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Section II- Exercise Physiology & Sports Medicine

Eccentric contraction-induced muscle injury does not change walking economy in older adults

by
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The aim of the study was to examine whether self-selected walking speed during downhill treadmill walking by older adults would result in muscle injury and changes in physiological responses during level walking . Twenty-six participants (age: 67 ± 4 yrs; height: 1.69 ± 0.09 m; body mass: 74.9 ± 13.1kg) were assigned to level (n = 11, 30 min, 0%) or downhill walking (n=15, 30 min, -10%) at a self-selected walking speed. Self-selected walking speed and exercise intensity were similar for both groups (level: 4.2±0.4 km·hr^{-1}, 42±6% VO_2max; downhill: 4.6±0.6 km·hr^{-1}, 44±15% VO_2max). After 48-hours, downhill walking had reduced maximal voluntary isometric force of the m. quadriceps femoris (-15%, P<0.001), indicative of muscle injury, but no changes were observed for walking economy, minute ventilation, heart rate and respiratory exchange ratio during level walking. For older adults, downhill walking at a self-selected walking speed causes muscle injury without any detrimental effect on walking economy. Regular downhill walking at a self-selected walking speed by older adults is an eccentric endurance activity that may have the potential to improve cardiovascular fitness and muscle strength.

Key Words: *Aging, downhill treadmill walking, isometric contractions, muscle damage, recovery.*

Introduction

Muscle activity while lengthening (i.e. eccentric contractions) occurs frequently during every day activities without noticeable effects on muscle function. However, if unaccustomed intense exercise involves eccentric contractions, this will result in muscle injury. Muscle injury is characterized by a reduction in the ability to produce maximal voluntary isometric force (MVIF) (Ahmadi et al., 2008; Chen et al., 2007, 2008; Park et al., 2008; Warren et al., 1999) and can last for several days (Chen et al., 2008).

Various eccentric exercise models have been used to examine the functional consequences of muscle injury (e.g. downhill running, Eston et al., 1995). For example, 48 hours after downhill running, the MVIF of knee extensor muscles was

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decreased by 16% (Braun & Dutto, 2003; Chen et al., 2007, 2008; Martin et al., 2005). A decrease in MVIF of 25% was shown for up to 3-days after a single downhill walk (Ahmadi et al., 2008). Studies on additional physiological responses during exercise while recovering from muscle injury, i.e. exercise with injured muscles, have been inconclusive (Braun & Dutto, 2003; Chen et al., 2007; Scott et al., 2003). Some studies have shown changes in heart rate, minute ventilation and respiratory exchange ratio (RER) during exercise with injured muscles (Braun & Dutto, 2003; Chen et al., 2007). For example, an increase in RER following downhill running was reported by Braun & Dutto (2003). This increase was attributed to an increase in the type II fiber recruitment in damaged muscles, increasing the anaerobic means of energy production and therefore, RER (Braun & Dutto, 2003). As far as we know, the physiological responses during walking exercise in older adults with injured muscles have not been investigated. It is possible that gait instability due to muscle injury may affect muscle activity that is required to stabilise walking. This could then contribute to different physiological responses during normal walking in older adults (Malatesta et al., 2003).

The aim of the present study was to examine in older subjects the effects of muscle injury by downhill walking on physiological and metabolic responses during level walking. It was hypothesised that level walking by older subjects with injured muscles would be associated with increased oxygen consumption (i.e. a decrease in walking economy).

Methods

Participants

Fourteen men and twelve women volunteered to participate in the study. The participants had not been involved in a structured exercise programme for at least 1 year prior to the beginning of the study. All participants lived an independent, non-institutional lifestyle. Before participating in the study, each individual completed a health history questionnaire and provided written informed consent. All procedures and protocols were approved by the University of Chichester Ethics Committee. Participants were instructed not to consume caffeine or sports drinks 2 hours prior to muscle function tests and refrain from any vigorous physical activity in the days prior to the treadmill walking sessions (details below). During the treadmill walking sessions participants wore the same footwear each time.

