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Effect of muscle fatigue and physical activity level in motor control of the gait of young adults

Fabio Augusto Barbieri [a,b,*], Paulo Cezar Rocha dos Santos [a], Rodrigo Vitório [a], Jaap H. van Dieën [b], Lilian Teresa Bucken Gobbi [a]

[a] UNESP, São Paulo State University at Rio Claro, LEPLO, São Paulo, Brazil
[b] Research Institute MOVE, Faculty of Human Movement Sciences, VU University Amsterdam, Amsterdam, The Netherlands

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ABSTRACT

The aim of this study was to analyze the effect of muscle fatigue in active and inactive young adults on the kinematic and kinetic parameters of normal gait and obstacle crossing. Twenty male subjects were divided into active (10) and inactive (10), based on self-reported physical activity. Participants performed three trials of two tasks (normal gait and obstacle crossing) before and after a fatigue protocol, consisting of repeated sit-to-stand transfers until the instructed pace could no longer be maintained. MANOVAs were used to compare dependent variables with the following factors: physical activity level, fatigue and task. The endurance time in the fatigue protocol was lower for the inactive group. Changes of gait parameters with fatigue, among which increased step width and increased stride speed were the most consistent, were independent of task and physical activity level. These findings indicate that the kinematic and kinetic parameters of gait are affected by muscle fatigue irrespective of the physical activity level of the subjects and type of gait. Inactive individuals used a slightly different strategy than active individuals when crossing an obstacle, independently of muscle fatigue.

1. Introduction

Fatigue affects the performance of daily activities, such as walking. To maintain motor performance in the presence of fatigue, adjustments in temporal and spatial parameters of gait are required [1–3]. Fatigue effects are task-dependent [4,5] and may thus be different for gait in environments of different complexity. While fatigue effects on gait characteristics have been studied to some extent in an unobstructed environment allowing free gait, characteristics of adaptive gait for example to cross or circumvent obstacles, as is commonly required in daily locomotion [6], has to the best of our knowledge not been studied previously.

Gait characteristics appear to be influenced by physical activity levels, with inactive individuals showing differences from active individuals in free gait reflective of a poor neuromuscular condition affecting both balance control and propulsion [9,16]. In adaptive gait, inactive individuals showed a lower walking speed and increased foot-obstacle horizontal distance of the leading limb compared to active individuals [8]. Physical activity levels also mediate fatigue development [9], with inactive individuals being more fatigable than active individuals [10], and may alter fatigue effects on motor performance.

The aim of this study, therefore, was to analyze the effects of muscle fatigue in active and inactive young adults on the kinematic and kinetic parameters of free and adaptive gait. We expected that the motor control of free and adaptive gait would be dependent on the physical activity level before and after fatigue induction and hypothesized interaction effects between physical activity level and fatigue. Furthermore, we expected that muscular fatigue affect free and adaptive gait differently. We analyzed spatial–temporal gait characteristics, which have been related to fall risk or have been shown adapted to decrease fall risk (e.g. gait speed, step duration, step width). In addition, we looked at the spatial relations between the feet and the obstacle, which determine the probability of tripping over or stepping on the obstacle. Finally, we analyzed vertical ground reaction forces to characterize weight acceptance and horizontal forces to provide insight into how speed is modulated.

2. Material and methods

2.1. Participants

Twenty young male adult participants of this study were classified into active and inactive (Table 1). The exclusion criteria

* Corresponding author at: Universidade Estadual Paulista, UNESP, IB, Rio Claro, Laboratório de Estudos da Postura e da Locomoção, Avenida 24-A, 1515 Bela Vista, CEP: 13.506-900, Rio Claro, São Paulo, Brazil. Tel.: +55 19 3526 4320; fax: +55 19 3534 6436.
E-mail addresses: barbieri@rc.unesp.br, barbieri_rc@hotmail.com (F.A. Barbieri).

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Table 1
Mean and standard deviation of the general characteristics, anthropometric measure, scores on the multidimensional fatigue inventory and habitual physical activity, maximal isometric force before (pre) and after (post) induction to fatigue and endurance time to fatigue for each group. (*) pre (≠) post; (+) active group ≠ inactive group.

		Group	
		Active	Inactive
Age (months)		296.5 ± 34.2	296.9 ± 35.4
Weight (kg)		73.2 ± 4.4	82.7 ± 17.6
Height (cm)		178.7 ± 10.1	178.8 ± 5.6
Percentage of body fat		9.6 ± 4.1+	20.1 ± 8.9
Multidimensional fatigue inventory (points)		47.5 ± 5.6	46.9 ± 10.3
Habitual Physical Activity (points)		10.4 ± 1.49+	5.9 ± 1.2
Maximal isometric force (N)	(pre)	3346.7 ± 1002.3*	3099.1 ± 1351.9*
	(post)	2923.2 ± 1132.4	2730.8 ± 1302.1
Endurance time to fatigue (s)		1018.4 ± 697.4+	416.4 ± 381.7

of the study were factors that could interfere with gait and other experimental procedures, such as medication use, presence of osteomyoarticular, neuromuscular or cardio-respiratory diseases and balance and vision disorders. During the sample selection process, 10 initially recruited subjects did not fit the criteria of the study. The study was approved by the local Ethics Committee (2055/2008).

