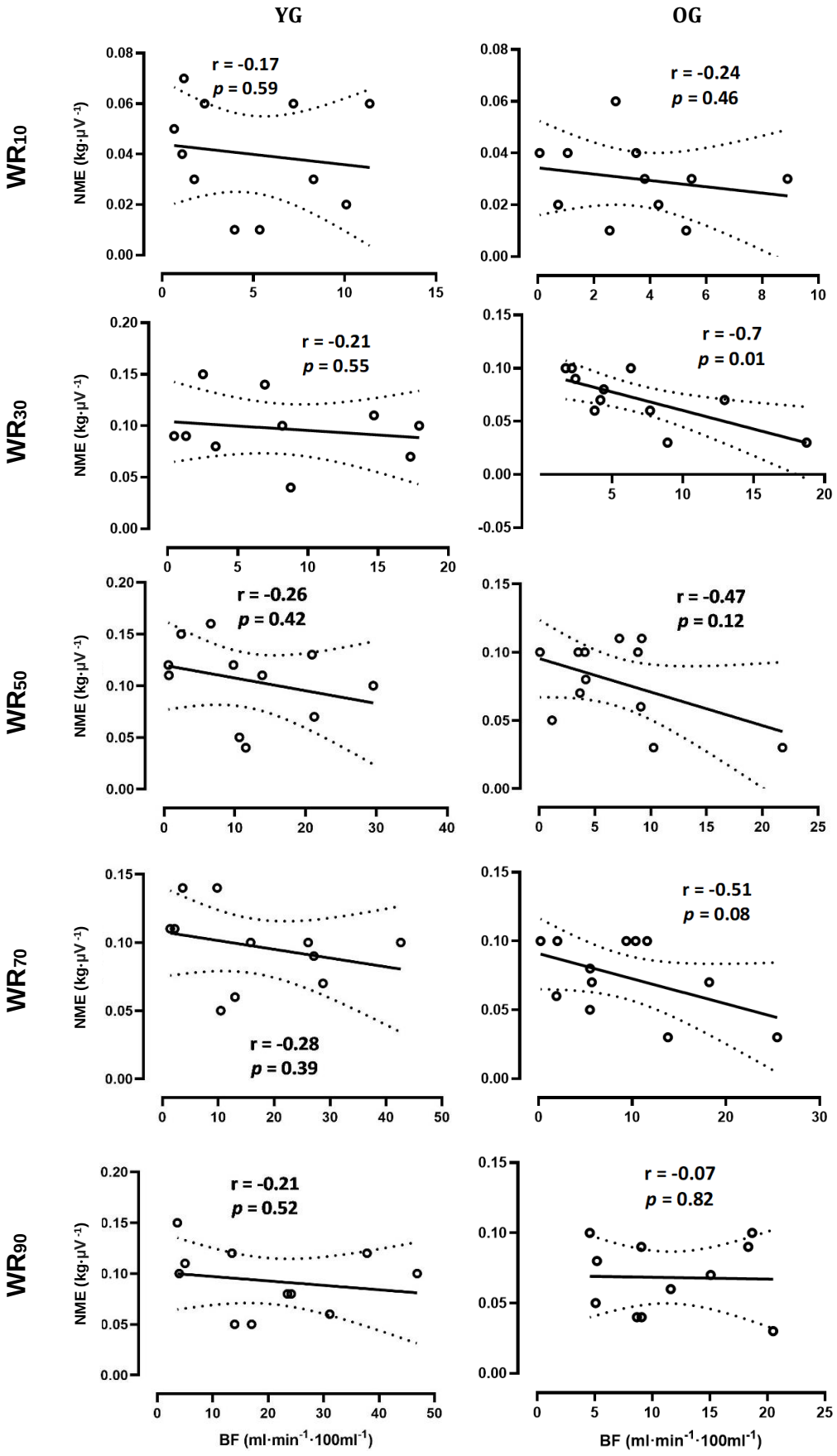


Figure 14. Association of neuromuscular efficiency and blood flow for brachioradialis.

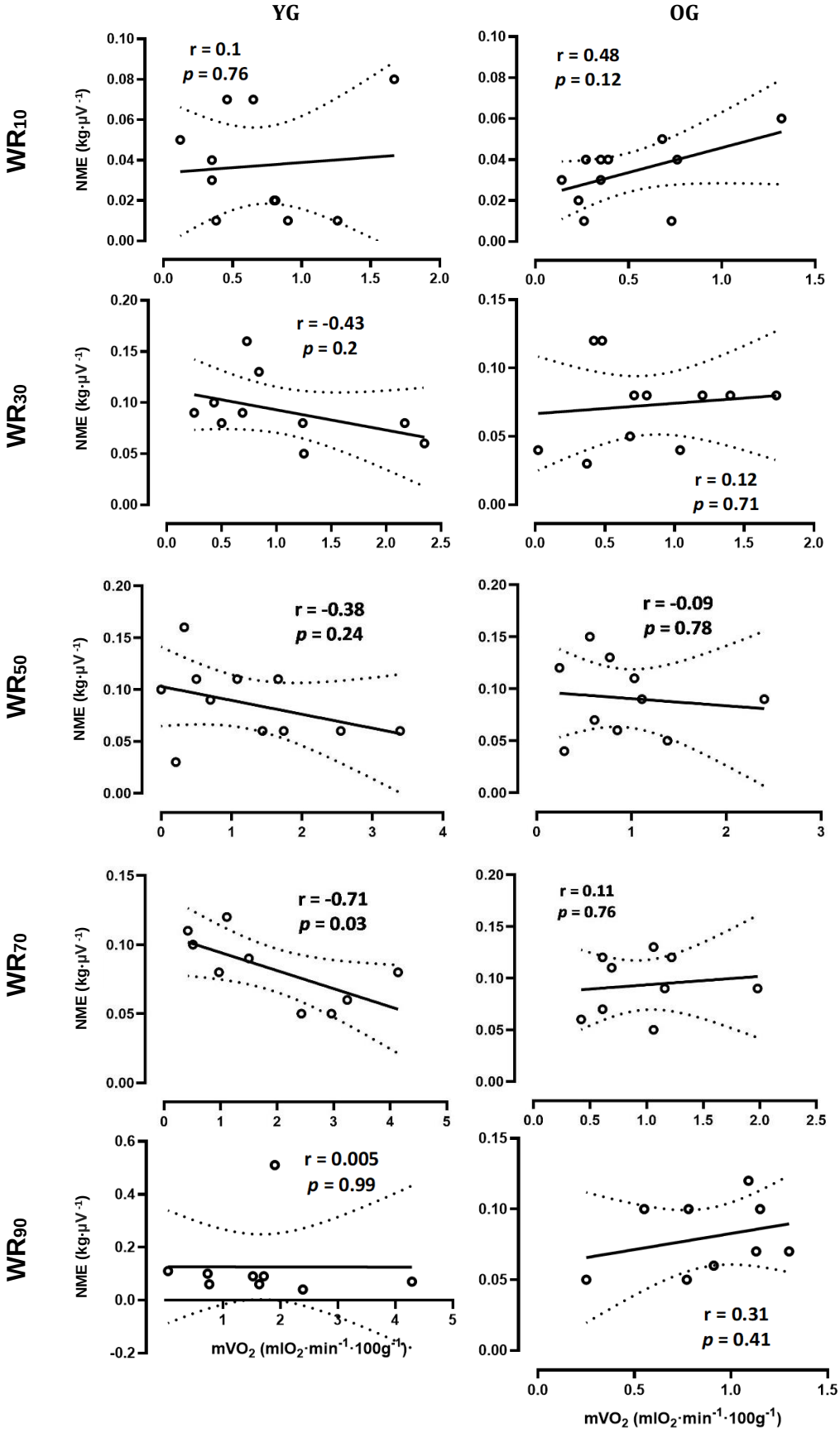


Figure 15. Association of neuromuscular efficiency and oxygen consumption for flexor digitorum superficialis.

