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Effects of Prolonged Downhill Running on Upper Body Muscle Functions

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EFFECTS OF PROLONGED DOWNHILL RUNNING ON UPPER BODY MUSCLE FUNCTIONS

By

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ABSTRACT

Downhill running exercise has shown damaging effects on the lower body muscles. However, its effects on the remote nonlocal upper limb muscle's neuromuscular functions are not well studied. **PURPOSE:** To examine the potential effects of a 1-hour downhill running exercise on the elbow flexor muscle neuromuscular functions and performance. **METHODS:** Seventeen healthy and physically active young adults (Control: n = 9; Running: n = 8) participated in and completed this study. The Control group rested for 30 minutes while the Running group performed 1-hour of downhill running at a 10% decline on a treadmill. Before (Pre), immediately after (Post), 24 hours (Post24), and 48 hours (Post48) after the Running or Control, dependent variables (knee extensor muscle soreness, passive knee extension range of motion [ROM], elbow flexor isometric strength, elbow flexor voluntary activation [VA], and the surface electromyography [EMG] amplitude of the biceps brachii during a submaximal isometric contraction at 50% of the Pre-testing maximal strength were measured. Separate two-way mixed factorial (time [ΔPost-Pre vs. ΔPost24-Pre vs. ΔPost48-Pre] × group [Control vs. Running]) analyses of variance (ANOVAs) were used to examine the potential changes in the dependent variables. **RESULTS:** Knee extensor muscle soreness level was significantly greater in the Running than that in the Control group following the downhill running exercise and remained elevated throughout the entire 48 hours after the exercise. This was accompanied by the knee extension isometric strength response (time merged marginal mean ± SE: Running = -6.9 ± 3.5% vs. Control = 1.0 ± 3.2%). There was no two-way time × group interaction, nor the main effect for group for the ROM, elbow flexion isometric strength, and elbow flexor VA. However, there was a main effect for

group (p = 0.005) for the elbow flexion resting twitch force (time merged marginal mean ± SE: Running = -19.6 ± 6.3% vs. Control = 8.7 ± 5.9%). **CONCLUSIONS:** The 1-hour downhill running exercise did induce muscle damage on the knee extensor muscles. In addition, the damaging exercise influenced the remote upper limb elbow flexor muscles at a peripheral level lasting a prolonged period.

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LIST OF ABBREVIATIONS

CON	Control Group
DOMS	Delayed-onset Muscle Soreness
EMG	Electromyography
EXP	Experimental Group
HR	Heart Rate
Hz	Hertz
ICC	Intraclass Correlation Coefficient
mA	Milliamps
MVIC	Maximal Voluntary Isometric Contraction
RMS	Root Mean Square
ROM	Range of Motion
SD	Standard Deviation
VA	Voluntary Activation
VAS	Visual Analog Scale

CHAPTER I

INTRODUCTION

Skeletal muscle damage is referred to as a state of long-lasting impaired muscle functions resulting from physical damage to muscle tissue (Clarkson and Tremblay 1988). Evidence suggests that skeletal muscle damage can also lead to reductions in the nervous system activation of the injured muscle (Doguet et al. 2016; Goodall et al. 2017; Hamlin and Quigley 2001; Prasartwuth et al. 2005; 2006), besides the decreased intrinsic force-producing capabilities of the muscle (Behrens et al. 2012; Janecki et al. 2014). As one of the central fatigue indices, voluntary activation level has been shown to decrease immediately after eccentric knee extension exercise (Souron et al. 2018). In addition, motor unit firing properties may also be altered immediately after a bout of eccentric elbow flexion exercise (Ye et al. 2015 Human Movement Science; Ye et al. 2014 J Musculoskelet Neuronal Interact), as compared to the concentric exercise. These changes in the nervous system may be due to the different neural activation strategies during the concentric vs. eccentric contractions (Duchateau and Enoka 2016).

In addition to influencing the muscle groups, exercise interventions usually affect non-local remote non-exercised or less-exercised muscle groups. These phenomena have been reported, and they were generally described as the term non-local effects. For example, fatiguing exercise can induce non-local muscle fatigue, which refers to muscle performance impairments in non-exercised muscle groups that could be located

contralateral, or ipsilateral, as well as inferior or superior to the fatigued muscle groups (Halperin et al. 2015 EJAP). Studies have shown that fatiguing one limb can impact the strength of the contralateral limb (Aboodarda et al. 2016, Kawamoto et al. 2014; Prieske et al. 2017), and interestingly, this non-local effect has also been seen between the elbow flexors and knee extensors (Aboodarda et al. 2016; 2017; Sambaher et al. 2016). Data from Aboodarda et al. (2017) suggests that upper limb corticospinal responses recorded during voluntary contractions are not only distant muscles history-dependent (i.e. could be modulated by prior activity of lower limb muscles), but they could also depend on the level of contraction in the tested muscle.

