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Original Article (short paper)

Incidence of injuries and associated factors in treadmill runners: a prospective cohort study

Priscila Monteiro Veras[1], Poliana Fernandes Moreira[1], Leonardo Lacerda Catharino[2], José Elias Filho[3], Diogo Simões Fonseca[2], Diogo Carvalho Felício[1,2]

[1]Universidade Federal de Juiz de Fora, Faculdade de Fisioterapia, Programa de Pós-graduação em Ciências da Reabilitação e Desempenho Físico-Funcional, Juiz de Fora, MG, Brasil;[2]Universidade Federal de Juiz de Fora, Faculdade de Fisioterapia, Juiz de Fora, MG, Brasil;[3]Universidade Federal de Juiz de Fora, Faculdade de Educação Física, Programa de Pós-graduação em Educação Física, Juiz de Fora, MG, Brasil.

Abstract - Aims: To determine the incidence of injuries in exclusive treadmill runners and the main associated factors in 24 weeks. **Methods:** The incidence of injuries was investigated every two weeks by an electronic form. To analyze the associated factors, muscle force output, range of motion, and flexibility were investigated. To perform a descriptive analysis (baseline) and injury predictive factors (regression), we divided runners into two groups, injured and uninjured. Comparisons between groups were assessed evaluated by Student's t-test, Mann-Whitney, or Chi-square test. The relationship between associated factors and incidence of injuries was estimated by Logistic regression analysis. The model's accuracy was assessed by the receiver-operating characteristic curve (ROC). Thirty-seven runners completed the study. **Results:** The incidence of injuries was 6.8 per 1,000 hours of exposure. Among the associated factors, we highlight that runners with higher hip flexor force output were 4 times more likely not to injure (OR 4.0; CI 95% 1.03 -16.23) and lower knee extensor force output was related to a greater chance of injury (OR .24; 95% CI .65 - .93). The area under the ROC curve was 0.84. **Conclusion:** The incidence of injuries in treadmill runners was high. The factors associated with the injuries were the output of the flexor strength of the hip and the extensor force of the knee.

Keywords: running; sports injuries; incidence; cohort studies.

Introduction

Running is considered a contemporary social phenomenon and it is one of the five most popular sports activities in the world[1]. Among several ways of practicing running, treadmill running stands out[2]. The number of treadmill users in the United States of America reached approximately 51.8 million in 2016[3]. The choice to run on a treadmill is related to convenience, social aspects, and climate[4]. It should be noticed that each type of running surface has its characteristics.

Several studies report kinematic and kinetic differences between treadmill and overground running. The main differences mentioned in a recent systematic review[5] were: less vertical displacement of the pelvis, less range of motion of knee flexion during stance, less peak propulsion, and increased moment of the sagittal plane of the ankle in the treadmill run. Another point reported in the literature is the different muscle recruitment, due to the rigidity of the surface[6]. Oliveira et al.[7] evaluated 11 muscles and observed greater electromyographic activation of the peroneus longus, tibialis anterior and soleus during the support phase in the overground running. In addition, treadmill running has less air resistance and energy cost[8], as demonstrated in a recent meta-analysis in which was pointed that the lactate concentration and oxygen consumption were lower in treadmill running at almost full speed[9].

Treadmills are widely used in the processes of conditioning and rehabilitation. Fonseca et al.[10] report that the treadmill seems to be the most appropriate surface for training, as it was a factor that resulted in less injury in half marathon runners. The incidence of injuries related to running and the biomechanical risk factors may vary depending on the population of runners[11], the definition of the injury, and the duration of the study follow-up[12]. However, we did not find prospective studies on injuries in exclusively treadmill runners.

Injuries in runners can lead to absenteeism at work, increased demand for health services, discontinuity of training, and lead to psychosocial repercussions[13]. Injuries are caused by several determinants, and the identification of its patterns and the risk factors are essential to managing preventive measures[14]. Recent systematic reviews on the topic noted that the number of the available evidence is scarce and the results are inconsistent[11,15]. Therefore, this study aimed to (1) determines running-related injuries incidence in treadmill runners and (2) investigate related biomechanical factors proposed by current literature[15], such as muscle force output, range of motion, and flexibility. We hypothesized that treadmill runner's injury incidence would be lower than overground runners and it would be associated with the biomechanical factors investigated.

Methods

Study Design

This is a prospective 24-week cohort study exclusively with treadmill runners by an online questionnaire. The research was approved by Universidade Federal de Juiz de Fora' Research Ethics Committee of the (2,362,240/2017). Informed written consent was obtained from all participants before their involvement in the study.