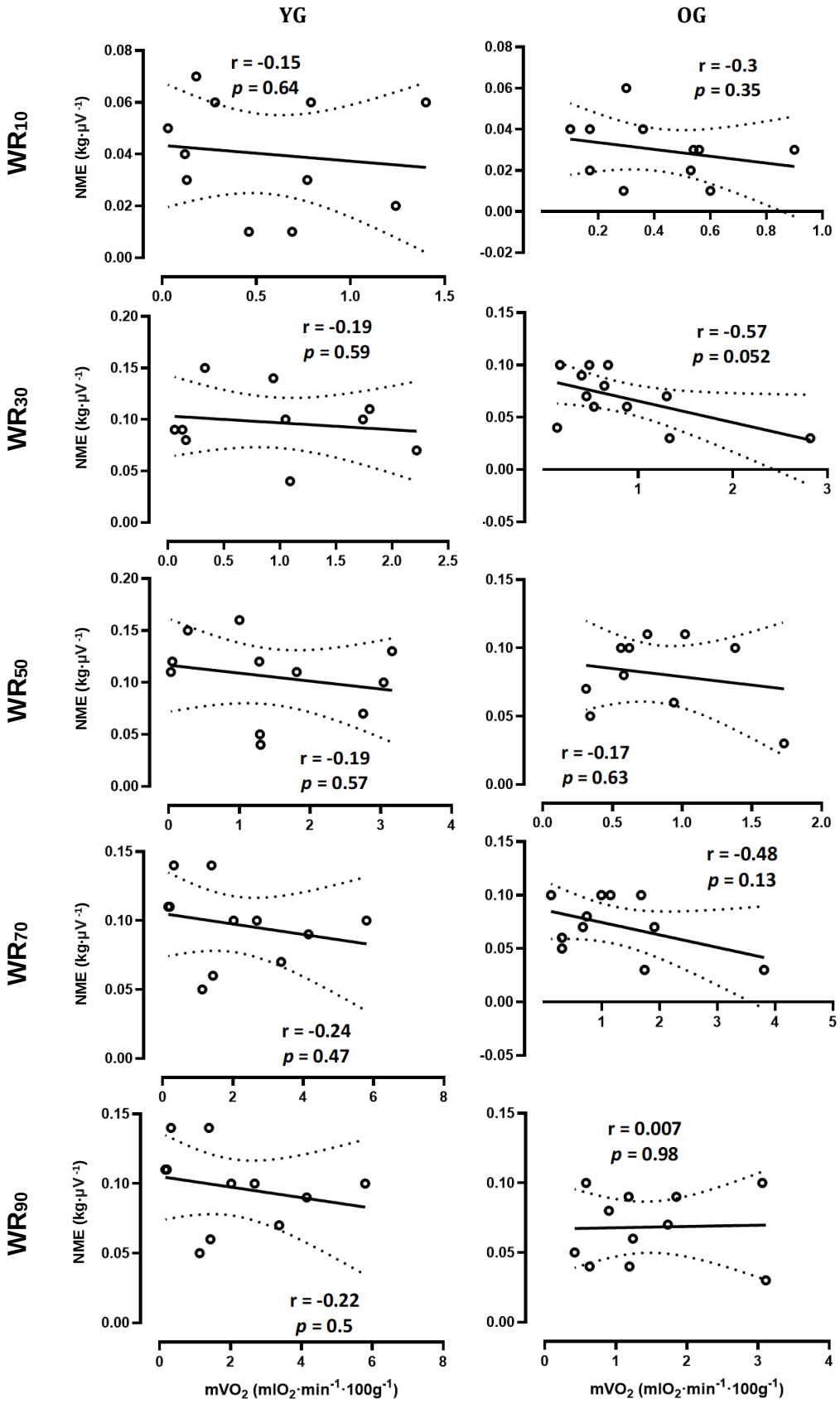


Figure 16. Association of neuromuscular efficiency and oxygen consumption for brachioradialis.

Discussion

To our knowledge, this is a pioneering study investigating the age-related differences in NME in relation to muscle BF and $\dot{V}O_2$. Although the results will be pointed out from a statistical point of view (considering significance), it is worth discussing dissimilarities and different trends, especially when comparing two groups. This idea would provide a better insight into the age-related effects. The main findings of the present study demonstrated that there were no group differences in resting BF and $m\dot{V}O_2$, and exercise force, EMG_{RMS}, and $m\dot{V}O_2$ across different WRs. However, some between-group differences were seen in NME_{BR} and BF_{BR}, which will be discussed later in this section. Besides, most variables exhibited changes in their levels across different intensities of exercise, having a trend of increase over higher WRs even though the rates of increase have not been identical between muscles and among variables of interest and exercise WRs. Furthermore, there were poor associations between NME with BF and $m\dot{V}O_2$ for two muscles, two groups, and five WRs, with no clear direction for correlations.

We would argue that our results may have been affected, at least partly, by the high physical activity and physical fitness level of participants, abrogating the possible aging effects on skeletal muscle physiology and function. Based on the self-reported PA, all the participants in OG were involved in moderate-to-vigorous PA, all having aerobic exercise, and eight out of 12 had strength training. Eight out of 12 reported +3 sessions of 60 minutes and more, four being physically active almost daily. This amount exceeds the minimum physical activity requirement recommended by leading organizations. Older participants also demonstrated an above-than-average $\dot{V}O_{2max}$ (41.84 $mlO_2 \cdot kg^{-1} \cdot min^{-1}$) compared to the healthy population of their age category (Norwegian healthy older adults; 39.2 and 35.3 $mlO_2 \cdot kg^{-1} \cdot min^{-1}$ for 60–69 and +70 years age categories, respectively (28)). Besides, the mean HG_{max} was comparable between YG and OG (12.97 vs. 12.33 kg). Therefore, it is plausible that OG's high physical fitness attenuated possible age-related declines in forearm musculature to some degrees.

Muscle BF and $\dot{V}O_2$ during rest and exercise

The results of the present study demonstrated that resting BF in FDS and BR did not significantly differ between YG and OG (figure 5), which is in line with our hypothesis. In resting conditions, 25% of cardiac output is directed to skeletal muscle. A 26% lower

resting BF has been reported in the supine leg position, and this attenuated BF has been attributed to 45% higher vascular resistance (29). Resting muscle BF relies on metabolic rate and $\dot{V}O_2$ which is per se dictated by muscle mass. Therefore, it is conceavable that reduced BF with age is partly due to lower muscle mass. However, even when expressed in relative values (adjusted for muscle mass), old age is accompanied by diminished supine leg BF (29). In contrast, these age-related differences in resting BF might not be present in an upright seated position (30, 31).

On the other hand, an age-associated decline in resting forearm BF has not been evidenced (22, 32, 33). in the study "Regular Aerobic Exercise Prevents and Restores Age-Related Declines in Endothelium-Dependent Vasodilation in Healthy Men" by DeSouza et al. (32), there was no significant difference between sedentary young and older groups (3.7±0.3 and 3.7±0.2 mL per 100 mL tissue per minute, respectively) in forearm BF. This lack of age-related difference was also the case between young and older endurance-trained groups. However, the older endurance-trained group exhibited higher, although non-significantly different, values in forearm BF at rest compared to their younger peers, which contradicts our results on recreationally active participants. In summary, they found no significant differences among four groups (sedentary old, sedentary young, endurance-trained old, and endurance-trained young) in resting mean arterial pressure, forearm BF, and forearm vascular conductance. Also, Jasperse et al. (22) demonstrated a comparable resting forearm BF between healthy young and older groups.

In the present study, there were comparable resting $m\dot{V}O_2$ values between YG and OG, with slightly higher values for YG for both muscles (figure 5). These results are consistent with previous findings by van Beekvelt et al. (27). They found no significant difference between young and older in resting $m\dot{V}O_2$ for forearm or leg. Even when comparing healthy young adults with older coronary heart disease patients (34), the results appear to be the same. Therefore, aging seems to significantly restrain neither resting BF nor $m\dot{V}O_2$. This lack of significant age-related effect on $m\dot{V}O_2$ was also seen in exercise bouts (figure 12). We found a non-significant main effect of group or group-by-WR interaction effect for both muscles investigated, contradicting our hypotheses on effect of aging on $m\dot{V}O_2$ in dynamic contractions. Nevertheless, albeit not significantly, YG demonstrated a greater O_2 consumption in both muscles which was more pronounced in WRs higher than 30%.

In line with the significant main effect of WR on $m\dot{V}O_2$, YG showed a generally linear increase in $m\dot{V}O_2$ across higher WRs (except for WR_{50} to WR_{70} in BR). It elevated from WR_{10} to WR_{90} by 237% and 483% for FDS and BR, respectively. The trend of increase for OG, however, was smoother by 179% and 325%. Both groups showed a minor decrease in $m\dot{V}O_2$ for FDS from WR_{70} to WR_{90}, while it continued to increase in BR. Similar trends were observed for BF (figure 11). Heightened BF values were seen in higher intensities in FDS and BR for YG (252% and 420%) and OG (309% and 300%), with a slight depression in values from WR_{70} to WR_{90} in FDS. Overall, these findings point to a possible shift of metabolic demands towards BR in higher exercise intensities. Besides, although YG showed higher values in all exercise WRs than OG, their older peers exhibited greater relative elevation in BF transitioning from the starting WR to the latest. No significant main effect of group on BF was found for both muscles, yet there was a significant group-by-WR interaction effect for BR. That means there was a difference in between-group differences in different WRs. More specifically, the mean differences between the two groups increased as the intensity of exercise elevated, with values of 1.34, 1.57, 4.5, 7.31, and 9.53 $ml \cdot min^{-1} \cdot 100ml^{-1}$ for WRs 1 to 5, respectively. These trends clearly show that higher WRs had further BF consequences for OG.

Some previous investigations aiming to explore the age-related effects on muscle BF and $\dot{V}O_2$ reported relatively similar results. Jasperse et al. (22) evaluated forearm BF in 11 young (19-29 years) and 11 older (60-74 years) adults with the same level of regular physical activity and forearm size in two dynamic HG exercise bouts: the brief (1 min) incremental loads until exhaustion; and the sustained (8 min) submaximal loads. Forearm BF was measured for a brief period during the relaxation phase after each exercise bout. Authors reported similar submaximal and peak forearm BF for young and older groups during 1-min incremental and 8-min sustained exercise bouts, with relatively greater values favoring the older group at higher WRs of sustained exercise. Van Beekvelt et al. (27) examined skeletal muscle oxidative function of 19 young and 12 older adults (mean age of 26.2 and 62.4 years, respectively) during whole-body exercise and isolated muscle work. They found no significant difference between young and older groups for end-exercise $m\dot{V}O_2$ and SmO_2 (muscle oxygen saturation) in forearm or leg muscles. However, SmO_2 responses were more pronounced for the young group during both exercises.

Kutsuzawa et al. (35) demonstrated that forearm muscle energy metabolism (measured by intracellular pH, phosphocreatine, and recovery of phosphocreatine) was not affected by aging. However, the older group's recovery rates of oxy- and deoxyhemoglobin during the initial 10s of recovery were significantly slower. The authors concluded that slower recovery rates of O_2Hb and HHb in the older group suggest an impaired O_2 supply probably due to attenuated peripheral circulation with aging. Moreover, the study by Donato et al. (20) showed limb-specific attenuation in skeletal muscle BF with aging. The authors reported that aging can result in reduced leg BF during exercise but may not influence forearm BF. Nevertheless, they noticed a more pronounced consequence for the older group's forearm blood flow at the highest relative exercise WR (60%).

The heterogeneity of findings on age-related effects on forearm musculature BF and oxygenation makes it challenging to conclude. However, we can argue that, although the general conclusion would be that forearm muscle blood flow and $\dot{V}O_2$ appear to be relatively preserved with age, there are still some differences between young and older adults. In most cases, better muscle function was seen among younger participants (27, 35). Yet, it was not the case in all the investigations, and, of course, on a few occasions, greater values have been seen among older individuals (22). These variable results between studies would reflect diversity in blood flow measurement techniques, exercise modalities and protocols, age range and gender composition, and physical fitness level. Overall, it is well documented that forearm muscle BF and $\dot{V}O_2$ continue to increase across higher exercise WRs, whose trends might not necessarily be identical among young and older individuals.