Preliminary Measures

Resting heart rate and blood pressure (Omron 705 IT, Medisave, UK) were measured after participants were seated for 20-minutes. Body mass (Seca Model 880, Seca Ltd., Birmingham, UK) was measured in normal clothing without shoes. Bioelectrical impedance was used to determine percentage body fat (BC418 MA, Tanita, UK). Body mass index was calculated by the following equation: BMI= body mass x height^{-2}

with body mass and height expressed in kilograms and meters, respectively. Participants were familiarised for all testing procedures with the exception of the downhill walk to avoid a potential repeated bout effect (Howatson et al., 2007). All subjects completed maximal voluntary isometric contractions before and after the walks (described below in detail). Following treadmill familiarisation, self-selected walking speed (SSWS) for level treadmill walking was determined for each individual. SSWS was a speed that an individual perceived to be able to maintain for 30-minutes. The starting treadmill speed was 2.5 $km \cdot hr^{-1}$ and was increased by 0.2 $km \cdot hr^{-1}$ every 30-seconds until the participant indicated that the next speed would be excessive. Participants then maintained the selected speed for 10-minutes. This design ensured ecological validity as the participants determined their own self-selected walking speed rather than the same or standardized walking speed for all participants (Ahmadi et al., 2008). Maximal walking speed (MWS) was determined overground on a 10 metre hard non-slip walkway (Tiainen et al., 2007). In this test, participants had a 3 metre acceleration and deceleration zone on either side of the 10 metre walkway. Participants were asked to walk as fast as possible along the 10 metre walkway. The fastest walking speed of 3 repeated tests was used for analysis. Predicted maximal oxygen uptake (VO_2max) was determined by the Rockport Fitness Walking Test (RFWT), a 1-mile overground walk that has been validated for older adults (Fenstermaker et al., 1992). Participants were instructed to walk the 1-mile at a fast constant pace, 28½ times around a wooden floored gymnasium (19x9). Participants walked alone with verbal encouragement to maintain effort throughout the test. The RFWT uses body weight, age, time to complete 1-mile and final heart rate to predict VO_2max (Fenstermaker et al., 1992). Heart rate was measured using a Polar Heart Rate monitor (FS1, Polar UK).

Experimental Design

Participants were randomly assigned to either a level walking group (n=11, LW) or downhill walking group (n=15, DW). Anthropometric and physiological characteristics of participants in both groups are shown in Table 1. The level and downhill walking group performed a 30-min walk at 0% and 10%, respectively, on a motorised treadmill (Woodway Ergo ELG 70, Cranlea & Co., Birmingham, UK) at the pre-determined SSWS. Physiological and metabolic measurements (described below) for each group were taken in the last 3 minutes during a 15 minute level treadmill walk at SSWS at baseline and 48 hours after the 30 minute walk.

Participants performed the maximal isometric muscle contractions of the knee extensor muscles 1 week before and 48 hours after the 30-minute walk, with testing at the same time of day. For all isometric contractions, participants were secured in a custom built chair for measurement of maximal voluntary isometric force (MVIF) of knee extensor muscles with hip and knee at 90° flexion.

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Velcro straps were placed around the participant's chest and waist to restrict movement of the upper body and hips. A cuff was placed around the participant's ankle (proximal to the *fibular* notch and *medial malleolus*) and attached to an s-beam load cell (RS250kg, Tedea Huntleigh, Cardiff, UK) via a steel chain at the base of the chair. Force of knee extensor muscles was recorded on a computer with a sampling frequency of 1000Hz using Chart 4 V4.1.2 (AD Instruments, Oxford, UK). Prior to performing MVIF contractions, participants conducted three sub-maximal contractions to become accustomed to the experimental set-up.

Physiological and metabolic measurements

Three minute collections of expired gases were made using Douglas bags (Cranlea & Co. Bourneville, Birmingham, UK.) in the last 3 minutes during a 15 minute level treadmill walk at SSWS. The Douglas bags were flushed with room air and fully evacuated prior to gas collection. Respiratory gas fractions (O_2 and CO_2) (Servomex Series 1400 gas analyser, Servomex plc., Crowborough, UK) and total volume of expired air (Harvard dry gas meter, Harvard Apparatus Ltd., Edenbridge, UK) were measured. The gas analyser was calibrated using a two point calibration: O_2 and CO_2 were zeroed using 100% nitrogen gas (Linde Gas UK Ltd., West Bromwich, UK); O_2 was spanned to 20.93% using room air and CO_2 spanned to 5.01% using a known gas mixture (15.06% O_2, 5.01% CO_2, 79.93% N) (Linde Gas UK Ltd., West Bromwich, UK). To calibrate the gas meter for volume measurements, room air was pumped through in 35L increments up to 175L using a 7L syringe (Model 4900, Has Rudolph Inc., Kansas City, USA). Volume of oxygen uptake (VO_2), using the Haldane transformation, respiratory exchange ratio (RER) (VCO_2/VO_2), minute ventilation (V_E) and walking economy (expressed in $ml \cdot kg^{-1} \cdot km^{-1}$) according to equation 1 with VO_2 in $ml \cdot kg^{-1} \cdot min^{-1}$ and speed in $km \cdot h^{-1}$ (Jones, 2006) were calculated.