Sample

Participants were sampled by convenience via research advertisements in fitness centers and on social networks. Were included both gender recreational runners, aged between 18 and 60 years old, who only trained on a motorized treadmill for at least 3 months and ran the minimal distance of 10 kilometers per week. In baseline, all participants should be without self-reported pain or musculoskeletal discomfort in the lower limbs, trunk, and musculoskeletal injuries for the last 06 months. Before the assessment (48 hours), the runners were instructed not to perform vigorous physical activity.

Assessment Procedures

All assessments and procedures were standardized and conducted by an experienced physiotherapist. A reliability study was conducted to evaluate intra-examiner reproducibility using the intraclass correlation coefficient (ICC), two-way mixed model, consistency, average measures (3,k). The sample size for the reliability study was estimated considering $H_0 = 0.4$, $H_1 = 0.75$, $\alpha = 0.05$, $\beta = 0.2$, and n=2 [16], resulting in 33 participants. The ICC results of each test were reported. The study took place between December 2017 and March 2019, and the data were collected in the Motion Analysis Laboratory from the Universidade Federal de Juiz de Fora.

The assessment consisted of 7 tests in total, with 5 measurements of strength and 2 range of motion. The tests are described below.

Isometric muscle force output (kgf/kg)

Assessed using microFet2™ manual dynamometer (Hoggan Health Industries, Draper, UT, USA) with threshold standardized as "HIGH" and in Kgf. The runner was asked to perform an isometric submaximal muscle contraction to familiarize himself with the procedure. Subsequently, the runner received a standardized verbal command ("One, two, three and now: force, force, force, force, force, and relax") to perform the maximum isometric contraction for five seconds, keeping the segment static. Peak values were recorded for three repetitions and mean values calculated and used as the final result. A rest period of 15 seconds was set between contractions. Measurements were normalized according to the bodyweight of each runner assessed, according to the following formula: (muscle force output (kgf)/body weight (kg)) x 100[17]. We used polyvinyl chloride (PVC) tube attached to the wall for dynamometer stabilization. All isometric strength measurements followed the same procedure described above.

Hip flexors (kgf/kg)

Measured with the runner in lateral decubitus position (LDP) on the stretcher, facing the wall, with the assessed lower limb upwards, one hand behind the head and the other along the body with hip and knee extended. The pelvis was stabilized with an inelastic belt, and the dynamometer was positioned on the tibia's anterior face, 5 cm above the medial malleolus, and coupled to a PVC tube fixed to the wall (Figure 1). The test was adapted from Thorborg et al.[18]. The intra-examiner reliability ($ICC_{3,k}$) for the right lower limb test was 0.96 and for the left lower limb was 0.90.

Hip extensors (kgf/kg)

Measured with the runner in the LDP on the stretcher, with the back facing the wall, the evaluated lower limb upwards, one hand behind the head and the other along the body, with hip and knee extended. The pelvis was stabilized with an inelastic belt, and the dynamometer was on tibia's posterior face, 5 cm above the medial malleolus, and attached to a PVC tube fixed to the wall (Figure 2). The test was adapted from Thorborg et al.[19]. The intra-examiner reliability ($ICC_{3,k}$) for the right lower limb was 0.93 and for the left lower limb was 0.94.

Hip abductors (kgf/kg)

Measured with the runner in the supine position on the stretcher, with hands behind the head, dynamometer 5 cm above the lateral malleolus coupled to a PVC tube fixed to the wall[19] (Figure 3). The intra-examiner reliability ($ICC_{3,k}$) for the right lower limb was 0.97 and for the left lower limb was 0.70.

External rotators (kgf/kg)

Measured with the runner sitting, with hip and knees flexed at 90º. The dynamometer was positioned 5 cm proximally to the medial malleolus of the assessed lower limb and attached to a PVC tube fixed to the wall[19] (Figure 4). The intra-examiner reliability ($ICC_{3,k}$) for the right lower limb was 0.86 and for the left lower limb was 0.88.

Knee extensors (kgf/kg)

Measured with the runner sitting, with hip and knees flexed at 90º. An inelastic belt was placed on the thighs, and the runner's arms were crossed at chest height. The dynamometer was positioned 5 cm above an imaginary bimalleolar line and coupled to a PVC tube fixed to the wall[19] (Figure 5). The intra-examiner reliability ($ICC_{3,k}$) for the right lower limb was 0.93 and for the left lower limb was 0.92.

Range of motion

Assessment of hip's passive stiffness (degrees): measured with the runner in the prone position. The examiner passively performed the hip medial rotation in all amplitudes for five times. After this procedure, the hip medial rotation was performed on the assessed limb until the first detectable resistance, then the inclinometer was placed 5 cm from the anterior tibial tuberosity (ATT)[20]. The intra-examiner reliability ($ICC_{3,k}$) for the right lower limb was 0.81 and for the left lower limb was 0.93.