Recently, evidence has shown that unilateral high intensity quadriceps eccentric exercise can contribute to reduced neuromuscular activity and physical work capacity of the non-exercised homologous contralateral muscle (Hedayatpour et al. 2018). Maximal knee extension force and task failure time during sustained knee extension contractions of the contralateral non-exercised leg were significantly reduced immediately after unilateral eccentric exercise. In addition, interestingly, these decrements persisted days after exercise. This finding indicates that delayed-onset muscle soreness (DOMS) induced by eccentric exercise 24 and 48 hours after exercise may partly contribute to reduced muscle force and physical work capacity in the unexercised contralateral homologous muscle. It is important to point out, that the majority of the study designs targeting to investigate the non-local effects did not examine the potential prolonged decrements of the non-local effects, which may last for days after high-intensity exercise. Besides Hedayatpour et al. (2018), the only study that examined these non-local effects demonstrated prolonged decrements in elbow flexor muscle voluntary activation and

strength following a 1-hour downhill running exercise (Brandenberger et al. 2018). Specifically, these researchers utilized the interpolated twitch technique to determine that the dysfunction in the distant muscle (elbow flexors) is due to reductions in voluntary activation (VA). Specifically, VA refers to the level of neural drive sent from the central nervous system to the target muscle to activate this muscle (Gandevia et al. 1995). It is typically estimated by delivering a supramaximal electrical stimulus to the motor nerve or muscle belly during a maximal voluntary isometric contraction (MVIC). This technique is referred to as twitch interpolation (Merton, 1954). In addition, voluntary activation is quantified by expressing the amplitude of the superimposed twitch as a fraction of the "resting twitch" which is evoked by the same stimulus in the same muscle during the relaxed state (Thomas et al. 1989). However, the authors (Brandenberger et al. 2018) did not include the use of surface electromyography (EMG) to examine the potential muscle excitation level changes after the downhill running exercise.

When compared the downhill running to the flat surface running, there are striking differences in the timing of events in the stance phase between these two exercises, even though the contact phase is independent of downhill angle (Eston et al. 1995). In addition, peak knee flexion angle, peak flexion velocity, maximum ankle dorsiflexion and peak dorsiflexion velocity all occur significantly later in the stance phase in downhill running. These biomechanical differences can result in more muscle damage in downhill than flat surface running, possibly due to the longer period of eccentric work for the knee extensors and ankle flexors. For example, after downhill running, muscular damage markers as well as mechanical stress have been found to increase when compared to those after the flat surface running (Mizrahi et al. 2000a).

Considering surface EMG may provide additional insights regarding the neural factors such as the muscle excitation, the purpose of this study is to determine if one-hour of downhill running exercise-induced muscle damage will cause a prolonged decline in the force production, voluntary activation, and specifically, the muscle activities of the non-local upper limb muscles. The information we obtain from this study regarding skeletal muscle damage following intense exercise, will help bolster our knowledge in regards to athletic training and performance.

CHAPTER II

METHODS

Study Design

In order to examine whether a 1-hour downhill running exercise would cause prolonged declines in the maximal force production, voluntary activation, and muscle activity of the non-local upper limb muscles such as the elbow flexors, a between-group design (experimental vs control group) was utilized. Subjects assigned to the experimental group (EXP) performed the measurements testing along with completing the downhill running exercise. Subjects assigned to the control group (CON) completed the same measurements; however, they rested for 30 minutes instead of performing the downhill running exercise. Before (Pre), immediately (Post), 24 hours (Post24), and 48 hours (Post48) after the muscle-damaging downhill running exercise, dependent variables (muscle soreness, passive knee extension ROM, elbow flexor isometric strength, voluntary activation of the elbow flexor muscles, surface electromyography (EMG) amplitude of the biceps brachii muscle, and knee extension isometric strength) were measured. All tests were done on the dominant arms and legs of the participants, based on the throwing and kicking preferences, respectively.

Subjects

A total of 17 healthy and physically-active young adults (Control: n = 9; Exercise: n = 8) participated in and completed this study (Table 1). Prior to participation, written consent was obtained via the consent form. All subjects also completed a pre-exercise questionnaire, indicating that they were healthy to engage in exercise and had no current or previous neuromuscular and musculoskeletal disorders. In addition, all subjects were instructed to refrain from any resistance exercises or running activities during the entire study period and to maintain all their normal routines, such as dietary intake, hydration, and sleep for the duration of their participation. This study was approved by the University of Mississippi Institutional Review Board (approval code: 19-106).