The active group was composed of individuals who performed physical activity for more than three months for at least three times a week and at least 1 h/day and the inactive group was composed of individuals who had not performed regular physical activity in at least the last 3 months [11,12]. In addition, participants filled out the questionnaire of habitual physical activity [13]. In this questionnaire the responses are scored on a five-point scale and result in three different indices reflecting physical activity during work, leisure time excluding sport and sport activities. The summation of the three indices was defined as the overall physical activity index. The values for the active group were ≥9 and the inactive group scored ≤7 [14].

2.2. Experimental design

Participants were instructed not to perform any strenuous physical activity 48 h before evaluation. The experiment was divided into 2 days. On the first day, participants filled out a questionnaire on medical history, the questionnaire of habitual physical activity and the multidimensional fatigue inventory [15]. The latter was used to determine the presence of fatigue prior to study, and no fatigue was found in either of the groups (Table 1). In addition, the anthropometric measurements were performed.

At the beginning of the second day, there was warm-up period of 5 min, with walking, stretching and movements in the leg press. After that, participants performed the trials of free and adaptive gait following the maximum voluntary isometric contractions. Immediately after the he maximum voluntary isometric contractions, the fatigue protocol was performed. Subsequently, the gait tests and the maximal voluntary contractions were performed once again.

2.3. Gait task

Three trials for each experimental condition, free and adaptive gait, with the order randomly defined were performed before and after the fatigue protocol. The starting point of each gait trial was adjusted to ensure that the obstacle was crossed with the right leg and that at least two strides were completed prior to obstacle crossing. The instruction given to the participant was to walk over an 8 m pathway, at self-selected speed. For the adaptive gait trials, the participant was instructed to avoid contact with the obstacle (15 cm high, 80 cm wide and 2 cm thick), which was positioned between two force platforms. For free gait we analyzed the stride (period between two consecutives heel contacts of the left limb) in the middle of the pathway, which was compared to the stride preceding the obstacle crossing for adaptive gait (approach phase). For adaptive gait, we additionally analyzed the crossing step (from heel contact of the left limb in front of the obstacle to heel contact of right limb behind the obstacle) and the step (from heel contact of the right limb behind the obstacle to heel contact of left limb behind the obstacle) after crossing the obstacle ($N + 1$).

2.4. Data collection

Ground reaction forces were measured using two force plates (AccuGait, Advanced Mechanical Technologies) at a sample rate of 200 samples/s, positioned across the central area of the pathway (20 cm away from each other). Acquisition of kinematic gait parameters was accomplished with a three-dimensional optoelectronic system (OPTOTRAK Certus), positioned in the sagittal right plane, using a sample rate of 100 samples/s. Four infrared emitters were placed over the following anatomical points: lateral face of calcaneus and head of the fifth metatarsus of the right limb, and medial face of calcaneus and head of the first metatarsus of the left limb. To determine the heel contact and toe-off of the limbs during gait, only the markers on the calcaneus and toe were used [16]. The data acquisition systems were electronically synchronized.

2.5. Isometric force measurements

After the free and adaptive gait trials, maximum voluntary isometric contractions were performed in a leg press device [17]. A load cell with precision of 0.98 N was used in combination with a signal amplifier (EMG System do Brasil Ltd.). The participant performed the test with both legs, with the instruction to produce maximum force as fast as possible. Total contraction duration was 5 s. The participants were seated in a backward inclined chair, with the hip joint at 90° (180° is full extension) and knee joint at 110° (180° is full extension). Participants performed two attempts before and after the fatigue protocol, with 2 min rest between attempts. The means of the two attempts before and after muscle fatigue were calculated for each participant.

2.6. Fatigue protocol

To induce fatigue, the participant performed the sit-to-stand task, with arms across the chest region from a chair [1], with the speed controlled by a metronome (30 beats/min). So, the cycle of sitting to standing and back to sitting was performed in 2 s. A standard chair (43 cm in height, 41 cm in width, 42 cm in depth) without arm rests was used for all participants. The instruction given to the participants was: stand up to an upright position with your knees fully extended, then sit back down and repeat this at the beat of the metronome until you can no longer perform the task.

The fatigue protocol was stopped and it was assumed that the leg muscles were fatigued when the subject indicated not to be able to continue the task, or when the subject no longer performed at the desired movement frequency, or after 30 min. The time