Blood flow regulation is managed by a series of central and peripheral mechanisms. Increased metabolic rate and oxygen consumption of active muscles during exercise challenge these systems (36, 37). Systemic control of vascular resistance by hormonal and neural factors results in a tight regulation of mean arterial pressure even as cardiac output increases dramatically (38, 39). The peripheral feedback plays an imperative role in adjusting relative blood flow distribution during exercise so that additional blood is directed to the working muscles. Vasodilation and vasoconstriction in each vascular bed are controlled by local mechanisms, including metabolic, endothelium-mediated, and myogenic responses, thereby delivering oxygen to tissues that require it

most (38, 40). At the onset of exercise, rapid vasodilation may also contribute to increased blood flow. Exercise-induced vasodilation within the first two to three seconds of exercise has been proven by several studies (41). There is also a second phase of increased BF following the onset of exercise, starting within 10-20 seconds into exercise and attempting to provide oxygen delivery to the working muscles at a level that matches the metabolic demands (42).

In addition to vasodilation, blood flow to capillaries of the contracting muscles is also redistributed following the onset of exercise through sympathetic vasoconstriction and functional sympatholysis (38, 43). During muscle contractions, blood flow can be impeded by the contraction of the surrounding musculature. Thus, perfusion depends on the magnitude of impairment during contraction and flow during relaxation (44). During dynamic handgrip exercise, blood flow to active muscles is lowest during contractions and peaks immediately after contractions (22). Therefore, our flows, measured as end-exercise values, probably represent the highest levels achieved in each minute of exercise. Blood flow is believed to be sufficient to sustain light to moderate intensity contractions, and however, it has been shown to be limited during heavy intensity contractions (45).

Furthermore, it has been shown that the amount of blood flowing through muscles varies depending on, among other influences, the amount of external work performed, muscle contraction frequency and duty cycle, and metabolic rate. We employed a contraction frequency of 60 per minute and a duty cycle of 1:1. At this frequency and duty cycle of dynamic HG exercise, higher WRs were substantially more challenging for the OG than YG to supply working muscles with higher BF and to extract more O_2, albeit not significantly different between two groups. Insufficient BF and O_2 delivery to the contracting muscles may lead to diminished peak performance and exercise tolerance and is correlated with having more difficulties executing activities of daily living, which is crucial for independent daily living among the older population (46). Therefore, our findings can have significant implications regarding plausible limitations older people may face during dynamic activities resembling daily activities.

A strength of the present study is the ability to elaborate on BF redistribution within forearm musculature, while most previous studies failed to do so. Doppler ultrasound and strain gauge plethysmography cannot provide information on the spatial distribution of blood flow within the active forearm musculature, while NIRS enabled us

to elaborate on between-muscle differences in the forearm. A positron emission tomography study (47) revealed that physically active older adults demonstrated more homogeneous BF patterns within working muscles than their younger peers during isometric knee extension exercise. These results suggest an impaired ability to redistribute blood flow effectively within the exercising muscle (48), which is consistent with the present study's findings. As discussed earlier in this section, YG showed a more remarkable change in BF and $m\dot{V}O_2$ and a possible redistribution of O_2 in the highest WR utilized in this study, possibly suggesting a more heterogeneous BF and a better dynamicity of blood distribution within forearm muscles.

NME

Since two groups demonstrated a relatively similar FDS_{NME} in HG exercise, it is speculated to be preserved with aging. Nevertheless, a borderline significant main effect of the group ($p=0.05$) was observed for BR_{NME}. Here it is worth discussing shortly around "borderline significant effect". Statistical significance is determined by a p-value, which is an arbitrarily assigned number that by convention should be 0.05. This means that by chance and by chance alone, the probability of observing an effect as large as that observed in the study population is less than 5% under the null hypothesis of no association. That is, the outcome is unlikely to be explained by chance. In this context, authors consider p values less (and sometimes equal and/or less) than 0.05 as statistically significant and reject the null hypothesis of no effect or association, and in cases greater than 0.05, they accept the null hypothesis. However, along with the recent developments in biostatistics, terms such as "borderline significance" have been increasingly used for p values slightly bigger than or equal to 0.05. These values likely indicate effects or associations, but they were not statistically significant because the study lacked sufficient power and this can be, among other reasons, due to inadequate sample size (49).

Accordingly, relying solely on this conventional cut-off p-value to conclude that an effect or association is not statistically significant might be misleading. It should not be a rule of thumb for concluding but rather a guide to further action. Furthermore, a p-value close to the cut-off p-value of 0.05 with a wide 95% confidence interval (CI) suggests that the data are compatible with an actual effect, but statistical power is not large enough

(possibly because of insufficient sample size) to exclude the chance as an explanation for the observed effect (49). Thus, based on a borderline significant main effect (p=0.05) of group on BR_{NME} with a 95% CI of <-0.01 to 0.04 (actual values: -0.0007 to 0.0431) for mean differences, it can be concluded that NME in BR was substantially different between two groups. Accordingly, even when examining recreationally highly active individuals, BR_{NME} may be attenuated with age.

With age, a series of changes occur in the neuromuscular system that can result in losses in force generation during prolonged contractile activities, ultimately leading to declines in physical function among the older population. First, declined muscle mass with age is associated with diminished muscular strength and force-generating capacity (50). However, the rate of decline in muscle mass can be muscle specific. One study demonstrated a lack of age-related difference in total cross-sectional area and a 12% lower lean muscle area of tibialis anterior in the older group (51). Another investigation showed no significant change in muscle size of the dorsiflexors in 20-year-old, 60-year-old, or 80-year-old men (52). On the contrary, some other muscle groups have shown a more profound decline. A 25-28% decrease in knee extensors mass has been demonstrated with age (53-55). Klein et al. (56) observed a greater decline in elbow extensor muscle cross-sectional area than elbow flexor with age. This muscle specificity in decline with age has been suggested to be associated with the age-related alterations in the pattern of use of muscles (56).

On the other hand, the variability in decline among different muscle groups might be due to selective atrophy of type II muscle fibers with age (1). As the fiber composition vary among different muscle groups, selective atrophy can affect the size of some muscle groups more than others. Regardless of muscle group specificity, type II muscle fibers are thought to be re-innervated by slow motor unit axons and thus actually transform to type I fibers, causing slower contractile properties (57). Theoretically, this slowing of contractile properties is believed to have an advantage for NME. A leftward shift in force-frequency relationships may lead to an increased NME (8) or a decrease in the central motor drive (10) necessary to produce a required amount of voluntary force. This was contradicted by a study by Ng et al. (58), showing a lower ratio of voluntary force production per unit surface EMG in dorsiflexors among the older group. Our findings on an age-related down-regulation of NME in BR align with Ng et al.'s results (58).

In the present investigation, there was a substantial main effect of group on NME only in BR. The trends in FDS were ambiguous, which might be partly due to anatomical and functional differences between the two muscles. For instance, the EMG-force relationship is suggested to reflect the fiber type composition and motor unit recruitment strategies of different muscles (59). FDS comprises around 60% (60) of type I muscle fibers, whereas the proportion is 40% for BR (61). There are some differences in size and twitch properties of type I and II motor units that would have an impact on EMG-force relationships (62). Further, a more pronounced age-related loss of muscle motor units may be seen in muscles with higher proportions of type II motor units.

Interestingly, the slope of the EMG-force relation was shown to increase with fewer motor units (62). However, the EMG-force association appears to be influenced by factors other than solely explained by the number of motor units and their twitch properties. These factors include, among other things, muscle BF and oxygenation, whose association with NME will be discussed in the following subsection. Lastly, it is vital to acknowledge our participants' PA level's effect on NME. A study by Seghers et al. (63) explained that NME was most remarkable for the older group with the highest PA level compared to their peers with less PA. Thus, we speculate that at least part of the assumed age-related declines in NME would have been blunted by the effect of PA/exercise among our OG.

Association of NME with BF and $m\dot{V}O_2$

Out of 40 associations tested between NME with BF and $m\dot{V}O_2$ (two groups × two muscles × two factors (BF and $m\dot{V}O_2$) × five WRs) in the present study, only three (7.5%) of them were found to be significant. A significant positive correlation ($r=0.74$, $p<0.01$) between NME_{FDS} and BF_{FDS} was observed for OG at WR_{10}. Besides, NME_{BR} and BF_{BR} at WR_{30} were significantly and negatively correlated ($r=-0.7$, $p=0.01$) for OG. A significant negative association ($r=-0.71$, $p=0.03$) was observed between NME_{FDS} and $m\dot{V}O_{2FDS}$ at WR_{70} for YG. Our results mainly show the dissociation of NME with BF and $m\dot{V}O_2$ in both muscle and both groups with no clear direction. Therefore, according to our findings, NME in the forearm does not appear to be influenced by O_2 supply and extraction in young and old individuals. On the contrary, some previous studies have shown that muscle force production and force at a given EMG activity level depend on muscle perfusion pressure

and O_2 delivery (64-67). However, it is noteworthy that two of them investigated leg musculature (65, 67), and two available studies on forearm and hand have used restricted BF (64, 66) (one used arm elevation (64) and one implemented BF compromise (66)), and none of them explored older population.

Hobbs and McCloskey (65) reported that when the lower extremity rises above the heart level, EMG activity of ankle extensors during constant-force contractions increases. The authors concluded that there is a downregulation of force at a given EMG activity with muscle perfusion pressure, thus necessitating augmentation of muscle activity to sustain the standard contractions. The same results were seen by Fitzpatrick et al. (64) on a hand muscle, adductor pollicis. When the hand was lifted 45 cm above the heart, force output from the muscle within several seconds declined and remained 22% below the steady-state level after 4 minutes. Interestingly, lowering the hand 45 cm below heart level caused an 8% improvement in force output. Authors also reported that the most pronounced alterations in force output were observed at higher intensities.

