

Muscular activity in different locomotion plans with the use of various shoes types and barefoot

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Abstract. The objective of this study was to evaluate the electromyographic activity of the muscles of the leg and spine associated with different types of shoes and barefoot, in the various plans of locomotion, in the situations before and after fatigue. **Methods:** Is a cross-sectional study, which was used a sample of convenience with 15 young women, aged between 18 and 35 years, sedentary. The examined muscles were tibialis anterior, gastrocnemius medialis and lateralis and erector spinae. The muscular activity was assessed during locomotion on flat surface, up and down stairs and in an inclined surface. The shoes were a high-heeled, small heeled, tennis, slipper and barefoot. **Results:** The results of electromyographic analysis showed that the muscles of the leg had greater electromyographic activity in the position of pre-fatigue of the lower limbs and erector spinae in the post-fatigue of the lower limbs, in most of the conditions and situations. **Discussion:** Adaptive conditions associated with regular use of high shoes, has been widely questioned in relation to the incidence of injuries. **Conclusion:** In post-fatigue of the lower limbs, there was a decline in the activities of the muscles of the leg and increased recruitment of the erector muscles justified by the need for greater stability of the spine and pelvis during the locomotion of young women.

Keywords: Ergonomics, occupational risk, gait, shoes

1. Introduction

One of the most prevalent aspects are women with complaints of discomfort in the lumbar region caused by the use of high heeled shoe [1]. Snow and Williams [2] described that there may be a link between attitude and the present discomfort, often associated with muscular fatigue and increase the forces of reaction soil during the use of such footwear.

Esenyel *et al.* [3]), Hong *et al.* [4] and Snow and Williams [2] showed that the major changes occur in the lower limbs (LL), according to the height of the

heel, occurs a significant increase in plantarflexion, changes in the orientation of bone structures of the ankle joints, metatarsal and metatarsophalangeals, changes in angles of insertion of the muscles of the foot and ankle and decrease the maximum angle of the knee during the balance and in the speed of knee's extension.

Previous work suggests that altered muscle activity will have a predictable effect on ground reaction forces. Such work has shown that the plantarflexors are the primary muscles contributing to the propul-

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sive impulse in the last half of stance during normal, unimpaired walking [5,6].

More specifically, the model developed by Neptune *et al.* [7] showed that the *gastrocnemius medialis* (GM) is the only ankle extensor that aids in swing initiation. In summary, there is little consensus regarding the functional role of the individual muscles pertinent to the swing phases of walking.

1.1. In walking, the body vaults up and over each stiff leg in an arc, analogous to an inverted pendulum. Kinetic energy in the first half of the stance phase is transformed into gravitational potential energy, which is partially recovered as the body falls forward and downward in the second half of the stance phase. As a leg strikes the ground, kinetic and gravitational potential energy is temporarily stored as elastic strain energy in muscles, tendons, and ligaments and then is nearly all recovered during the propulsive second half of the stance phase [8].

The static work is highly fatiguing and, whenever possible, should be avoided. When it is not possible, can be alleviated through changes in posture, use of comfortable shoes or through support for parts of the body in order to reduce the static contractions of the muscles [9].

Among the best resources for prevention is to choose the lowest shoes, which give greater support and balance, not forcing some areas of the body. Another good practice is regularly lengthening the muscles of the thigh and calf [10].

Today, more women are included in the labor market and the use of height heels is frequent, mainly associated with the aesthetic issue. Little has been studied on the influence of footwear in the joints of LL. Due to reports of annoyances such as pain, postural changes and deformities in the feet, it is extremely important to check what type of shoes would be more appropriate and more comfortable for everyday use.

1.1. Objective

The objective of this study was to evaluate the electromyographic activity of the muscles of the leg and spine associated with different types of shoes and barefoot, in the various plans of locomotion, in the situations before and after fatigue.

2. Methodology

2.1. Design of the study and sample

This is a cross-sectional study, which was used a sample of convenience with 15 young women, aged

between 18 and 35 years, sedentary. The exclusion criteria were women who had joint stiffness, pain that disable the tests, lower limbs discrepancy (over one centimeter), had the ankle sprain less than six months, have been diagnosed with ligament rupture in the ankles, have been subjected to physical therapy or surgery in the lower limbs less than six months. Obese women - Body mass index (BMI) ≥ 30 [11], pregnant, diabetic, wear aid to march, presence of swelling of the ankle and feet, hypertrophy over two centimeters of calf and thigh. That possessed hallux valgus, bunion of the V metatarsus and Morton's neuroma that impossibilities the procedures. This study was approved by the Research Ethics Committee of the Centro Universitário Newton Paiva with the number of internal project 0082, in March 06, 2008.