Walking economy = VO_2 x 60/walking speed

Gas volumes are presented at a standard temperature (0°C) and pressure (100.3kPa) of dry gas (i.e. STPD). Heart rate was recorded at 30 second intervals during the gas collections using a Polar heart rate monitor (FS1, Polar UK), with average heart rates calculated.

Maximal voluntary isometric force (MVIF) of knee extensors

Before the walk, participants produced 3 maximal voluntary isometric contractions of 3-5 seconds each with 3-min recovery between each effort (Seynnes et al., 2005). Strong verbal encouragement was provided and an additional contraction was performed if there was more than 30N between penultimate and last contraction (this only occurred on two occasions). Maximal voluntary isometric force was calculated as the highest value that was maintained over a 1-s period during the contraction. After the walk, participants performed 1 maximal voluntary isometric contraction.

Statistical Analysis

Statistical analysis was undertaken using SPSS for Windows V16.0 (SPSS, Chicago, Illinois). Normal distribution of the data was tested using a Kolmogorov-Smirnov test. Some of the data sets (baseline MVIF, VO_2 and RER) were shown to be significant (P<0.05) (not normally distributed). However tests for skewness, Box's test of equality of covariance matrices, and Levenes test of equality of error variances were non-significant (P> 0.05), allowing further parametric tests to be applied. Changes from baseline values were calculated 48 hours after the walks. A 2-way ANOVA was used to examine the change of the baseline values across time and between conditions (level walking vs. downhill walking) for all parameters. When the 2-way ANOVA showed a significant difference between conditions or over time pre-planned one sample T-tests were used to compare the change over time and values at each time point. A one sample T-test was used to compare the percentage change from baseline for MVIF for both conditions. Statistical significance was set at P<0.05.

Results

Anthropometric and physiological characteristics

Anthropometric (height, body mass, BMI, % body fat) and physiological characteristics (resting heart rate, resting blood pressure and predicted maximum oxygen uptake) of participants are presented in Table 1. Participants in the level walking (LW) and downhill walking (DW) group had similar values for all anthropometric and physiological parameters (P≥0.12).

Walking speeds

Self-selected treadmill walking speeds for the level and downhill walking group were 4.2 ± 0.4 $km·hr^{-1}$ and 4.6 ± 0.6 $km·hr^{-1}$, respectively, and not different between groups (P=0.09). For both groups, the self-selected walking speeds were at equal percentages of their maximal walking speed (LW: 50 ± 8 %, 8.6 ± 1.4 $km·hr^{-1}$; DW: 54 ± 9 %, 8.8 ± 1.4 $km·hr^{-1}$) (P=0.33).

Isometric force of knee extensors

Maximal voluntary isometric force (MVIF) of the knee extensors for the LW and DW groups at baseline and 48 hours after their walking session are presented in Figure 1.

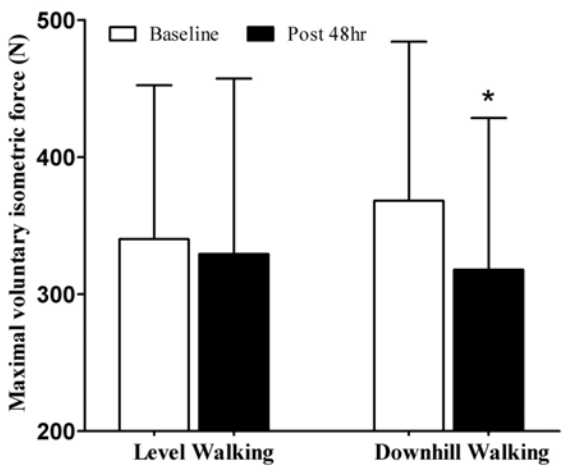

Figure 1

*Maximal voluntary isometric force of knee extensor muscles at baseline and 48 hr after a 30-minute level (0%) or downhill (-10%) walk at self-selected walking speeds. Data are reported as mean ± SD. *, Significant decrease from baseline value, P<0.001*

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The MVIF's at baseline were similar for both groups (LW: 340.2 ± 112.2 N, DW: 368.2 ± 116.02 N, P=0.54). MVIF values recorded at 48 hours for both groups were also similar (LW: 329 ±127.9 N, DW: 317 ± 110.8 N, P=0.81), therefore, pre-planned T-tests were not needed. At 48 hours, the LW MVIF values were similar to baseline values (t=1.39, *P*=0.2) whereas the DW MVIF values were 15% lower (t=5.77, *P*<0.001).