Drouin et al. (66) tested the hypothesis that muscle force is downregulated for a given EMG level when O_2 delivery is reduced in the forearm. They examined eight young men and eight young women through bouts of 5-min non-fatiguing steady state rhythmic handgrip exercise followed by periods of 2-min brachial artery compression to reduce forearm BF by ~50% of steady state. Their outcomes revealed that when forearm BF was compromised, EMG/force of FDS increased. Therefore, these results expand upon the relative importance of O_2 delivery and muscle perfusion pressure in regulating force production at a given EMG activity.

The discrepancy between the present study's outcomes and those revealed by preceding research could be explained by some methodological dissimilarities. The preceding studies on forearm and hand musculature used changes in muscle perfusion pressure and BF through elevation of limb and BF compromise, while we kept the limb at the heart level and did not apply any BF compromise. Thus, it can be speculated that in the absence of any reduced O_2 delivery to the active musculature, muscle BF and oxygenation might be enough to meet the metabolic demands of dynamic contractions in forearm muscles across different submaximal WRs. This was the case both for YG and OG. Moreover, Fitzpatrick et al. (64) used involuntary contractions made by electrical stimulation while we implemented voluntary contractions. Lastly, Drouin et al. (66)

utilized 5-min exercise bouts which were far longer than what we implemented in each WR and may have caused different metabolic demands than ours.

Although we saw lower values in NME_{BR} and BF_{BR} among older participants compared to their younger counterparts, we found a poor association between NME and BF in this muscle. Even though we collected EMG data as closely as NIRS measurements, they might not necessarily represent the same muscle compartments. That means the recorded BF and $m\dot{V}O_2$ might be from the part of musculature that has been more or less active than the part we collected EMG data. According to the unique architectural properties of the vascular network and the dispersed nature of motor units, at submaximal contractions where not all the muscle fibers are activated, BF can be more than what is necessary, resulting in an overperfusion of inactive muscle fibers (68). As a result, for instance, if these inactive muscle fibers were at the site of NIRS measurements, the results could be misleading. This could lead to a mismatch of O_2 delivery and extraction and an unreal association between these parameters and EMG activity. Nevertheless, we can not say for sure that this was or was not the case in our experiment.

Conclusion

We sought to elucidate the age-related differences in NME, measured by the ratio of force production to the level of EMG activity, BF and $m\dot{V}O_2$ in forearm musculature. We also tried to explore the association of NME with BF and $m\dot{V}O_2$ with a particular focus on the older group. Findings on our participants showed that despite that there were some minimal differences, NME, BF and $m\dot{V}O_2$ over different submaximal WRs of dynamic exercise of forearm muscles are relatively preserved with age. However, there seem to be potential differences in the rate of muscle aging within forearm musculature since we saw substantial differences between the two groups in BR, especially for NME and muscle BF. Most daily living activities are dynamic and occur at different submaximal intensities. Therefore these results can have significant implications as a measure of the neuromuscular effort and metabolic demands older adults require to perform activities related to physical function.

On the other hand, we observed a poor association between NME with BF and $m\dot{V}O_2$, suggesting that muscle O_2 delivery and extraction would be enough in young and older individuals across different WRs of dynamic handgrip exercise of short duration.

Nevertheless, we can draw these conclusions only on recreationally highly active individuals, as we recruited in the present study. We are unaware of these associations among the sedentary older population. Besides, we believe that at least some non-significant age-related differences would have reached the statistical cut-off if we could recruit a larger number of participants. Poor statistical power may have blunted some aging effects and associations in the present study. Hence, further studies in this area are warranted to draw solid conclusions. More extensive studies on inactive or minimally active individuals are recommended to be conducted to give a further and clearer vision of the "normal aging" process. Furthermore, investigating the population of late old age is essential since most physiological function declines later than in early old age.

References

1. Evans WJ, Lexell J. Human aging, muscle mass, and fiber type composition. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 1995;50(Special_Issue):11-6.
2. Fukagawa NK, Wolfson L, Judge J, Whipple R, King M. Strength is a major factor in balance, gait, and the occurrence of falls. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 1995;50(Special_Issue):64-7.
3. Davies C, White M. Contractile properties of elderly human triceps surae. Gerontology. 1983;29(1):19-25.
4. Cupido CM, Hicks AL, Martin J. Neuromuscular fatigue during repetitive stimulation in elderly and young adults. European journal of applied physiology and occupational physiology. 1992;65(6):567-72.
5. Narici M, Bordini M, Cerretelli P. Effect of aging on human adductor pollicis muscle function. Journal of Applied Physiology. 1991;71(4):1277-81.
6. Kent-Braun JA, Ng AV, Doyle JW, Towse TF. Human skeletal muscle responses vary with age and gender during fatigue due to incremental isometric exercise. Journal of Applied Physiology. 2002;93(5):1813-23.
7. Lanza IR, Russ DW, Kent-Braun JA. Age-related enhancement of fatigue resistance is evident in men during both isometric and dynamic tasks. Journal of Applied Physiology. 2004;97(3):967-75.
8. Vandervoort AA, McComas AJ. Contractile changes in opposing muscles of the human ankle joint with aging. J Appl Physiol (1985). 1986;61(1):361-7.
9. Campbell MJ, McComas AJ, Petito F. Physiological changes in ageing muscles. J Neurol Neurosurg Psychiatry. 1973;36(2):174-82.
10. Doherty TJ, Vandervoort AA, Brown WF. Effects of ageing on the motor unit: a brief review. Can J Appl Physiol. 1993;18(4):331-58.

11. Ng AV, Kent-Braun JA. Slowed muscle contractile properties are not associated with a decreased EMG/force relationship in older humans. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences. 1999;54(10):B452-B8.

12. Wigmore DM, Damon BM, Pober DM, Kent-Braun JA. MRI measures of perfusion-related changes in human skeletal muscle during progressive contractions. Journal of Applied Physiology. 2004;97(6):2385-94.

13. Lanza IR, Larsen RG, Kent-Braun JA. Effects of old age on human skeletal muscle energetics during fatiguing contractions with and without blood flow. The Journal of physiology. 2007;583(3):1093-105.

14. Wright JR, McCloskey D, Fitzpatrick RC. Effects of muscle perfusion pressure on fatigue and systemic arterial pressure in human subjects. Journal of Applied Physiology. 1999;86(3):845-51.

15. Hart EC, Lopez MG, Casey DP. Altered microvascular control of exercising skeletal muscle blood flow: the unfortunate male? The Journal of physiology. 2010;588(Pt 20):3851.

16. Carlson RE, Kirby BS, Voyles WF, Dinenno FA. Evidence for impaired skeletal muscle contraction-induced rapid vasodilation in aging humans. American Journal of Physiology-Heart and Circulatory Physiology. 2008;294(4):H1963-H70.

17. Poole JG, Lawrenson L, Kim J, Brown C, Richardson RS. Vascular and metabolic response to cycle exercise in sedentary humans: effect of age. American Journal of Physiology-Heart and Circulatory Physiology. 2003;284(4):H1251-H9.

18. Proctor DN, Koch DW, Newcomer SC, Le KU, Leuenberger UA. Impaired leg vasodilation during dynamic exercise in healthy older women. Journal of applied physiology. 2003;95(5):1963-70.

19. Proctor DN, Parker BA. Vasodilation and vascular control in contracting muscle of the aging human. Microcirculation. 2006;13(4):315-27.

20. Donato AJ, Uberoi A, Wray DW, Nishiyama S, Lawrenson L, Richardson RS. Differential effects of aging on limb blood flow in humans. American Journal of Physiology-Heart and Circulatory Physiology. 2006;290(1):H272-H8.

21. Lawrenson L, Poole JG, Kim J, Brown C, Patel P, Richardson RS. Vascular and metabolic response to isolated small muscle mass exercise: effect of age. American Journal of Physiology-Heart and Circulatory Physiology. 2003;285(3):H1023-H31.

22. Jasperse JL, Seals DR, Callister R. Active forearm blood flow adjustments to handgrip exercise in young and older healthy men. The Journal of physiology. 1994;474(2):353-60.

23. Kirby BS, Voyles WF, Simpson CB, Carlson RE, Schrage WG, Dinenno FA. Ascorbic acid increases muscle blood flow during dynamic exercise in older healthy humans. Wiley Online Library; 2008.

24. Ferrari M, Quaresima V. A brief review on the history of human functional near-infrared spectroscopy (fNIRS) development and fields of application. Neuroimage. 2012;63(2):921-35.

25. Piantadosi CA. Early development of near-infrared spectroscopy at Duke University. Journal of biomedical optics. 2007;12(6):062102.

26. Jones S, Chiesa ST, Chaturvedi N, Hughes AD. Recent developments in near-infrared spectroscopy (NIRS) for the assessment of local skeletal muscle microvascular function and capacity to utilise oxygen. Artery research. 2016;16:25-33.

27. van Beekvelt M, Bolme SB, Berg M. THE ROLE OF PHYSICAL FITNESS IN DETECTING AGE-RELATED DIFFERENCES IN SKELETAL MUSCLE OXIDATIVE FUNCTION DURING WHOLE-BODY AND ISOLATED MUSCLE WORK: 346. Medicine & Science in Sports & Exercise. 2021;53(8S):108.

28. Loe H, Rognmo Ø, Saltin B, Wisløff U. Aerobic capacity reference data in 3816 healthy men and women 20–90 years. PloS one. 2013;8(5):e64319.

29. Dinenno FA, Jones PP, Seals DR, Tanaka H. Limb blood flow and vascular conductance are reduced with age in healthy humans: relation to elevations in sympathetic nerve activity and declines in oxygen demand. Circulation. 1999;100(2):164-70.

30. Hunt BE, Farquhar WB, Taylor JA. Does reduced vascular stiffening fully explain preserved cardiovagal baroreflex function in older, physically active men? Circulation. 2001;103(20):2424-7.

31. Seals DR. Habitual exercise and the age-associated decline in large artery compliance. Exercise and sport sciences reviews. 2003;31(2):68-72.