2.2. Instruments

It was used the electromyography EMG System, model EMG 1600, (EMG System, Sao José dos Campos, Brazil), connected to a microcomputer with eight surface electrodes active bipolar Ag/AgCl. The test results were stored and analyzed by specific software, following the manufacturer's manual.

The electromyography (EMG) is a technique that allows the documentation of the electrical signals generated by muscle cells, which allows the analysis of muscle activity during movement or simple linked to a task. It is necessary to understand concepts relating to EMG to ensure the validity and reliability of this instrument of evaluation of studies in the field of rehabilitation and the clinical practice of physiotherapists.

The validity and accuracy of the assessment of muscular activity, through the use of EMG, are related to the process of tracking signals and correct conducting of the procedures for analysis and knowledge of possible interference during the process of collecting [12,13].

It was used a flat surface with a distance of six meters, a ramp of one meter and sixty centimeters with an inclination of 16° and a ladder with three steps, with height of 16 cm and width of 24 cm.

2.3. Procedures

Initially, all volunteers were informed about the objectives and procedures of the study and then

signed the term of free and informed consent. Then, there was a standardized assessment, done by a properly trained examiner, for identification, history and physical examination of each voluntary. On physical examination, was done the goniometry of dorsiflexion, bilaterally.

After evaluation, the voluntary made an assortment, through sealed envelope to randomization of the plans of locomotion and shoes to be used during the collection of muscular activity before and after the protocol of fatigue.

It was demarcated a distance of six meters for locomotion in the flat surface. During the analysis, was despised the two meters initial and final in order to avoid interference in the electromyography's collection during acceleration and deceleration of the walk.

An examiner done the trichotomy of the points of insertion of the electrodes following the recommendations of Cram *et al.* [12] and clean the place through friction with gauze and alcohol. The examined muscles were *tibialis anterior* (TA), *gastrocnemius medialis* (GM) and *lateralis* (GL) and *erector spinae* (ERET), all bilaterally. Two electrodes were placed in the region where the examiner found, by palpation, the region of greater muscle contraction [12]. The electrodes were posted at a distance of two centimeters of each. It placed an reference electrode on the right acromion as a way to standardize the measures.

After the placement of electrodes, it was observed the "silence" of the muscle, and then called up the contraction of muscles to be examined during their movements made by them in order to confirm the correct positioning of equipment. It was subsequently held a maximum voluntary contraction isometric (MVCI) of each muscle in the standardization of data and further analysis of muscular activity. The data were stored on specific software.

The muscular activity was assessed during locomotion on flat surface, up and down stairs (three steps with each 15 cm tall) and in an inclined surface (16°).

The shoes were: high-heeled type Chanel, small heeled type Chanel, tennis, slippers and barefoot. Were considered high-heeled shoes those with height between nine and eleven centimeters and small heeled shoe those between five and seven centimeters. For the tennis was necessary that it had a heel lifting of two to four centimeters.

Foot switch was used to determine the stages of the walk, flash sync with the electromyography in order to determine the beginning of the movement and recording the walk. A metronome was used to

cadence and standardizes the walk speed to 110 steps per minute in the flat surface.

After collecting with the use of all shoes, in their movements for locomotion above, the participant was referred to a protocol of fatigue of the *triceps surae*, bilaterally. This protocol consisted in the participant execute movements of bending plant concentric and eccentrically, continuously, until the sensation of burning and not support more repetitions [14,15].

After the implementation of this protocol, they did the same pre-fatigue measures, which, the sequence of footwear and activities were, previously randomized. All data for analysis of locomotion in the various plans, using the various footwear and barefoot, were stored in the specific software equipment for later analysis.