Table 1

Anthropometric and physiological characteristics of LW (n = 11, 6 men and 5 women) and DW participants (n = 15, 8 men and 7 women) (mean±SD)

	Age (yr)	Height (m)	Body mass (kg)	BMI ($kg\cdot m^{-2}$)	Male BF (%)	Female BF (%)	RHR ($b\cdot min^{-1}$)	RBP (mm Hg)	VO_2max ($mL\cdot kg^{-1}\cdot min^{-1}$)
LW	65 ±4	1.68 ±0.10	75.1 ±18.5	26.4 ±4.5	29.1 ±8.5	31.4 ±6.9	77 ±11	147/86 ±25/10	29.7 ±7.0
DW	68 ±4	1.69 ±0.08	74.7 ±8.0	25.7 ±2.6	26.4 ±5.5	34.3 ±5.1	73 ±9	137/83 ±5/9	29.6 ±9.1

LW, level walking; DW, downhill walking; BMI, body mass index; BF, body fat; RHR, resting heart rate; VO_2max, maximum oxygen uptake; *RBP, resting blood pressure*

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Table2

Physiological and metabolic responses during a 15 minute level walking economy test at baseline and 48 h after a 30 minute treadmill walk on a level (0%) or downhill (-10%) gradient. Data are presented as mean ± SD.

Indicators	Level Walking		Downhill Walking	
	Baseline	Post-48hr	Baseline	Post-48hr
VO_2 ($mL\cdot kg^{-1}\cdot min^{-1}$)	11.1± 3.4	11.6 ± 1.6	11.9 ± 1.4	11.7 ± 2.0
V_E ($L\cdot min^{-1}$)	22.5 ± 4.9	22.1 ± 4.4	22.3 ± 4.5	22.2 ± 5.3
RER	0.92 ± 0.06	0.92 ± 0.04	0.93 ± 0.04	0.92 ± 0.04
HR ($b\cdot min^{-1}$)	101 ± 10	98 ± 8	103 ± 7	99 ± 8
Walking economy ($mL\cdot kg^{-1}\cdot km^{-1}$)	168.4 ± 10.9	163.3 ± 14.3	157.5 ± 21.4	152.4 ± 25.5

VO_2, oxygen uptake; V_E, minute ventilation; RER, respiratory exchange ratio; HR, heart rate.

Walking economy

The self-selected walking speeds at which walking economy was evaluated were at similar intensities (as a percentage of predicted VO_2max) for the level (42 ± 6%) and downhill (44 ± 15%) walking groups (*P*=0.98). At these intensities, the mean oxygen uptake values (VO_2) of 11.1 ± 3.4 $ml·kg·min^{-1}$ for LW and 11.9 ± 1.4 $ml·kg·min^{-1}$ for DW were similar (*P*=0.76) (Table 2). Metabolic and physiological responses during the walking economy test at baseline and after 48 hours were not different for either LW or DW group (*P*>0.07) (Table 2), therefore pre-planned T-tests were not performed. There were no differences for metabolic and physiological responses during level walking (*P*>0.34) for both groups at 48 hours (Table 2).

Discussion

The present study provided two novel findings. First, a 30-minute downhill treadmill walk (-10%) by older adults at a self-selected walking speed (SSWS) resulted in a substantial reduction in the ability to produce maximal voluntary isometric force (MVIF) of the knee extensor muscles at 48 hours. Such reduction in the ability to produce maximal voluntary isometric force is a strong indicator of the presence of muscle injury (Warren et al., 1999) induced by the downhill walk. Second, the presence of muscle injury in knee extensor muscles in older adults was not associated with changes in physiological (e.g. walking economy) and metabolic responses during level walking at self-selected walking speed.

Maximal Voluntary Isometric Force

In the present study, the MVIF values at baseline for men (440 N, n=14) and women (259 N, n=12) were comparable to other studies (Frontera et al., 1991; Harries & Bassey, 1990; Tracy & Enoka, 2002). For example, Frontera et al., (1991) reported for men and women (45-78 yrs) a MVIF of 422 N and 273 N, respectively. Participants in the present study experienced a 15% decline in MVIF following downhill walking at a self-selected walking speed. We are not aware of other studies that reported decrements in the ability to produce maximal isometric force in older adults following downhill walking or running. Interestingly, however, the decrement in MVIF by downhill running in young adults can be of similar proportion compared to ours. For example, Chen et al., (2008) reported at 48 hours a decrement of 18% after a 30 min downhill run (-15%) at 70% of their pre-determined VO_2max. A decline of 12% in MVIF was reported 48 hrs after downhill running (Chen et al., 2007). Martin et al., (2005) reported a 19.6% MVIF reduction 30 minutes after downhill running (7 $km·h^{-1}$). In the present study, the self-selected walking speed equated to an oxygen consumption of 11.94 $ml·kg·min^{-1}$ whereas other studies used running intensities that were more than three times greater (37.7 $ml·kg·min^{-1}$ (Chen et al., 2007); 38.8 $ml·kg·min^{-1}$ (Chen et al., 2008). These downhill running studies were performed with young