Table 1: Participant Information

	EXP (n = 8)	**CON (n = 9)**
Age (years)	20.5 ± 1.4	21.0 ± 1.1
Height (cm)	175.1 ± 6.2	180.6 ± 6.3
Body Weight (kg)	67.6 ± 3.2	78.2 ± 10.9
Stimulation Intensity (mA)	72.9 ± 9.9	86.6 ± 11.4
Downhill Running Speed (mph)	7.7 ± 0.7	N/A

Procedures

Familiarization Visit

The first visit to the laboratory was to familiarize the subjects with the testing procedures and downhill running exercise (only EXP group). During this visit, subjects' standing height and body mass were measured first, followed by the familiarization to the Visual Analog Scale (VAS) and the knee extensor range of motion (ROM) measurement procedures. Then the subject was familiarized with the isometric strength testing of the elbow flexion exercise. Specifically, the subject practiced contraction of his/her elbow flexor muscles against the immovable apparatus as a warm-up for the maximal voluntary isometric contractions (MVICs) as well as to ensure the testing setup was comfortable. Following this practice, the researcher then proceeded to clean the subject's bicep brachii muscle with an alcohol wipe, followed by using a razor to shave the surface hair and the dead skin. Once the skin was prepared, two stimulating electrodes (ValuTrode CF5050; Axelgaard; Fallbrook, CA, USA) were placed on the skin over the proximal belly and the distal tendon of the biceps muscle (Magnus et al. 2010). The electrodes were connected to a constant-current stimulator (Digitimer model DS7AH; Hertfordshire, England, UK). Participants were then asked to simply relax their elbow flexor muscles for the stimulation amplitude determination. This involved the researcher starting with a series of control twitches at 60 milliamps (mA), and increasing by 20 mA every 20 seconds until the involuntary twitch force reached a plateau. This exact amount of current was used in calculation for the twitch interpolation procedure later in the experimental visit.

After the stimulation amplitude determination, the subject was familiarized with the submaximal isometric trapezoid contractions at 50% of the MVIC. Once completed, the subject was allowed to rest as the researcher set up the leg extension machine

(Steelflex PLLE 200; Steelflex Fitness, Taipei, Taiwan) for the familiarization of the dominant leg knee extension isometric strength testing.

Finally, for subjects in the EXP group, they were familiarized with the downhill running protocol. Specifically, the researcher calculated the subject's maximal heart rate (HR) by subtracting the subject's age from 220. Then the subject ran with a HR monitor (Polar; Kempele, Finland) for a duration of 5-10 minutes on a flat treadmill at a pace that their HR was consistently around 85% of the maximal HR. After the pace was determined, the treadmill was then adjusted to the downhill setup at 10% decline. The subjects were instructed to run at the recorded pace for a few minutes to ensure they would be comfortable with this type of exercise. Once the familiarization was completed, the subjects were asked to return to the laboratory for the experimental visits for any three consecutive days at roughly the same time each visit.

Experimental Visits

During the first experimental testing visit (Visit 2), the subjects returned to the laboratory where pre-testing dependent variables were measured in the following order: muscle soreness (VAS), passive knee extension ROM, elbow flexor isometric strength with twitch interpolation, surface EMG amplitude during the elbow flexion isometric trapezoid contraction, and knee extensor isometric strength. If assigned to the EXP group, following the pre-tests, the subjects were allowed to warm up for approximately 5 minutes with the running speed they preferred, before they attempted to complete the 1-hour downhill running with the predetermined pace. Subject's HR was monitored every 5

minutes throughout the duration of the running. Upon completion, subjects were given a few minutes to rest and rehydrate before the Post-measurements. Immediately after, 24 hours, and 48 hours following the exercise, the same dependent variables were assessed in the exact same manner and order as they were measured during the Pre-testing.

Measurements

Muscle Soreness (Visual Analog Scale)

Muscle soreness was assessed using a 100-mm visual analog scale (VAS). The VAS scale shows "No soreness" on the far-left side and "Unbearable pain" on the far-right side. Subjects were asked to flex and extend their dominant quadriceps muscles several times and to mark a vertical line on the VAS scale at the location representing their current soreness level from the knee extensor muscle.

Passive Knee Extension Range of Motion (ROM)

The passive knee extension ROM was measured with a Baseline® Bubble® inclinometer (Fabrication Enterprises Inc., White Plains, NY, USA) placed on the dominant heel of each subject. The subjects were asked to lay prone on a medical table with their feet hanging completely off the table. The researcher would then slowly lift the ankle of the dominant leg to fold the knee. With a completely relaxed position, the subjects notified the investigator when they felt a stretch or tension from their quadriceps muscle. Approximately two to six trials were conducted until two values within two

degrees were obtained (Killen et al. 2019). The passive knee flexion was then calculated as the average of the trials.