32. DeSouza CA, Shapiro LF, Clevenger CM, Dinenno FA, Monahan KD, Tanaka H, et al. Regular aerobic exercise prevents and restores age-related declines in endothelium-dependent vasodilation in healthy men. Circulation. 2000;102(12):1351-7.

33. Taddei S, Galetta F, Virdis A, Ghiadoni L, Salvetti G, Franzoni F, et al. Physical activity prevents age-related impairment in nitric oxide availability in elderly athletes. Circulation. 2000;101(25):2896-901.

34. Gayda M, Gremeaux V, Drigny J, Juneau M, Nigam A. Muscle VO 2 and forearm blood flow repeatability during venous and arterial occlusions in healthy and coronary heart disease subjects. Clinical hemorheology and microcirculation. 2015;59(2):177-83.

35. Kutsuzawa T, Shioya S, Kurita D, Haida M, Yamabayashi H. Effects of age on muscle energy metabolism and oxygenation in the forearm muscles. Medicine and science in sports and exercise. 2001;33(6):901-6.

36. Busso T, Chatagnon M. Modelling of aerobic and anaerobic energy production in middle-distance running. European journal of applied physiology. 2006;97(6):745-54.

37. Schwarz M, Urhausen A, Schwarz L, Meyer T, Kindermann W. Cardiocirculatory and metabolic responses at different walking intensities. British journal of sports medicine. 2006;40(1):64-7.

38. Delp MD, Laughlin MH. Regulation of skeletal muscle perfusion during exercise. Acta Physiol Scand. 1998;162(3):411-9.

39. Fadel PJ. Arterial baroreflex control of the peripheral vasculature in humans: rest and exercise. Med Sci Sports Exerc. 2008;40(12):2055-62.

40. Saltin B, Radegran G, Koskolou MD, Roach RC. Skeletal muscle blood flow in humans and its regulation during exercise. Acta Physiol Scand. 1998;162(3):421-36.

41. Saunders NR, Tschakovsky ME. Evidence for a rapid vasodilatory contribution to immediate hyperemia in rest-to-mild and mild-to-moderate forearm exercise transitions in humans. J Appl Physiol (1985). 2004;97(3):1143-51.

42. Shoemaker JK, Hughson RL. Adaptation of blood flow during the rest to work transition in humans. Med Sci Sports Exerc. 1999;31(7):1019-26.

43. DeLorey DS, Wang SS, Shoemaker JK. Evidence for sympatholysis at the onset of forearm exercise. J Appl Physiol (1985). 2002;93(2):555-60.

44. Kagaya A, Ogita F. Blood flow during muscle contraction and relaxation in rhythmic exercise at different intensities. Ann Physiol Anthropol. 1992;11(3):251-6.

45. MacDonald MJ, Naylor HL, Tschakovsky ME, Hughson RL. Peripheral circulatory factors limit rate of increase in muscle O(2) uptake at onset of heavy exercise. J Appl Physiol (1985). 2001;90(1):83-9.

46. Hughson RL, Tschakovsky ME, Houston ME. Regulation of oxygen consumption at the onset of exercise. Exerc Sport Sci Rev. 2001;29(3):129-33.

47. Rudroff T, Weissman JA, Bucci M, Seppanen M, Kaskinoro K, Heinonen I, et al. Positron emission tomography detects greater blood flow and less blood flow heterogeneity in the exercising skeletal muscles of old compared with young men during fatiguing contractions. J Physiol. 2014;592(2):337-49.

48. Hearon CM, Jr., Dinenno FA. Regulation of skeletal muscle blood flow during exercise in ageing humans. J Physiol. 2016;594(8):2261-73.

49. Tshikuka JG MM, Molefi M, Masupe T, Matchaba-Hove RB, Mbongwe B, Tapera R. Addressing the Challenge of P-Value and Sample Size when the Significance is Borderline: The test of random duplication of participants as a new approach. International Journal of Statistics in Medical Research. 2016;5(3):214-8.

50. Lanza IR, Towse TF, Caldwell GE, Wigmore DM, Kent-Braun JA. Effects of age on human muscle torque, velocity, and power in two muscle groups. J Appl Physiol (1985). 2003;95(6):2361-9.

51. Kent-Braun JA, Ng AV, Young K. Skeletal muscle contractile and noncontractile components in young and older women and men. J Appl Physiol (1985). 2000;88(2):662-8.

52. McNeil CJ, Vandervoort AA, Rice CL. Peripheral impairments cause a progressive age-related loss of strength and velocity-dependent power in the dorsiflexors. J Appl Physiol (1985). 2007;102(5):1962-8.

53. Macaluso A, Nimmo MA, Foster JE, Cockburn M, McMillan NC, De Vito G. Contractile muscle volume and agonist-antagonist coactivation account for differences in torque between young and older women. Muscle Nerve. 2002;25(6):858-63.

54. Trappe TA, Lindquist DM, Carrithers JA. Muscle-specific atrophy of the quadriceps femoris with aging. J Appl Physiol (1985). 2001;90(6):2070-4.

55. Callahan DM, Kent-Braun JA. Effect of old age on human skeletal muscle force-velocity and fatigue properties. J Appl Physiol (1985). 2011;111(5):1345-52.

56. Klein CS, Rice CL, Marsh GD. Normalized force, activation, and coactivation in the arm muscles of young and old men. J Appl Physiol (1985). 2001;91(3):1341-9.

57. Roos MR, Rice CL, Vandervoort AA. Age-related changes in motor unit function. Muscle Nerve. 1997;20(6):679-90.

58. Ng AV, Kent-Braun JA. Slowed muscle contractile properties are not associated with a decreased EMG/force relationship in older humans. J Gerontol A Biol Sci Med Sci. 1999;54(10):B452-8.

59. Lawrence JH, De Luca CJ. Myoelectric signal versus force relationship in different human muscles. J Appl Physiol Respir Environ Exerc Physiol. 1983;54(6):1653-9.

60. Hwang K, Huan F, Kim DJ. Muscle fibre types of the lumbrical, interossei, flexor, and extensor muscles moving the index finger. J Plast Surg Hand Surg. 2013;47(4):268-72.

61. Johnson MA, Polgar J, Weightman D, Appleton D. Data on the distribution of fibre types in thirty-six human muscles. An autopsy study. J Neurol Sci. 1973;18(1):111-29.

62. Zhou P, Suresh NL, Rymer WZ. Model based sensitivity analysis of EMG-force relation with respect to motor unit properties: applications to muscle paresis in stroke. Ann Biomed Eng. 2007;35(9):1521-31.

63. Seghers J, Spaepen A, Delecluse C, Colman V. Habitual level of physical activity and muscle fatigue of the elbow flexor muscles in older men. Eur J Appl Physiol. 2003;89(5):427-34.

64. Fitzpatrick R, Taylor JL, McCloskey DI. Effects of arterial perfusion pressure on force production in working human hand muscles. J Physiol. 1996;495 (Pt 3):885-91.

65. Hobbs SF, McCloskey DI. Effects of blood pressure on force production in cat and human muscle. J Appl Physiol (1985). 1987;63(2):834-9.

66. Drouin PJ, Kohoko ZIN, Mew OK, Lynn MJT, Fenuta AM, Tschakovsky ME. Fatigue-independent alterations in muscle activation and effort perception during forearm exercise: role of local oxygen delivery. J Appl Physiol (1985). 2019;127(1):111-21.

67. Luu BL, Fitzpatrick RC. Blood pressure and the contractility of a human leg muscle. J Physiol. 2013;591(21):5401-12.

68. Murrant CL, Fletcher NM, Fitzpatrick EJH, Gee KS. Do skeletal muscle motor units and microvascular units align to help match blood flow to metabolic demand? Eur J Appl Physiol. 2021;121(5):1241-54.

Appendix 1: Consent Form (Norwegian)

INVITASJON TIL DELTAKELSE I FORSKNINGSPROSJEKT

Vi søker friske deltakere i alderen 18-40 år og 60-80år som er moderat aktive på fritiden.

BAKGRUNN OG HENSIKT

Forskningsstudiet undersøker muskelfunksjon i aldring.

Måling av hele kroppens oksygenforbruk under aktivitet kan gi verdifull informasjon om kroppens fysiske form, og er i tillegg et indirekte mål for muskulært oksygenforbruk. Å måle oksygenforbruket til hele kroppen er forholdsvis enkelt, men krever fysisk aktivitet på høy intensitet. Å måle oksygenforbruket i en enkelt muskel er mer komplisert og har først i de siste tiår blitt tilgjengelig med nær-infrarød spektroskopi (NIRS). Ved å bruke denne metoden kan vi måle oksygenforbruket i de enkelte aktive musklene, og vi kan undersøke energiomsetningen i muskelen uten at det krever fysisk aktivitet på høy intensitet. I dette forskningsprosjektet vil vi måle oksygenforbruket til enkelte muskler både under helkroppsarbeid (sykling) og under isolert muskelarbeid (håndgrep-øvelse) for å undersøke om lokale målinger kan brukes for å studere muskelfunksjon i aldring. I tillegg vil vi undersøke muskelaktivitet i de enkelte musklene ved hjelp av elektromyografi (EMG) som måler den elektriske aktiviteten i muskulaturen. Både NIRS og EMG måles ikke-invasivt ved hjelp av å plassere eletkroder og NIRS-enhetene direkte på huden.

Vi søker etter friske deltakere i alderen 18-40 år og 60-80 år som er moderat aktiv på fritiden (mosjonister). For å delta i prosjektet kan du ikke ha en historikk med hjerte-, lunge- eller karsykdommer. Deltakere kan ikke ha bevegelsesproblemer eller metabolske sykdommer som fedme (BMI=vekt(kg) / høyde(m)^2 over 30), diabetes, ukontrollert høyt blodtrykk, og heller ikke være nåværende røyker.

Studien gjøres i forbindelse med tre mastergradsoppgaver ved institutt for nevromedisin og bevegelsesvitenskap, NTNU.

HVA INNEBÆRER STUDIEN?