2.4. Data Reduction

For electromyography analysis was used the software AqDanalysis following the manufacturer's recommendations. To standardize the data was used calculation of the Root Mean Square (RMS) and calculation of the percentage of MVCI. The processing of data included electromyography's rectification and filtering of signals. Data were collected at a frequency of 1000 Hz, were filtered with a high pass filter of 10 Hz and with a low pass filter of 500Hz. The amplifiers had an input impedance of 2 $\mu\theta$ and CMRR of 1000 $\mu\theta$ and lower data acquisition at frequencies from 10 to 1000 Hz.

3. Statistical Analysis

Descriptive statistics, tests of normality (Shapiro-Wilk) and tests of equal variance (Levene) were made for all variables, using the statistical package Statistical Package of Social Science for Windows (SPSS) as 15.0. (SPSS Inc ©., Chatanoga, IL).

It was used to test Post Hoc with Scheffé's correction for multiple comparisons, in order to establish the effect of interaction of shoes.

For analysis of the influence of the situations of pre and post fatigue, in the different plans and with different shoes and barefoot, was used t Student paired samples. The level of significance was established α equal to 5%.

4. Results

4.1. Sample's Characterization

Participated of this study 15 volunteers with ages ranging from 18 to 31 years (23.4 ± 3.37 years), sedentary. Of the fifteen voluntary, thirteen were right handed and two were left handed. The description of the volunteers is demonstrated in Table 1.

Table 1
Participants description

Volunteer	Age (years) ($23,4 \pm 3,6$)	Shoe Size (cm) ($36 \pm 1,13$)	Dominance
1	22	36	Right
2	21	36	Right
3	23	35	Right
4	18	36	Right
5	20	37	Left
6	21	36	Right
7	22	33	Right
8	22	36	Left
9	25	37	Right
10	23	38	Right
11	24	37	Right
12	31	36	Right
13	30	36	Right
14	22	35	Right
15	27	36	Right

4.2. Assessment of muscular activity pre and post-fatigue

For the assessment of muscular activity with the use of shoes and barefoot in the various plans of locomotion in situations of pre and post fatigue were found the following significant differences for their conditions of use or not use of footwear.

In this study were analyzed the muscles right tibialis anterior (RTA), left *tibialis anterior* (LTA), right *gastrocnemius medialis* (RGM), left *gastrocnemius medialis* (LGM), right *gastrocnemius lateralis* (RGL), left *gastrocnemius lateralis* (LGL), right *erector spinae* (RERET) and left *erector spinae* (LERET) that had significant differences (Table 2).

Table 2
Comparison of the muscles eletromyographyc activity

Muscle	Shoe	Condition	p Value
RTA - support LLL	Barefoot	Ramp down	0,001
	Small heeled	Flat surface	0,010
LTA - support RLL	Barefoot	Ramp up	0,005
	Small heeled	Flat surface	0,028
RGM - support RLL	Slipper	Down stairs	0,007
	Tennis shoe	Flat surface	0,049
RGM - support LLL	High heeled	Flat surface	0,002
LGM - support RLL	Barefoot	Down stairs	0,009
	High heeled	Ramp up Up stairs	0,039 0,049
LGM - support LLL	Tennis shoe	Up stairs	0,032
	High heeled	Flat surface Ramp down	0,008 0,036
RGL - support RLL	Barefoot	Flat surface	0,007
LGL - support LLL	Barefoot	Ramp up	0,001
	Small heeled	Ramp up	0,036
RERET - support RLL	Barefoot	Up stairs	0,011
	Slipper	Down stairs Flat surface Down stairs Ramp up Ramp down	0,001 0,049 0,001 0,001 0,015
	Tennis shoe	Flat surface Down stairs Ramp up Ramp down	0,008 0,022 0,022 0,016
	Small heeled	Up stairs Ramp up	0,033 < 0,001
	High heeled	Flat surface Ramp down	0,008 0,015