Elbow Flexor Isometric Strength with Twitch Interpolation

For the elbow flexor isometric strength testing, the subjects performed 3 separate MVICs with a 60-second rest between consecutive trials. Seated with an upright position, the subject's dominant arm was rested on a padded table, where the pad was firmly pushing against the armpit. At the same time, the subject's wrist was attached by a strap, connecting to a load cell (Model SSM-AJ-500; Interface, Scottsdale, AZ, USA). The other end of the load cell was connected to an immovable steel frame. Extra care was taken so the subject's arm was parallel to the floor, and the elbow joint was at a 90-degree angle (Figure 1). Following the brief warm-up (several isometric contractions with 50% of their perceived maximal effort), the subjects were asked to produce three, 3-second maximal isometric elbow flexion as fast as they could, and then as hard as possible in order to produce maximal explosive force. During each MVIC, the investigator counted down from 3 and then verbally encouraged the subjects with a "pull, pull, pull" until it was time for them to relax. The subjects were given a minute to rest between consecutive trials. During the second and third MVICs, twitch interpolation technique was used. With the same stimulation electrodes placement as during the Familiarization Visit, a paired pulse stimulation (100 Hz) was delivered at about 2.5 seconds into the MVIC, followed by the same paired pulse stimulation delivered about 4 seconds after the MVIC, during the relaxed state. The stimulation current intensity used

for these twitches equaled 1.3 time of the current intensity recorded from the amplitude determination procedure during the Familiarization Visit.

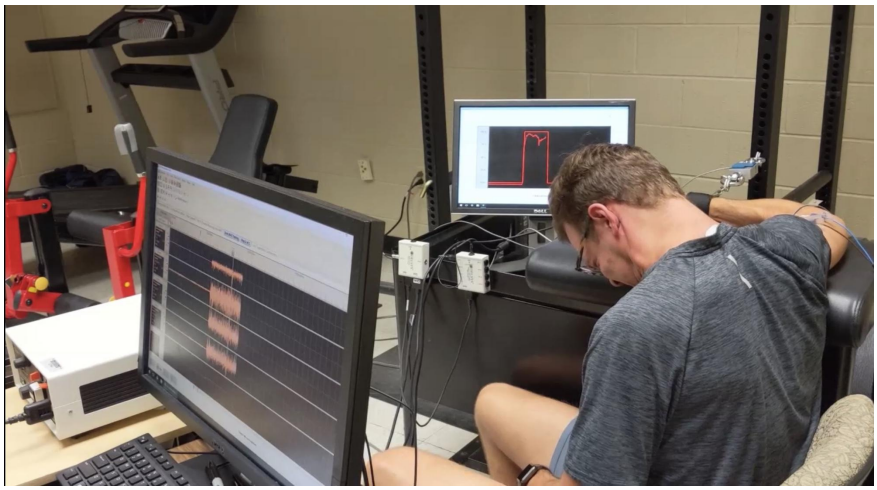

Figure 1: Elbow Flexion Isometric Testing Setup

Submaximal Isometric Trapezoid Contraction

This test was performed with the same setup as the elbow flexion isometric strength testing. The subjects contracted their elbow flexor muscle isometrically with a "ramp-up, hold, and ramp-down" manner. A computer monitor was provided to display the target force template, as well as the subject's real-time force output. Specifically, the subjects gradually increased the force output from 0% (rest) to 50% of their Pre-MVIC for 5 seconds (10% MVIC per second), held it for 10 seconds, and then gradually decreased it to 0% MVIC for 5 seconds. At least two repetitions of the trapezoid contraction were performed at each measurement point. In addition, the force template

(50% of the Pre-MVIC from Visit 2) was always constant throughout all experimental visits.

Knee Extension Isometric Strength

For the knee extension isometric strength testing, the subjects performed three, 3-second MVICs with a 60-second rest between trials. A load cell (Model SSM-AJ-500; Interface, Scottsdale, AZ, USA) was used to measure the isometric force generated by the knee extensor muscles. Specifically, one end of the load cell was connected to the lever of the ankle pad, and the other end was connected to the backside of the knee extension machine through a steel chain (Figure 2). Prior to any contraction, the knee extension machine was adjusted so that the subject's back was upright, and then knee was bent approximately at 75 degrees (knee full extension = 180 degrees). The ankle pad was also adjusted to the subject's preference. Throughout the entire study, the ankle pad and back positions were noted by the researcher as to ensure that the positions were consistent. The subjects were strapped in with a Velcro® belt around the waist level to minimize hip movements. Subjects were instructed to perform several warm-up contractions with 50% of their maximal effort. During each MVIC, the investigator counted down from 3 and then verbally encouraged the subjects with a "push, push, push" until it was time for them to relax. The subjects were instructed to extend the leg into the pad as fast and hard as they could for 3 seconds.

Figure 2: Knee Extension Isometric Testing Setup

Data Analyses

Force

After the elbow flexion and knee extension isometric strength testing, the offline force signal was digitized with a 12-bit analogue-to-digital converter (NI USB-6259 M Series; National Instruments, Austin, TX, USA), sampled at 20KHz with a 16-channel Bagnoli desktop EMG system (Delsys, Inc., Natick, MA, USA), and then stored in a laboratory computer (Dell XPS 8900, Round Rock, TX, USA) for further analyses. For each three-second MVIC, the peak 0.5 second window (other than the superimposed twitch area) was chosen and then calculated as the maximal force output. The average of the three maximal force output was calculated as the maximal isometric strength.