Prosjektet er delt opp i **tre** testdager, som vil foregå med noen dagers mellomrom for å sikre fullstendig restitusjon. Hvis du ønsker å delta i studien må du avstå fra annen trening de dagene målingene gjennomføres, samt i minst

48 timer før testing. Deltaker må i tillegg avstå fra å innta koffein og tobakk på testdagene, og unngå å konsumere alkohol 24 timer før testene.

Under de forskjellige testene samles det inn data om oksygenforbruk i hele kroppen, oksygenforbruk i muskulaturen, hjertefrekvens, hjertets minuttvolum, blodtrykk, muskelaktivitet og blodlaktat.

Det er anbefalt å ha på passende treningstøy bestående av en løstsittende t-skjorte og en tettsittende shorts for å forenkle plasseringen av måleinstrument på kroppen og siden dette gjør utførelsen av fysisk aktivtet mer behagelig.

Testdag 1 og 2 vil bli gjennomført i NTNU's lab på ved Nevro Øst på St.Olavs Hospital. BIA-analysen på testdag 3 gjennomføres på AHL-senteret på St.Olavs Hospital.

TESTDAG 1. På testdag 1 vil du bli stilt noen spørsmål om ditt aktivitetsnivå og nåværende helsestatus, før det gjennomføres noen enkle funksjonstester for balanse, ganghastighet og styrke.

Etter dette vil vi feste elektroder på halsen, brystet (midt på og på siden) og på ryggen din, samt EMG-elektroder og NIRS lysdioder på underarmen, låret og leggen. Dette utstyret må være på under resten av testene.

For å måle oksygenforbruket i lår- og underarmsmuskelen vil en mansjett rundt låret og armen pumpes opp en gang i henholdsvis 1 og 10 minutter som midlertidig klemmer av blodstrømmen (arteriell okklusjon). Denne målingen blir gjennomført i hvile i sittende posisjon, og det er viktig å sitte helt i ro for å kunne oppnå gode målinger.

Videre testes maksimal håndgrepsstyrke i et håndgrepsdynamometer. Etter dette gjennomføres også en håndgripetest med gradvis økende belastning for å estimere underarmsmuskulaturens maksimale evne til å ta opp oksygen under lokalt arbeid. Testdagen avsluttes med en sykkeltest med gradvis økende belastning for å estimere laktatterskel og kroppens maksimale evne til å ta opp oksygen. Sykkeltesten innebærer 5-6 målinger av blodlaktat som gjøres ved å hente en dråpe blod fra et stikk i fingeren. Disse testene krever maksimal innsats, og kan oppleves som krevende.

Det kan forventes å bruke omtrent 3 timer på å gjennomføre testene på dag 1.

TESTDAG 2. På starten av den andre testdagen vil det bli gjennomført en armløftprosedyre. Her vil du sitte stille uten å prate, hvor armen blir flyttet til 3 forskjellige posisjoner i to runder. Målinger av oksygenering vil bli tatt samtidig. Testdagen innebærer også to tester som innebærer fysisk aktivitet. Den første test er en submaksimal test som gjennomføres med et håndgrepergometer, hvor hver belastning er fulgt av enten en venøs okklusjon eller en arteriell okklusjon. Den andre testen gjennomføres på sykkelergometer, og er en submaksimal test på to belastninger, fulgt av noen minutter med kortvarige arterielle okklusjoner. Til slutt gjøres antropometriske målinger (omkrets og hudfoldtykkelse) på ulike punkter på kroppen som arm, lår, legg, rygg og hofte, og vi vil måle armvolum i en vannsylinder.

Det kan forventes å bruke omtrent 3 timer på å gjennomføre testene på dag 2.

TESTDAG 3. KROPPSANALYSE. Testen gjøres med en kroppsanalysemaskin (BIA), og vil foregå på morgenen (kl.06.30-09.00). For å få en gyldig test krever det at man faster fra kvelden før, og man må derfor møte opp på tom mage. En slik analyse gir et godt estimat av din kroppssammensetning som vekt, fettmasse og muskelmasse i de ulike kroppsdelene. Du vil få med deg dine resultater hjem når alle testdagene er gjennomført. *Det kan forventes å bruke 10 minutter på denne analysen. Husk å møt opp på tom mage*.

MULIG FORDELER OG ULEMPER

Denne studien samler inn normaldata som bidrar til nyttig kunnskap om forskjellene i oksygenforbruk under helkroppsarbeid og lokalt muskelarbeid, og kan gi oss kunnskap om mulige endringer i muskelfunksjon med aldring. Disse målingene kan ikke gi direkte informasjon om muskelfunksjonen og aldring hos den enkelte deltaker. Likevel kan vi tilby deg et oppsummerende skriv som inkluderer info om din kroppssammensetning (fett- og muskelmasse), kondisjon og styrkeresultater.

Maksimaltestene kan medføre noe ubehag, men de vil bli utført med kyndig personell til stede og etter etablerte prosedyrer. I tillegg kan mansjetten som brukes i studien oppleves som ubehagelig. Dette gjelder spesielt i starten av okklusjonen (avklemmingen), men ubehaget varer bare under selve testen og det medfører ingen skader. Utover dette vil ikke deltagelse i prosjektet medføre økt risiko eller ubehag utover det som vil oppleves i en normal treningssituasjon.

HVA SKJER MED TESTENE OG INFORMASJONEN OM DEG?

Testene du gjennomfører og informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. For å sikre din anonymitet i studien vil det tildeles et deltakernummer som knytter deg til dine opplysninger og resultatene gjennom en navneliste. Vi registrerer ingen direkte personidentifiserbare opplysninger og det vil ikke være mulig å spore deg i dataene som lagres underveis i studien, eller i resultatene av studien når disse publiseres.

FRIVILLIG DELTAKELSE

Det er frivillig å delta i studien. Du kan når som helst og uten å oppgi noen grunn trekke deg fra prosjektet. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side eller kontakt oss (masterstudenter) på Øystein Skar Rosvold (Qysteinskar@gmail.com | tlf. 46420876), Andrea Spirka (andrspi@stud.ntnu.no | tlf: 40081541) eller Mani Izadi (Manii@stud.ntnu.no tlf: 48636180). Om du nå sier ja til å delta, kan du senere trekke tilbake ditt samtykke. Dersom du senere ønsker å trekke deg eller har spørsmål til studien kan du kontakte oss (masterstudenter) eller prosjektleder Mireille van Beekvelt (mireille.van.beekvelt@ntnu.no | tlf. 73413283).

Prosjektet er godkjent av Regional komité for medisinsk og helsefaglig forskningsetikk, Midt-Norge.

SMITTEVERN (COVID-19)

Grunnet smittesituasjonen vil det bli gjennomført noen særegne tiltak for å minske smitterisikoen på testdagene:

- Ta en grundig håndvask med såpe og vann ved ankomst.

- Prøv å være i kontakt med færrest mulig flater ved ankomst.

- Prøve å holde seg til et så lite område på sykehuset som mulig.

- Garderobe og dusj kan dessverre ikke benyttes. Deltaker kan skifte i rommet det skal testes i, hvor personell kan forlate rommet om ønskelig.

- Hold deg hjemme om du er syk

Noen av testene som vil bli gjennomført vil være umulig å gjennomføre ved å holde 1 meter avstand. I disse tilfellene vil vi bruke munnbind og deltakeren vil få tilbud om munnbind om ønskelig. Ved testing av oksygenopptaket vil deltakeren ikke ha mulighet til å benytte munnbind.

Kapittel A- utdypende forklaring av hva studien innebærer

Bakgrunnsinformasjon om studien.

- Studien gjennomføres i forbindelse med et mastergradsprosjekt ved institutt for nevromedisin og bevegelsesvitenskap, NTNU.

Undersøkelser deltageren skal gjennomføre

- Som deltaker møter du opp tre ganger på St. Olavs Hospital.
- Testdag 1: Måling, registrering og testing av alder, vekt, høyde, balanse og ganghastighet, oksygenforbruk, hjertefrekvens, minuttvolum, blodlaktat og estimering av fettprosent. En okklusjonstest hvor blodstrømningen i en fot og en arm klemmes av. Videre gjennomføres måling av hjertefrekvens, minuttvolum, slagvolum, blodtrykk, muskelaktivitet og oksygenforbruk for hele kroppen, samt arm-, lår- og leggmuskulatur. En test av maksimal håndgrepsstyrke vil bli gjort, etterfulgt av en test for håndgrepsstyrke med gradvis økende belastning. Til slutt vil det bli gjennomført en maksimal sykkeltest, som inkluderer målinger av blodlaktat.
- Testdag 2: På starten av testdagen gjennomføres en armløftprosedyre hvor deltakeren sitter i ro, og armen manuelt blir flyttet. Videre utføres tre submaksimale tester (2 håndgrep aktivitet, 1 sykling). Venøs eller arterielt okklusjon påføres i sammenheng med 2 av testene. Måling av hjertefrekvens, minuttvolum, muskelaktivitet og oksygenforbruk for hele kroppen og i lår/arm-muskulatur.
- Testdag 3: Analyse av kroppssammensetning i en kroppsanalysemaskin.

Tidsskjema

- Testingen vil foregå i løpet av vinteren (hovedsakelig desember-januar) 2021-2022.

Mulige ubehag

- Mansjetten som blåses opp kan oppleves som ubehagelig og litt vond, men det er bare under avklemmingen.
- Det kan oppleves som ubehagelig når man presser mot utmattelse seg på de fysiske testene, på samme måte som under vanlig trening og konkurranse.

Kapittel B - Personvern, biobank, økonomi, forsikring

Personvern

Opplysninger som registreres om deg er kjønn, alder, høyde, vekt, omkrets på ulike steder, mål av hudfoldtykkelse på låret, oksygenforbruk i hele kroppen og i bein/arm-muskulatur, kroppssammensetning, muskelaktivitet, minuttvolum, blodlaktatnivå, blodtrykk, hjertefrekvens og slagvolum. All data samles inn og oppbevares avidentifisert. Bare prosjektmedarbeidere vil ha tilgang til data. NTNU ved dekanus på Det Medisinske Fakultetet (DMF) er databehandlingsansvarlig.