Continue

RERET - support LLL	Barefoot	Up stairs	0,034
		Down stairs	0,014
			Ramp down
	Slipper	Flat surface	0,002
		Up stairs	0,002
		Ramp up	< 0,001
	Tennis shoe	Ramp down	0,002
		Flat surface	0,016
		Down stairs	0,001
	Small heeled	Ramp up	< 0,001
		Down stairs	0,001
		Ramp up	0,005
	High heeled	Ramp down	0,041
		Up stairs	0,048
		Ramp down	0,021
LERET - support RLL	Barefoot	Subir escada	0,037
		Down stairs	0,002
	Slipper	Flat surface	< 0,001
		Up stairs	0,015
		Down stairs	0,022
	Tennis shoe	Ramp up	0,004
		Ramp down	0,007
		Flat surface	< 0,001
	Small heeled Salto alto	Down stairs	< 0,001
		Ramp up	0,011
		Flat surface	0,026
	High heeled	Down stairs	0,011
		Ramp up	0,022
		Ramp down	< 0,001
	LERET - support LLL	Barefoot	Up stairs
Down stairs			0,003
Ramp down			0,004
Slipper		Flat surface	< 0,001
		Up stairs	0,025
		Down stairs	0,036
Tennis shoe		Ramp up	0,009
		Ramp down	< 0,001
		Flat surface	< 0,001
Small heeled		Down stairs	< 0,001
		Ramp up	0,003
		Down stairs	0,005
High heeled		Ramp up	0,001
		Ramp down	0,039
		Up stairs	0,004
High heeled	Ramp up	0,004	
	Ramp down	0,001	

*Right lower limb (RLL), Left lower limb (LLL)

5. Discussion

The results of electromyographic analysis of the muscles evaluated showed that the muscles of the leg had greater electromyographic activity in the position of pre-fatigue of the lower limbs and *erector spinae* in the post-fatigue of the lower limbs, in most of the conditions and situations.

The muscle TA is the primary engine for dorsiflexion of the ankle and aid in its stabilization [16].

In this study, the muscles LTA and RTA showed significant differences when the volunteers were barefoot in the conditions ramp up and ramp down, respectively, during the balance of the walk and with the small-heeled shoes, in the plan, during the balance of the walk. Moreover, there was also an increase in electromyographic activity post-fatigue, except for the RTA barefoot ramp up.

The TA muscle controls the positioning of the foot both at the stage of support, with an increase in stability of the support of the segment in contact with the ground, as during the balance phase through the movement of dorsiflexion, which prepares the foot to the next support of the calcaneus, during the course of the walk [17,18]. This may be a factor that justified the difference found in those muscles while ramp up and down, during the balance phase of the walk.

Perry [18] describes a quick activation of the TA muscle during the initial phase of assessment of the march as a method of preparing for the detachment of the distal segment of the LL of the soil and in the terminal phase of the balance in order to maintain the dorsiflexion of the ankle to increase stability for the beginning of the new phase of the initial contact of the distal segment with double support.

With the co-activation of the muscles of the leg during the support of the distal segment of lower limb and because of the protocol of fatigue greater activation of the TA, can also manifest itself as a form of recruitment of this muscle for greater stability of the distal segment of lower limbs during the cycles of the march.

The muscle *gastrocnemius* is comprised of two portions, the medial and lateral. It is an important knee flexor and places the plantar flexion of the ankle, as a biarticular muscle.

On the activation of muscle RGM, there were significant differences when the volunteers were in slipper down stairs and tennis shoes in the plan, at the stage of support, and high-heeled shoes in the plan, during the balance of the march. There was also an increase in electromyographic activity post-fatigue, only with the use of slipper.

The LGM showed significant differences on barefoot condition down stairs and ramp up at the stage of support from right lower limb of locomotion, with the use of tennis shoes while rising ladders at the stage of support of left lower limb, in the high-heeled shoes ramp down at the stage of support of left lower limb and climbing stairs at the stage of support of the

right lower limb. There was also an increase of electromyographic activity post-fatigue, only with the use of tennis shoes.

The RGL showed significant difference in barefoot condition in the flat surface, during the support of the march. The LGL showed significant difference in barefoot condition ramp up during the support of locomotion.

The *gastrocnemius* medial and lateral portion, aid in propulsion during the locomotion of the individual in daily and professional activities. The prevalence of major activity of this muscle during the support of the motion can be understood because the need of maintaining the stability of body mass, absorbing and dissipating the reactive forces, as both acts in the increase phase as the initial support to control the bending knee, as an biarticular muscle [19].

Gefen *et al.* [20] showed a significant increase in the GL electromyographic activity in relation to GM with the use of high heels in women who had regular habit of use and non-regular. They inferred that lateral portion was more activated due to an intense need for contraction to compensate the strength of reaction soil. They also evaluated that the muscular fatigue of *gastrocnemius* was predominant in lateral portion during the use of high heeled shoe.