Voluntary Activation

During the elbow flexion isometric strength testing, the two interpolated twitch measurements (superimposed twitch force and resting twitch force) were averaged to determine the voluntary activation (VA). VA was estimated using the following equation: VA (%) = (1 - superimposed twitch force/resting twitch force) × 100% (Allen et al. 1995).

Surface EMG acquisition and signal processing

During the elbow flexion maximal isometric contractions, as well as the submaximal trapezoid contractions, bipolar surface EMG signals were recorded through a five-pin surface array EMG sensor (dEMG sensor, Delsys, Inc., Natick, MA) attached on the biceps brachii muscle belly based on the recommendations from SENIAM (Surface Electromyography for the Noninvasive Assessment of Muscles) (Hermens et al., 1999). This special sensor array comprised five cylindrical probes (0.5 mm diameter) located at the center and the corners of a 5 × 5 mm square. Thus, 4 separate bipolar EMG signals were detected based on the pairwise differences in the five probes, and all four channels were selected for subsequent analyses. The reference electrode (Model USX2000; Axelgaard, Fallbrook, CA, USA) was placed on the seventh cervical vertebrae (C7). Prior to any electrode placements, the investigator shaved and cleaned the skin surface with rubbing alcohol, and medical tapes were used to firmly fixate the electrodes on the skin sites. All analog bipolar EMG signals were collected and amplified (gain=1000) with a Bagnoli 16-channel EMG system (Delsys, Inc., Natick, MA, USA) and filtered with high and low pass filters set at 20 Hz and 450 Hz, respectively. The filtered signals were then digitized at a sampling rate of 20000 Hz with a 12-bit analog-to-digital converter (NI

USB-6259 M Series; National Instruments, Austin, TX). Synchronized with the maximal force signal (highest 0.5-s portion from the MVICs), the amplitude of each channel of the selected EMG signal was calculated as the root mean square (RMS), and the EMG amplitude was then calculated as the average of the 4 RMS from the 4 channels. This value then served as a normalization purpose for each recorded EMG signal from the submaximal trapezoid contractions.

CHAPTER III

RESULTS

Statistical Analyses

The absolute changes (Δ: Post-Pre; Post24-Pre; Post48-Pre) of the passive knee extension ROM, VAS, VA, and the normalized EMG amplitude during submaximal trapezoid contractions, along with percent changes (%Δ: Post-Pre; Post24-Pre; Post48-Pre) of the elbow flexion and knee extension isometric strength, and resting twitch force, were calculated for further statistical analyses. Assumptions for normality of distribution for these dependent variables were checked and confirmed using the Shapiro-Wilk test. Specifically, separate two-way (time [ΔPre-Post vs. ΔPost24-Pre vs. ΔPost48-Pre] × group [CON vs. EXP]) mixed factorial ANOVAs were conducted to examine the responses of all dependent variables across time between groups. The partial η^2 statistic is provided for all repeated measure comparisons, with values of 0.01, 0.06, and 0.14 corresponding to small, medium, and large effect sizes, respectively (Cohen 1988). All statistical tests were conducted using statistical software (IBM SPSS Statistics 25.0; IBM, Armonk, NY) with alpha set at 0.05. The data were presented as mean ± standard deviation (SD).

Baseline Values

The baseline (Pre-values during the second visit) dependent variables were examined with the independent t-tests between groups [CON vs. EXP]. No significant differences were present for all dependent variables (Table 2).

Table 2: Baseline (Pre-testing) comparisons of the Dependent Variables for both experimental (EXP) and control (CON) groups.

Variable	EXP (n = 8)	CON (n = 9)	P-value
ROMPre (°)	100.2 ± 21.8	88.9 ± 20.1	0.283
VASPre (mm)	4.2 ± 4.6	17.7 ± 21.3	0.101
ArmMVCPre (N)	257.2 ± 62.1	293.0 ± 48.6	0.203
LegMVCPre (N)	372.2 ± 102.3	441.0 ± 121.4	0.229
RestingPre (N)	35.9 ± 22.3	47.3 ± 18.3	0.264
VAPre	93.27 ± 4.63%	94.59 ± 3.58%	0.615
EMGTrapPre	51.35 ± 14.60%	45.16 ± 12.69%	0.364

Passive Knee Extension Range of Motion (ROM) and Muscle Soreness (VAS)

For the ΔROM, the results from the two-way ANOVA showed that there were no significant group × time ($F = 0.789$, $p = 0.464$, partial $\eta^2 = 0.050$) interaction, nor main effects for group ($F = 2.645$, $p = 0.125$, partial $\eta^2 = 0.150$) and time ($F = 0.692$, $p = 0.508$, partial $\eta^2 = 0.044$).

