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Effects of leg muscle fatigue on gait in patients with Parkinson's disease and controls with high and low levels of daily physical activity

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ABSTRACT

Patients with Parkinson's disease (PD) are more susceptible to muscle fatigue, which can damage their gait. Physical activity can improve muscle condition, which is an important aspect during walking. The aim of this study was to analyze the effects of lower limb muscle fatigue on gait in patients with PD and healthy individuals, grouped according to physical activity level. Twenty Patients with PD (PD group) and 20 matched individuals (control group) were distributed according to physical activity level into four subgroups of ten individuals (active and inactive). Participants performed three walking trials before and after lower limb muscle fatigue, induced by a repeated sit-to-stand task on a chair. Kinematic (stride length, width, duration, velocity and percentage of time in double support) and kinetic (propulsive and breaking anterior–posterior and medio-lateral impulse) gait parameters were analyzed. In both groups, participants increased stride length and velocity and decreased stride duration and braking vertical impulse after lower limb muscle fatigue. The PD groups presented higher step width and percentage of double time support than the control groups before muscle fatigue. The control groups increased step width and decreased percentage of time in double support, while the PD groups did not change these parameters. For physical activity level, active individuals presented longer stride length, greater stride velocity, higher braking and propulsive anterior–posterior impulse and shorter step width than inactive individuals. Groups sought more balance and safety after lower limb muscle fatigue. Physical activity level does not appear to modify the effects of lower limb muscle fatigue during unobstructed walking in individuals with PD or controls.

1. Introduction

The general increase in human life expectancy coincides with an increase in the number of people with chronic diseases, such as Parkinson's disease (PD). Patients with PD present several motor and non-motor impairments [1], including a higher perception of fatigue than age-matched controls [2]. The exacerbated perception of fatigue is caused by musculoskeletal and neurophysiological impairments associated with PD, particularly resulting from altered norepinephrine and serotonin production due to degeneration of neurons of the raphe nuclei and locus coeruleus [1,3]. However, little is known about the effects of fatigue on movement in patients with PD. Previous studies indicate that gait is affected by fatigue in an age-dependent manner [4]. Gait adjustments with muscle fatigue are more pronounced in individuals over 40 years of age than in younger individuals. These adjustments appear to be aimed at maintaining adequate control of balance in the fatigued condition [4]. It is conceivable that individuals with PD demonstrate even more pronounced gait adjustments, since patients with PD present deficits in muscle strength and motor control [5].

Muscle fatigue could be expected to affect gait less in individuals with higher physical activity levels, due to their better neuromuscular and cardiovascular condition [6], which influences the process of muscle fatigue development [7]. However, the effects of muscle fatigue on gait in young adults are not dependent on their physical activity level [8]. This might be due to young adults having substantial remaining capacity to deal with the

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limited balance threat of normal unperturbed gait even with substantial muscle fatigue. Thus, whether this is generalized to older and diseased populations is unknown. Regular physical activity improves functional capacity [9] and walking ability [10] in patients with PD and likely slows down fatigue development, but whether it improves their gait in a fatigued state is unknown.

Therefore, the aim of the present study was to analyze the effects of lower limb muscle fatigue on gait in patients with PD and in healthy individuals, grouped according to physical activity level. We expected that patients with PD would be more affected by lower limb muscle fatigue than healthy controls. In addition, we hypothesized that both groups would improve anterior–posterior and medio-lateral balance control after lower limb muscle fatigue. Furthermore, we hypothesized that there would be an interaction between lower limb muscle fatigue and physical activity level, with greater effects of muscle fatigue on gait parameters in inactive participants of both groups.

2. Methods

2.1. Participants

After signing the informed consent, forty subjects participated in the study which had been approved by the local ethics committee (#3083/2011); 20 individuals with PD (PD group), according to the UK Brain Bank Criteria [11], and 20 neurologically healthy matched-individuals (control group). Individuals were included if they met the following inclusion criteria: (i) independently living in the community, able to walk without the use of any aids, not presenting balance or vision disorders (to guarantee no interference from individual disorders, walking limitations or safety during walking); (ii) did not have diabetes, hypertension, cardio-respiratory diseases. In addition, for patients with PD, the individuals were included in the study if the stage in Hoehn & Yahr Scale (H&Y) [12] was $\leq$3. During the sample selection process, 19 patients with PD and 4 neurologically healthy individuals were initially recruited but did not fit the criteria of the study.