Rett til innsyn og sletting av opplysninger om deg og sletting av prøver

Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede prøver og opplysninger, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Forsikring

Forsøkspersonene i prosjektet er omfattet av pasientskadeloven.

Informasjon om utfallet av studien

Ved endt studie har alle deltakerne rett til å få informasjon på gruppenivå om utfallet/ resultatet av studien.

SAMTYKKE TIL DELTAKELSE I STUDIEN

Jeg bekrefter å ha mottatt muntlig eller skriftlig informasjon om studien.

Jeg samtykker til å delta i prosjektet og til at mine personopplysninger og mine data brukes slik det er beskrevet.

(Signert av prosjektdeltaker, dato)

Jeg bekrefter å ha gitt informasjon om studien

(Signert, rolle i studien, dato)

Appendix 2: Consent Form (English)

Invitation to participation in research project

We are looking for healthy participants between 18-40 years of age and 60-80 years of age, who are moderately physically active in their free time.

BACKGROUND AND PURPOSE

The research study investigates muscle function with aging.

Measurement of whole-body oxygen consumption during physical activity can provide valuable information about the body's physical fitness, as well as providing an indirect measurement of muscular oxygen consumption. To measure whole-body oxygen consumption is relatively simple but requires physical activity at high intensity. To measure local oxygen consumption in a single muscle is however more complicated and have just recently during the few decades been made available through near-infrared spectroscopy (NIRS). By utilizing this method we can measure oxygen consumption in specific active musculature, and in turn investigate energy transformation in the muscle. In this research project we will measure oxygen consumption in both specific muscles during isolated work (grip exercise) as well as for whole-body activity (cycling) to investigate if local measurements can be used to study the role of muscle function in aging. Additionally, we will investigate muscle activation in the specific muscles with the use of electromyography (EMG). Both NIRS and EMG is measured through electrodes placed on the skin.

We are looking for healthy participants within the age range of 18-40 and 60-80 years of age, who are moderately/recreationally active in their free time. To participate you cannot have any history with cardiovascular- or pulmonary disease. Participants cannot have problems with moving around, metabolic disease like obesity (BMI=weight(kg) / height(m) ^{2} over 30), diabetes, uncontrollably high blood pressure, nor being a current smoker.

The research project is done in relation to master's degree project of three students at the department of neuroscience and movement science at NTNU.

WHAT DOES THE RESEARCH PROJECT INCLUDE?

The project is split into 3 test days, that will take place with a few days of rest in between to ensure full recovery. If you wish to participate in the project you have to abstain from other exercise during these test days, as well as at least 48 hours before the testing starts. You also must abstain from consuming caffeine before the testing. During the different tests, data about full-body and local oxygen consumption, heartrate, cardiac output, muscle activity as well as blood lactate will be collected.

The participants are encouraged to bring proper training clothes for the tests; loosely fit t-shirt and a tight short. This is because the tests include physical activity, as well as it makes placement of all the measurement devices on the skin easier.

TEST DAY 1:

On test day 1 you will be asked some questions about your physical activity habits as well as current health status. Then a couple of functionality tests for balance, gait speed and strength will be performed. After this, EMG-electrodes will be placed on your neck, chest (in the middle and on the side) and your back, in addition to NIRS-electrodes which are placed on the forearm, thigh and calf. This equipment will be kept on during the remainder of the test day. To accurately assess oxygen consumption in leg- and forearm musculature a cuff will be placed around your thigh and upper arm, which will be inflated for 1 and 10 minutes respectively which temporarily occludes the blood flow into the limb (arterial occlusion). This measurement will be done at rest in a sitting position, and it is very important to sit as still as possible to ensure an accurate measurement.

Further, maximal handgrip strength will be tested in a handgrip dynamometer. After this another handgrip test with increasing load will be done to estimate the forearms' maximal ability to consume oxygen during local work. The test day will be concluded by performing a cycling test with a gradually increasing load to estimate your lactate threshold and your body's maximal ability to consume oxygen during exercise. The cycling test includes 5-6 measurements of blood lactate which will gathered from a drop of blood after a prick of your finger. These tests require maximal effort and can be experienced as uncomfortable.

It is expected to spend roughly 3 hours performing test day 1.

TEST DAY 2:

At the start of the second test day an arm lift procedure will be performed. During this test you will be sitting quietly without talking or moving, where the arm will be moved into three different positions in 2 rounds, 3 minutes each. Measurements of oxygenation will be done at the same time. The test day also includes 3 tests which include physical activity. The first two tests will be performed with a handgrip dynamometer, where the tests are from low to high intensity. The last test is a submaximal test that will be performed on a cycling ergometer. This test has two different loads, where arterial occlusions will be applied after each load. This is just a partial occlusion, where the blood flow is not completely occluded. Lastly some anthropometric measurements will be conducted (circumference and skinfold thickness) on your arm, thigh, calf, back and hip. Arm volume will also be measured with a water cylinder.

It is expected to spend roughly 3 hours performing test day 2.

TEST DAY 3: BODY ANALYSIS

The last test day a body analysis (BIA) will be conducted. This will take place during the morning (06.30-09.00). To get a valid test you need to measure in a fasted state, meaning that you must show up with an empty stomach (do not eat anything after waking up that morning). This analysis gives a good estimate of your body composition, detailing weight, fat mass and muscle mass for your different body parts. You will get these results with you home when the test days are completed.

It is expected to spend roughly 10 minutes on this analysis. Remember to show up with an empty stomach.

POSSIBLE BENEFITS AND DISADVANTAGES

This study collects normative data that contributes to useful information about the differences in oxygen consumption during whole body work as well as local muscle work and can give us better knowledge about possible changes in muscle function with aging. These measurements cannot give us direct information about the muscle function and aging of the specific participant. Nevertheless, we can offer you a summarizing document which contain your body composition (fat- and muscle mass) as well as your results for your cardiorespiratory fitness and strength.

The maximal tests can cause some discomfort but will be conducted with proper personnel present and with already established procedures. Additionally, the occlusion can be experienced as uncomfortable. This is usually worst in the beginning of the occlusion period, where the discomfort usually dissipates during the test. The discomfort is only temporary (during the test) and does not pose any risk of injury. This project will not pose any risk or discomfort other than what would be expected from a normal exercise situation.

WHAT HAPPENS WITH THE TEST RESULTS AND INFORMATION ABOUT YOU?

The tests you perform and the information that is registered about you will only be used as described in line with the purpose of the study. To ensure your anonymity you will be given a participation number which links you with your information and results through a list of names. Vi register no direct identifiable information about you that would make it possible to trace you within the data that is collected throughout the study, nor in the results of the study when it is published.

VOLUNTARY PARTICIPATION

It is completely voluntary to participate in the project. You can at any time without providing an explanation withdraw from the project. If you want to participate, you will sign the consent form at the last page of this document or contact the master's students at Øystein Skar Rosvold (Qysteinskar@gmail.com | tlf. 46420876), Andrea Spirka (andrspi@stud.ntnu.no | tlf: 40081541) or Mani Izadi (Manii@stud.ntnu.no tlf: 48636180). If you now consent to participate in the project, you can still withdraw your consent at any time. If you later want to

withdraw from the project, you can contact the master's students or the project leader Mireille Van Beekvelt (mireille.van.beekvelt@ntnu.no | tlf. 73413283).

The project is approved by the Regional Committees for Medical and Health Research Ethics, Midt-Norge.

SMITTEVERN (COVID-19)

Because of the current covid situation some special measures to lower the risk of contamination needs to be upheld during the test days:

-Wash your hands thoroughly with soap and water when arriving to the test location.

-Try avoiding touching surfaces, to the best of your ability.

-Avoid spending more time on the hospital grounds than necessary.

-Wardrobe and showers will unfortunately not be available for use. The participant can change in the room where the tests will be conducted. The personnel can leave the room if wanted.

-Stay home if you are ill.

-Try to keep 1 meter distance

Some of the tests that will be conducted makes it impossible to keep over 1 meter. During these tests the personnel will use face masks, and the participant will get a face mask if wanted.

Chapter A – in-depth explanation of what the study involves

Background information about the study

The study is conducted in association with a master's degree project at the department of neuroscience and movement science, NTNU.

Testing the participant will conduct

- As a participant you show up at St. Olavs Hospital three times
- Test day 1: Measurement, registration and testing of age, weight, height, balance and gait speed, oxygen consumption, heart rate, cardiac output blood lactate and estimation of body fat percentage. An occlusion test where the blood flow is restricted in a foot and an arm. A measurement of heart rate, cardiac output, stroke volume, blood pressure, muscle activation and oxygen consumption for whole-body as well as locally for the arm, thigh and leg musculature. A test of maximal handgrip force will be done, followed by a test of handgrip strength with a gradually increasing load. Lastly, a maximal cycling test will be performed, which includes measurement of blood lactate.
- Test day 2: An arm lift procedure is conducted at the start of the day. Three submaximal tests will be performed (2 handgrip, 1 cycling). Arterial occlusion is applied for 2 of these tests. Measurement of heart rate, cardiac output, muscle activation, oxygen consumption for both whole-body and locally in arm and thigh musculature.
- Test day 3: Analysis of body composition in BIA.

Schedule

- Testing will be conducted during the winter (mainly from December-january 2021-2022.

Potential discomfort

- The occlusion cuff can be experienced as uncomfortable and slightly painful, but only during the occlusion.
- Pushing towards exertion during the maximal tests can be experienced as uncomfortable, similar to experiences during normal physical activity and competition.

Chapter B – Privacy, biobank, economy and insurance

Privacy

Information that is registered about you is: gender, age, height, weight, circumference of body parts, measurements of skinfold thickness, oxygen consumption for whole-body and locally, body composition, muscle activation, cardiac output, blood lactate, blood pressure, heart rate and stroke volume. All data is collected and stored unidentifiably. Only the project staff will have access to the data. Dekanus at NTNU at the Faculty of Medicine and Health Sciences are responsible for data processing.