The two-way ANOVA for the ΔVAS indicated a significant group × time ($F = 5.873$, $p = 0.007$, partial $\eta^2 = 0.281$) interaction, and a main effect for group ($F = 101.058$, $p < 0.001$, partial $\eta^2 = 0.871$). The follow-up one-way repeated measure

ANOVAs showed a significant main effect for time for the EXP group (F = 4.814, p = 0.026, partial η^2 = 0.407), but not for the CON (F = 0.672, p = 0.439, partial η^2 = 0.077). In addition, the independent t-tests showed significant differences between the two groups at all time points (Figure 3).

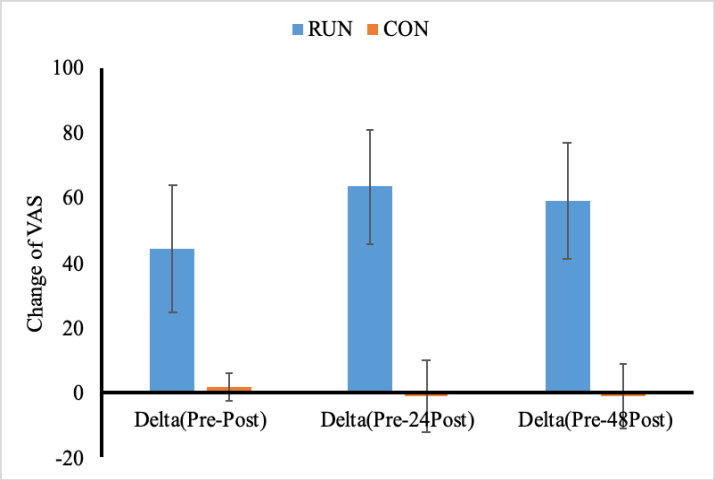

Figure 3: Mean ± SD of the change of the VAS (ΔVAS) for both EXP and CON groups.

Knee Extension and Elbow Flexion Isometric Strength

For the knee extension isometric strength, the two-way ANOVA showed that there was no significant group × time (F = 2.153, p = 0.134, partial η^2 = 0.126) interaction. However, there were main effects for group (F = 2.929, p = 0.044, partial η^2 = 0.163) and time (F = 9.011, p = 0.001, partial η^2 = 0.375). After collapsing across time, the follow-up independent t-test showed significant difference between the CON and EXP groups (mean ± SE: EXP vs. CON = -6.9 ± 3.4% vs. 1.0 ± 3.2%, p = 0.044). When

collapsed across group, significant differences were observed between ΔPost-Pre and Δ1D-Pre (p = 0.014), and between ΔPost-Pre and Δ2D-Pre (p = 0.004) (Figure 4).

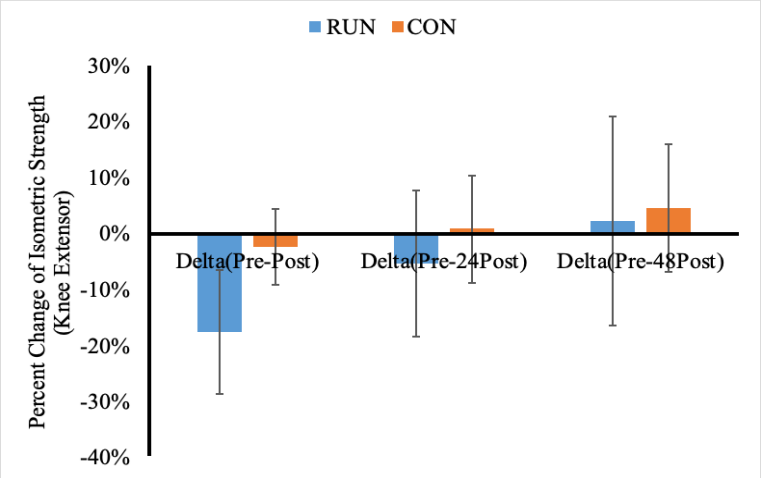

Figure 4: Mean ± SD of the Percent Change of Knee Extensor Isometric Strength for both EXP and CON groups

The two-way ANOVA for the elbow flexion isometric strength showed that there were no significant group × time (F = 0.317, p = 0.731, partial η^2 = 0.021) interaction, nor a main effect for group (F = 0.236, p = 0.634, partial η^2 = 0.016). However, there was a main effect for time (F = 5.423, p = 0.010, partial η^2 = 0.266). After collapsing across group, significant differences were found between ΔPost-Pre and Δ1D-Pre (p = 0.003), and between ΔPost-Pre and Δ2D-Pre (p = 0.038) (Figure 5).