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individuals and we do not know the force decrements that would result from downhill walking at a self-selected walking speed in young individuals.

Walking economy

In older adults, muscle injury from downhill walking did not change physiological (e.g. walking economy) and metabolic responses (V_E, RER and HR) during a self-selected level treadmill walk 48 h later. These results confirm the findings of other studies (Hamill et al., 1991; Paschalis et al., 2005) on effects of eccentric exercise, although with running as the exercise modality (Scott et al., 2003). However, Chen et al., (2007) reported an increased VO_2 consumption of 4-7% at three different intensities (65, 75 and 85% VO_2max) for up to three days after a 30-minute downhill run (-15% gradient, 70% VO_2max). Running economy was significantly effected at 80 and 90% VO_2max but not at 70% (Chen et al., 2009). Braun & Dutto (2003) found significant increases in V_E, RER and HR and running economy. Interestingly, the study by Braun & Dutto (2003) was performed with male endurance athletes. Such individuals are proposed to have a well refined gait pattern in comparison to participants with a lower training status, and it is possible that muscles of trained individuals have increased sensitivity to the physiological and metabolic consequences of muscle damage (Braun & Dutto, 2003). The suggestion that individuals with a lower training status are less sensitive to muscle damage has not been verified and needs further investigation. Subjects in our study can be considered non-trained older adults which could make them less susceptible to the physiological consequences of unaccustomed eccentric contractions injury than trained older adults but this needs further investigation.

The absence of response from muscle injury on walking economy and other metabolic parameters in the current study and others (Hamill et al., 1991; Paschalis et al., 2005; Scott et al., 2003) following eccentric exercise may also be due to the exercise intensity at which economy was tested (Paschalis et al., 2005). Paschalis et al., (2005) suggested that running economy is not affected by muscle injury at low running velocities. In our study, older adults with muscle injury were tested at a walking speed at approximately 40-50% of their predicted VO_2max. This intensity is lower than intensities in the two studies that found a change in running economy following eccentric exercise (Braun & Dutto, 2003; Chen et al., 2007). Because the exercise intensity is linked to recruitment of muscle fibres, a relatively low exercise intensity will predominantly recruit type I muscle fibres (i.e. slow-twitch). Type I muscle fibres seem to be less susceptible to muscle injury from eccentric exercise than type II fibres (i.e. fast-twitch) (Fridén et al., 1983). Therefore, it is likely that in the present study, the walking intensity during level walking would not have sufficiently recruited injured fast-twitch muscle fibres. In addition, the level walking speed in the present study by the downhill walking group was

1.29 m·sec^{-1} and 0.27 m·sec^{-1} slower than the speed with the greatest instability (Malatesta et al., 2003). Thus, the relatively low intensity of the self-selected walking speed in addition to a walking speed that is not inherently instable in the present study may explain the lack of change in RER, HR and V_E to walking exercise with injured skeletal muscle. Future studies are encouraged to examine whether effects of muscle injury in older subjects would be related to walking intensity. It is likely that the participants in the present study were able to maintain recruitment of non-injured muscle fibres during level walking at self-selected walking speed and, therefore, did not jeopardize physiological and metabolic responses.

It is concluded that unaccustomed eccentric exercise in the form of downhill walking at a self-selected walking speed by older adults produced muscle injury. Muscle injury of the knee extensor muscles in older subjects did not result in changes in walking economy or other physiological (heart rate and minute ventilation) and metabolic responses (respiratory exchange ratio) when walking level at a self-selected walking speed. It may be that the lack of response is related to the relatively low intensity of the level walk and the untrained status of the elderly subjects. When older adults would perform exercise that causes injury, it can be expected that injured muscles in the older adult would recover over time. Interestingly, the potential of injured muscles in older adults to regenerate and improve strength would make downhill walking at a self-selected walking speed in older adults a viable exercise intervention to examine adaptation in strength and functional ability.

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