The right of insight into- and deleting of information about you

If you agree to participate in the project, you have the right to get insight into what information is registered about you. Further, you have the right to correct any potential mistakes in the information registered about you. If you want to withdraw from the project, you can demand to have all collected data about you deleted, unless the data is already included in analysis or used in scientific publications.

Insurance

Participants in the project is covered by "pasientskadeloven" (patient injury law).

Information about the outcome of the study

At the end of the study all participants have the right to get information at group level of the outcome/result of the study.

Consent of participation in the project

I confirm having received oral or written information about the study.

I consent to participating in the project, and to having information about my person being collected and used as described.

(Signed by project participant, dato)

I confirm to having given information about the study.

(Signed, role in the study, dato)

Appendix 3: Questionnaire

SPØRRESKJEMA

--- Bakgrunn ----------

Q1 **Hvordan vil du beskrive helsa di nå?**
How would you describe your current health?

1		Dårlig
2		Ikke helt god
3		God
4		Svært god

Q2 **Røykevaner**
Smoking habits

1		Jeg har aldri røykt
2		Jeg har røykt AV OG TIL tidligere
3		Jeg røyker AV OG TIL nå (ikke daglig)

Q3 **Omtrent hvor ofte har du i løpet av de siste 12 måneder drukket alkohol?**
(Regn ikke med lettøl)
How often did you drink alcohol during the last 12 months (on average)?
(excluding light beer)

1		Ikke drukket alkohol siste 12 måneder
2		1 gang i måneden eller sjeldnere
3		2-4 ganger per måned
4		2-3 ganger per uke
5		4 eller flere ganger per uke
6		Jeg har aldri drukket alkohol

Q4 **4a) Har du drukket alkohol 24 timer før test?**

Did you drink alcohol during the last 24 hours before the test

1		Ja
2		Nei

4b) Hvis ja, Hvor mange enheter?

If yes, how many units/glasses

1		1 glass
2		2 glass
3		> 2 glass

4c) Og type drikke

Type of drink?

1		Sprit
2		Øl
3		Vin
4		Annen (spesifiser) .....

Q5 **5a) Har du hatt noe mat/drikke som innholder koffein siste 6 t?**

(f. eks. kaffe, te, energidrikk, cola, sjokolade)

Did you have a caffeine containing drink during the last 6 hours?

1		Ja
2		Nei

5b) Hvis ja, hvor mange enheter?

If yes, how many units/cups

1		1 kopp / can
2		2 kopper /cans
3		> 2 kopper / cans
4		Annen (gr / tabletter) .....

5c) Og type drikke

Type of drink?

1		Kaffe *(80 mg/kopp)*	BR / E / I / D
2		Te *(44 mg/kopp)*	BL / G / H / D
3		Energidrikk *(80 mg/boks)*	
4		Cola (33 mg/boks)	
5		Sjokolade (45 mg/50 g)	D / M
6		Supplements *(200 mg/tablet)*	
7		Annen (spesifiser)	

Koffeininnhold i drikker og sjokolade

	per dl	per porsjon
Koke- og filterkaffe	40 mg	80 mg per kopp à 2 dl
Energidrikker	32 mg	80 mg per boks à 2,5 dl 160 mg per 5 dl
Espresso	268 mg	107 mg i en liten kopp à 0,4 dl
Te	22 mg per dl	44 mg per kopp à 2 dl
Coladrikker	10 mg	33 mg per boks à 3,3 dl 50 mg per flaske à 5 dl (halv liter)
Mørk sjokolade	90 mg	45 mg i 50 gram sjokolade
Lys sjokolade	19 mg	9,5 mg i 50 gram sjokolade

Coffee

BR	= Brewed
E	= Espresso
I	= Instant
D	= Decaff

Tea

BL	= Black
G	= Green
H	= Herbal
D	= Decaff

Chocolate

D	= Dark
M	= Milk

FHI: *https://www.fhi.no/ml/kosthold/fakta-om-koffein/*

Q6 **Kvinnelige deltakere: Er du, eller har du vært i overgangsalderen?**
Female participants: Are you in menopause or postmenopause?

1		Ja
2		Nei

Hvis ja, når var (omtrent) siste mensen?
If so, roughly how long ago was the last menstruation?

1		0-1 år
2		1-5 år
3		5-10 år
4		> 10 år

Menopause is the time that marks the end of the menstrual cycles. It is diagnosed after 12 months have gone by without a menstrual period. Women are considered to be postmenopausal when they have not had their period for an entire year.

--- Din aktivitet ----------

Q7 **Hvor ofte driver du mosjon?** (Ta et gjennomsnitt)
Med mosjon mener vi at du f.eks. går tur, går på ski, sykler, svømmer eller driver trening/idrett.
How often are you physically active?

1		Aldri
2		Sjeldnere enn en gang i uka
3		En gang i uka
4		2-3 ganger i uka
5		Omtrent hver dag

Q8 **Dersom du driver slik mosjon, så ofte som en eller flere ganger i uka; hvor hardt mosjonerer du?** (Ta et gjennomsnitt)
How often are you physically active?

1		Jeg driver sjeldnere enn en gang i uka med mosjon
2		Jeg tar det rolig uten å bli andpusten eller svett
3		Jeg tar det så hardt at jeg blir andpusten eller svett
4		Jeg tar meg nesten helt ut

Q9 **Hvor lenge holder du på hver gang?** (Ta et gjennomsnitt)
What is the duration of a typical exercise bout?

1		Mindre enn 15 minutter
2		15-30 minutter
3		30-60 minutter
4		Mer enn 60 minutter

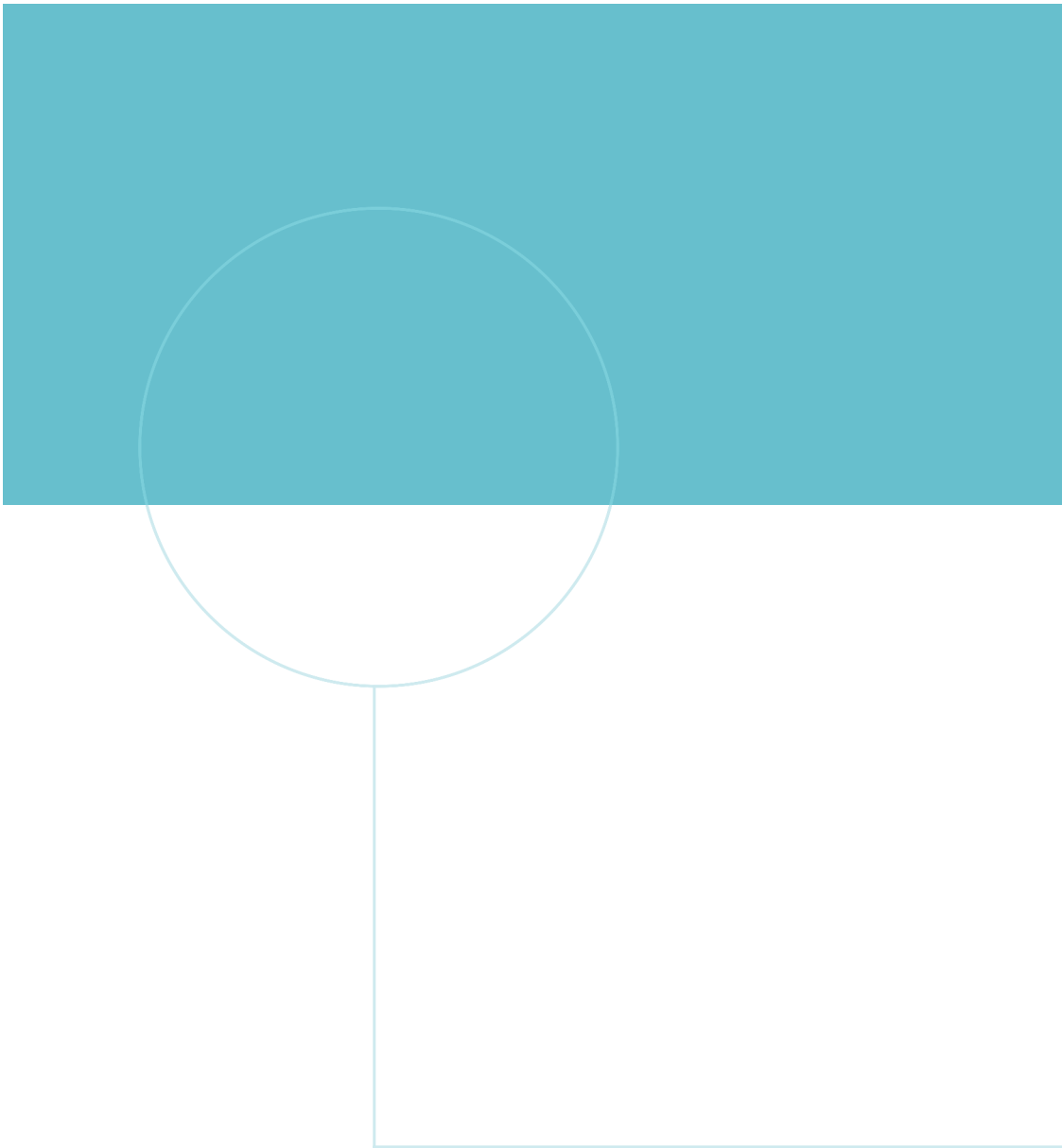
Q10 **Hvilken aktivitetsform gjør du mest av?** (ranger 1-5 hvor 1 er mest)
What activity do you most often do? (order 1-5 with 1 as most)

1		Styrketrening med egen kroppsvekt
2		Styrketrening med vekter
3		Ballidrett
4		Klatring
5		Sykling
6		Langrenn/rulleski
7		Intervalltrening
8		Løping/jogging
9		Gåing
10		Yoga
11		Annen (spesifiser) .....

Q11 **Har du unngått utmattende trening 24-48 timer før test?**

1		Ja
2		Nei

Hvis nei, hva slags trening var det .....



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Science and Technology