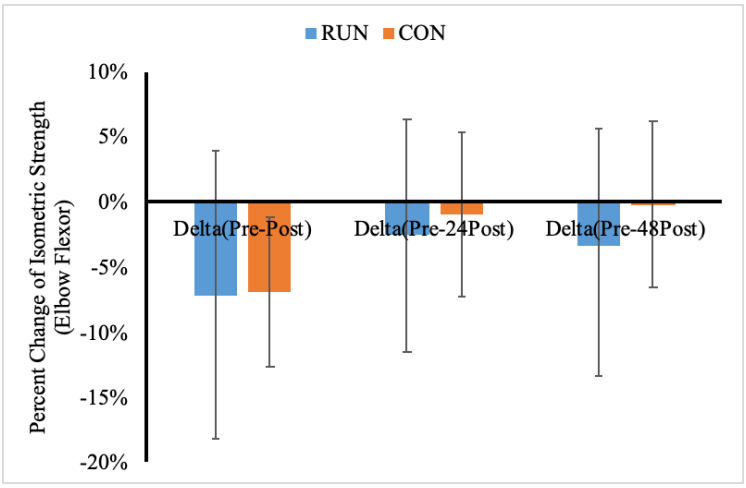

Figure 5: Mean ± SD of the Percent Change of Elbow Flexor Isometric Strength for both EXP and CON groups

Elbow Flexor Muscles Resting Twitch and Voluntary Activation

For the elbow flexion resting twitch force, the two-way ANOVA showed that there was no significant group × time (F = 1.113, p = 0.342, partial η^2 = 0.069) interaction. However, there were main effects for group (F = 10.760, p = 0.005, partial η^2 = 0.418) and time (F = 5.646, p = 0.008, partial η^2 = 0.273). After collapsing across time, the follow-up independent t-test showed significant difference between the CON and EXP groups (mean ± SE: EXP vs. CON = -19.6 ± 6.3% vs. 8.7 ± 5.9%, p = 0.003). When collapsed across group, significant differences were observed between ΔPost-Pre and Δ1D-Pre (p = 0.025), and between ΔPost-Pre and Δ2D-Pre (p = 0.03) (Figure 6).

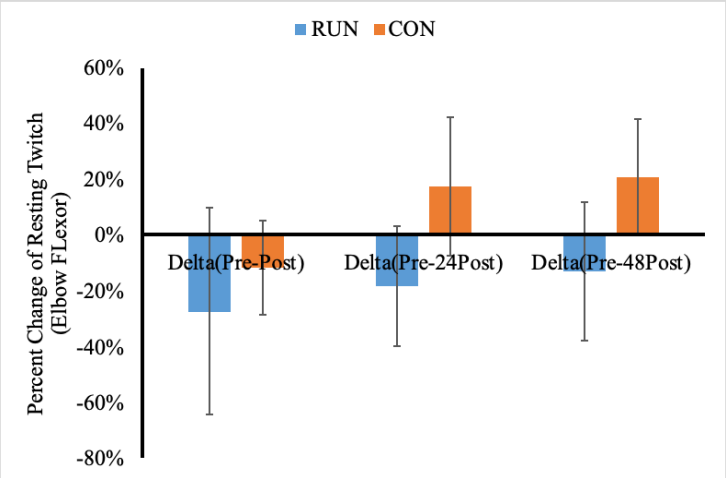

Figure 6: Mean ± SD for the Percent Change of the Elbow Flexor Resting Twitch for both EXP and CON groups

The two-way ANOVA for the elbow flexor muscle voluntary activation showed that there were no significant group × time (F = 1.212, p = 0.320, partial η^2 = 0.119) interaction, nor the main effects for group (F = 1.394, p = 0.268, partial η^2 = 0.134) and time (F = 1.214, p = 0.320, partial η^2 = 0.119).

Biceps Brachii Surface EMG Amplitude

The two-way ANOVA for the surface EMG amplitude during the submaximal trapezoid isometric contraction indicated a significant group × time (F = 4.239, p = 0.024, partial η^2 = 0.220) interaction. The follow-up one-way repeated measure ANOVAs showed no significant main effect for time for the EXP group (F = 3.176, p = 0.073, partial η^2 = 0.312) or for the CON (F = 1.278, p = 0.305, partial η^2 = 0.138). In addition, the independent t-tests showed no significant differences between the two groups at all time points (Figure 7).

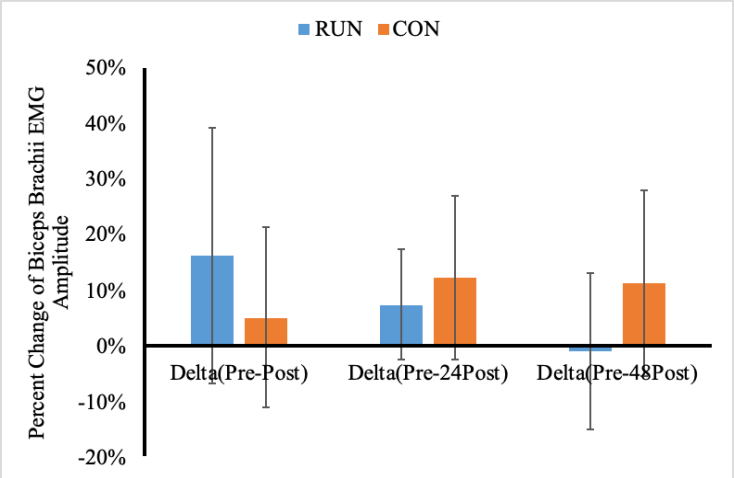

Figure 7: Mean ± SD of the Percent Change of Biceps Brachii EMG Amplitude for both EXP and CON groups