In this study, the medial portions of the muscle *gastrocnemius* had greater electromyographic activity than the lateral portions. What can be explained by the fact the inversion movement of the feet increases with the imbalance body marked by the use of shoes with little stability as slippers and high heeled shoes and the low use of shoes with high heels [16,20].

The ERET are important anti-gravity muscles and work predominantly on a static form during most of the day. Tissues liabilities, such as capsules, ligaments and discs of the spine become overwhelmed after the active elements become less effective and less on muscle fatigue [21].

Most of the conditions and situations before and after fatigue of the leg muscles assessed with the use of different shoes and barefoot, showed significant differences for the ERET muscles bilaterally.

The ERETE alone, showed significant differences only with the use of slipper upstairs at the stage of support from RLL and down stairs at the stage in support of the LLL locomotion. Using high heels showed significant differences down stairs, with support from RLL and the ramp up, with the support of RLL and LLL. The RERET isolated, had significant differences with the use of tennis, ramp up and down with support from RLL, and with small heels to upstairs with support from RLL.

No significant differences were found for ERET bilaterally on barefoot condition in the flat surface and to ramp up, with support from RLL and LLL, and ramp down with support from RLL, with the use of tennis, to upstairs, with support from RLL and LLL and ramp down with support from LLL, with the use of small heels in the flat surface, with support from RLL and LLL, upstairs with support of LLL, down stairs with support of RLL and ramp down with support of RLL; with the use of high heels, in support of the LLL, upstairs with support from RLL and down stairs with support of LLL.

For electromyographic activity of the muscles of the *erector spinae*, significant difference in the condition of pre and post-fatigue in most of the conditions of study with all types of shoes and barefoot. These findings contradict with those found in the study of Bendix *et al.* [22] in which this muscles were evaluated and were not statistically significant differences with the use shoes to high heels.

The analysis indicated minor electromyographic activity of the muscles of the spine when compared to the leg muscles in the position of pre-fatigue, due to lower demand of the voluntary muscle injury after reaching the required balance wearing high heeled shoes. Because of the use of the protocol of fatigue, it can be inferred that the *erectors* were more recruited to maintain the posture during locomotion, offsetting the reduction in the activation of other muscles evaluated. As suggested by Lee *et al.* [23], the *erector* muscles adapt to the situation of fatigue offsetting the reduction of activation of the muscles of lower limbs.

Casarin [24] found greater electromyographic activity of the muscles GM and GL bilaterally than *erectors spinae*, so growing proportion to the elevation of the heel. There was no significant difference between the voluntary barefoot only on condition that the group was not using daily.

The slipper was the shoe that promoted greater electromyographic activity of the *erector spinae* bilaterally. This may be justified by this be an unstable footwear without support on the side of the foot and the back of the calcaneus, when compared to other shoes used.

5.1. Clinical Relevance

The regular use of heels, especially the high, can lead to learning motor of the women that uses these shoes more often because the repetition of a task is a determining factor for cortical plasticity that, in turn, automatically generates the gesture [25]. Conse-

quently, there may be a lower recruitment of fibers to perform a task and reduced energy expenditure.

The fatigue of the muscles of the leg has caused greater activation of the ERET muscles to compensate the reduction of activation of the fatigued muscles, which suggests a major energy expenditure of these muscles, with possible consequences functional.

Adaptive conditions, such as weakness, muscle imbalance and shortening associated with regular use of high shoes, has been widely questioned in relation to the incidence of injuries as sprains, knee and ankle, and postural changes such as increased lumbar lordosis or its rectification.

Therefore, preventive actions such as implementation of a programme of regular physical activity, muscle strengthening and stretching, should be prescribed and targeted to women with this habit, and should be implemented in companies in order to prevent injuries and tables of pain. Thus, it could prevent the decrease in productive capacity and decrease the rate of absenteeism, reducing expenses in the health system existing in the country.

6. Conclusion

The electromyographic assessment showed, in most of the conditions, a greater activity of the muscles of the leg in pre-fatigue, particularly with high-heeled shoes and slipper, probably by instability and non-habit of regular use of these shoes. In post-fatigue of the lower limbs, there was a decline in the activities of the muscles of the leg and increased recruitment of the *erector* muscles justified by the need for greater stability of the spine and pelvis during the locomotion of young women.

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