Within the groups, two sub-groups ($n = 10$) were formed, according to physical activity level (active and inactive group). The Modified Baecke Questionnaire for Older Adults (MBQOA) [13] was used to determine the physical activity level. The active group was composed of individuals who scored $\geq$5 on the questionnaire and the inactive group was composed of individuals who scored $\leq$4 [14]. The PD group and the control group were matched by gender, age, body height and body mass and these parameters were similar in the sub-groups. The PD sub-groups were matched according to the PD stages and the clinical characteristics. A neuropsychiatrist performed a clinical assessment of the patients with PD to determine the stage of the disease in each patient and to test them on the motor section of the Unified Parkinson's Disease Rating Scale (UPDRS) [15], H&Y [12] and Mini-Mental State Examination (MMSE) [16].

2.2. Maximum voluntary contraction protocol

Maximum voluntary isometric contractions were performed on a leg press device [4,9]. A load cell with a precision of 0.98 N was used in combination with a signal amplifier (EMG System do Brasil Ltda.). The participants performed the test using both lower limbs simultaneously (hip joint angle = 110° and knee joint angle = 90° with 180° as full extension) and were instructed to produce maximum force as fast as possible for 5 s. Two attempts were performed before and after lower limb muscle fatigue, with a 2 min rest between attempts. The means of the two attempts before and after muscle fatigue were calculated for each participant. The maximum voluntary contraction was used to confirm the presence of muscle fatigue [4,8].

2.3. Lower limb muscle fatigue protocol

To induce lower limb muscle fatigue, participants performed a repeated sit-to-stand task from a chair with arms across the chest region [4,8]. The frequency of the sit-to-stand movement was controlled by a metronome (30 cycles/min). A standard chair (43 cm in height, 41 cm in width and 42 cm in depth) without armrests was used for all participants. The instructions given to the participants were: stand up in an upright position with knees fully extended, then sit back down and repeat the task at the beat of the metronome until you can no longer perform the task. The fatigue protocol was stopped when one of the following conditions was met; the participant indicated their inability to continue, the movement frequency fell below and remained below 30 cycles/min after encouragement, or after 30 min. The time to fatigue was recorded. The gait task and subsequently the maximal voluntary protocol were repeated immediately after the fatigue protocol.

2.4. Gait task

Participants performed three trials of unobstructed gait before and after the lower limb muscle fatigue protocol. Participants received the instruction to walk over an 8 m wooden pathway, which was covered with a black rubber carpet (3 mm thick), at a self-selected speed. The gait parameters of the stride (period between two consecutive heel contacts of the right limb) in the middle of the pathway were analyzed in the study.

2.5. Data analysis

Acquisition of kinematic gait parameters was accomplished with a three-dimensional optoelectronic system (OPTOTRAK Certus – 3D Motion Measurement System – Northeim Digital – NDI, Waterloo, Ontario, Canada), positioned in the right sagittal plane, using a sampling rate of 100 samples/s. Infrared emitters were placed over the lateral aspect of the calcaneus and the head of the fifth metatarsus of the right limb, and over the medial aspect of the calcaneus and the head of the first metatarsus of the left limb. Data were filtered using a 5th order low-pass digital Butterworth filter (zero-lag) with a cutoff frequency of 6 Hz. Stride length, stride duration, stride velocity, percentage of time in double support and step width were calculated.

Ground reaction forces were measured using a force plate (AccuGait, Advanced Mechanical Technologies) with a sampling frequency of 200 Hz, synchronized with the Optotrak system. The force plate was positioned across the central area of the pathway. The kinetic data were filtered using a 4th order low-pass digital Butterworth filter (zero-lag) with a cutoff frequency of 16 Hz. The magnitude of the ground reaction force was normalized by body weight from an acquisition in the orthostatic position and braking and propulsive vertical and anterior–posterior impulses were calculated.

2.6. Statistical analysis

The analysis with G*Power software showed that a sample size of at least 32 individuals (8 in each group) was needed for an 80% probability to detect a difference of 20% between the two groups for the primary outcome (stride velocity) with a type I error of 0.05, based on previously published data [4]. The statistical analyses were performed with SPSS 18.0 for Windows®. The level of significance was set at 5% for all analyses. Physical activity level was compared between the PD and control groups using one-way ANOVA. Time to fatigue was compared between the four sub-groups using a two-way ANOVA, with group and physical activity level (active and inactive sub-groups) as factors. The gait parameters and maximum voluntary isometric contractions were