CHAPTER IV

DISCUSSON

This study aimed to examine whether a 1-hour downhill running exercise could induce prolonged declines in the force production, voluntary activation, and specifically, the muscle excitation levels of the non-local upper limb muscles such as the elbow flexors. The main findings of this study are: 1) Leg muscle soreness level increased immediately following the downhill running exercise intervention, and it remained elevated at 24 and 48 hours after the downhill running, compared to Control; 2) The decline in the knee extension isometric strength was significantly larger than that of the Control following the downhill running; 3) Elbow flexion isometric strength, voluntary activation, and biceps brachii muscle excitation levels were not affected by the downhill running exercise interventions; and 4) The reduction in the elbow flexor muscle resting twitch force was significantly greater after the downhill running, when compared to the control group.

Previously, leg muscle soreness levels have been measured following downhill running exercise interventions (Byrnes et al. 1985; Schwane et al. 1983; Broadbent et al. 2010; Maughan et al. 1989). Our findings are in line with these studies: leg muscle soreness increased immediately following exercise and remained elevated days after exercise. The exercise durations across the studies differed slightly with the longest run lasting 1-hour and the shortest lasting 30 minutes. Regardless of these differences in

duration, leg muscle soreness increased immediately and remained elevated. Accompanied by the leg muscle soreness result was the leg isometric strength, which suggests the damaging effect of downhill running. Specifically, exercise-induced muscle damage is characterized by decreased muscle functions such as the prolonged decline in maximal isometric muscle strength following eccentric work (Hesselink et al. 1996). Hesselink et al. (1996) also found that the muscle damaging effect increases progressively with the number of forced lengthening contractions. Running down an incline requires quadriceps muscles primarily to perform eccentric contractions causing greater delayed-onset muscle soreness (Schwane et al. 1983) and greater muscle damage (Eston et al. 1995) than does running on the level, during which muscles perform similar amounts of concentric and eccentric contractions.

Following the similar muscle damaging protocol as our study, Brandenberger et al. (2018) reported that the loss of elbow flexor isometric MVC force following the downhill running protocol could be attributed to the decrements in VA. However, these findings were not observed from the current study. Relative to the Control group, our subjects in the experimental group did not experience significant strength loss in the elbow flexor muscles. Moreover, the VA level, along with the surface EMG amplitude of the biceps brachii muscle in the current study were also not influenced by the downhill running exercise. These findings suggest that the central or neural factors did not seem to be affected by the 1-hour downhill running. It is not clear how the discrepancies between the results from the current study and those from Brandenberger et al. (2018) were originated. The slightly differed exercise protocols (e.g., downhill running speed was based on the subjects' 75% of V̇O2peak at the flat surface) might have contributed to the

different findings. In addition, the subjects' training statuses might have also played a role. For example, in the current study all subjects were recreationally active, running at least once a week while the subjects recruited for the Brandenberger et al. (2018) study were not specifically trained for running. It would be intriguing to observe the results of a study that recruited participants across a broader range of fitness levels (a level of "no running" to a college athletics level) and note the effects on the upper limb muscles following a downhill running exercise.

Interestingly, different from the observation from Brandenberger et al. (2018), the decrements of the elbow flexor resting twitch force were significantly greater after the downhill running, as compared to those of the Control group. Since the same electrical stimulation was delivered to the biceps brachii muscle belly, a decline in the resting twitch indicates the decreased capability of the muscle fibers to generate force. Thus, this finding suggests that the downhill running exercise induced some peripheral changes at the muscle fiber level in the non-local remote upper limb muscles. It was not our intention to examine the exact mechanism(s) inducing this change, but it could be due to the posture change as well as the arm swing motion during the prolonged downhill running exercise.

The current study showed an interesting finding regarding the non-local effects following a prolonged downhill running exercise. However, it is important to address some limitations of this study. First and foremost, even though our study had a few more subjects than Brandenberger et al. (2018) had, the current study still suffers from small sample size, specifically under a between-group research design. Second, the downhill running speed determination in the current study was based on the theoretical maximal

heart rate of the subjects. This, comparing with the VO_2peak method, might have not provided a strong stimulus and exercise intervention to induce muscle damage.

In conclusion, a 1-hour downhill running exercise lead to increased leg muscle soreness, decreased knee extensor isometric strength, as well as a decrease in the upper limb muscle's resting twitch force. More evidence from future studies will be necessary to determine the possible mechanism(s) accounting for the prolonged peripheral changes in the non-local remote muscle groups, following the downhill running exercise.

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