Hamstring muscle flexibility (degrees): measured with the runner in the supine position and the assessed hip flexed at 90°. The contralateral limb was maintained extended, the inclinometer positioned with the magnetic base on the tibia's anterior edge 15 cm from the center of ATT, and the examiner extended the leg until the first resistance[21]. The intra-examiner reliability ($ICC_{3,k}$) for the right lower limb was 0.79 and for the left lower limb was 0.82.

Definition of running-related injury and incidence calculation

The primary outcome of this study was the incidence of musculoskeletal and skin injuries in treadmill runners. We defined injury as any running-related pain/discomfort of musculoskeletal[22–24] /skin[25] origin that has been severe enough to prevent the runner from running at least once. The incidence was calculated considering the time (running hours) and injuries (number) normalizing for 1000 hours[24,26].

Follow-up

In the follow-up period, an online questionnaire was sent to the runners every two weeks by e-mail. It had questions regarding injuries and the absence of training due to injury, the performed distance, and the training duration. Runners that did not respond to two questionnaires, consecutive or not, ran on another surface or stopped running for any reason that was not associated with a running-related injury were excluded.

Statistical analysis

Descriptive statistics were used to characterize the sample, and data expressed as mean ± standard deviation or percentage, when appropriate. Shapiro-Wilk test was used to evaluated data normal distribution.

Comparisons of baseline variables between injured and uninjured groups were made using the unpaired Student's t-test, Mann-Whitney test, or chi-square test. Both lower limbs were evaluated, although, for the injured runners, the analyzed data were obtained from the injured lower limb and the dominant (determined by which leg they kick)[27] with one used for non-injured.

To estimate the relationship between associated factors and the injury incidence, a backward stepwise multivariate logistic regression was used and the odds ratio (OR) with a 95% confidence interval estimated. The goodness of fit was evaluated with the Hosmer-Lemeshow test and accuracy assessed by the Receiver-Operating Characteristic (ROC) curve. A significance level (α) = .05 was considered and all analyzes were processed using the SPSS 22.0 program (SPSS Inc, Chicago, USA).

Figure 1 - Hip flexors (kgf/kg).

Figure 2 - Hip extensors (kgf/kg).

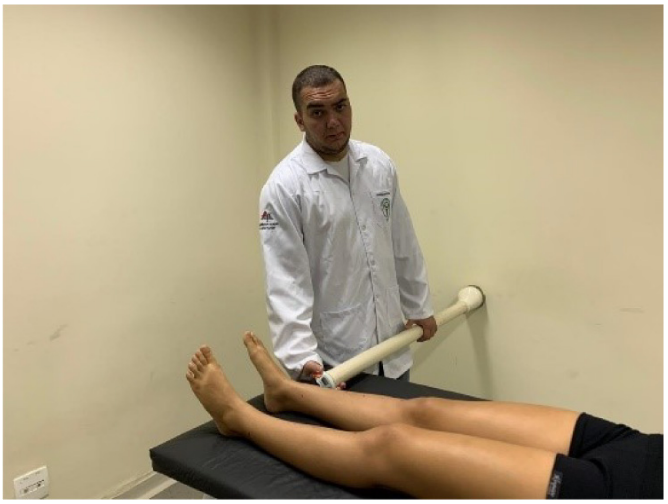

Figure 3 - Hip abductors (kgf/kg).

Figure 4 - External rotators (kgf/kg).

Figure 5 - Knee extensors (kgf/kg).

Results

From 42 included runners, 37 completed the whole study protocol (Figure 6).

Runners' baseline characteristics are summarized in Table 1. There was no significant difference between the groups at the baseline. The injuries incidence was 6.8 per 1,000 hours of running. During the follow-up, 13 injuries (11 musculoskeletal and 2 integuments) were recorded. There were 10 injured runners of whom 7 suffered one musculoskeletal injury, 2 suffered two musculoskeletal injuries, and 1 runner suffered 2 integumental injuries (blisters). The proportion of musculoskeletal injuries by anatomical region was knee (31%), hip (23%), leg (15%), thigh (8%), and lumbar spine (8%). Integumental injuries occurred in the calcaneal region (15%). During the 24 weeks, runners totaled 12693 km, with a weekly average of 14 km per runner.

Table 2 presents the relationship between associated factors in the baseline. There was no statistically significant difference between the groups.

Table 3 presents the logistic regression analysis, expressed as the odds ratio. Higher hip flexor force output (kgf/kg) was identified as 4 times more likely to have no injury in the final model (OR 4.0; 95% CI 1.03-16.23) and lower knee extensor force output (kgf/kg) as the highest chance of injury (OR .24; 95% CI (65-93).

The Hosmer-Lemeshow quality test (p = .438) showed no mismatch of the final model to the data and the area under the ROC curve was 0.84 (figure 7) with a 95% CI (.65-1.0).

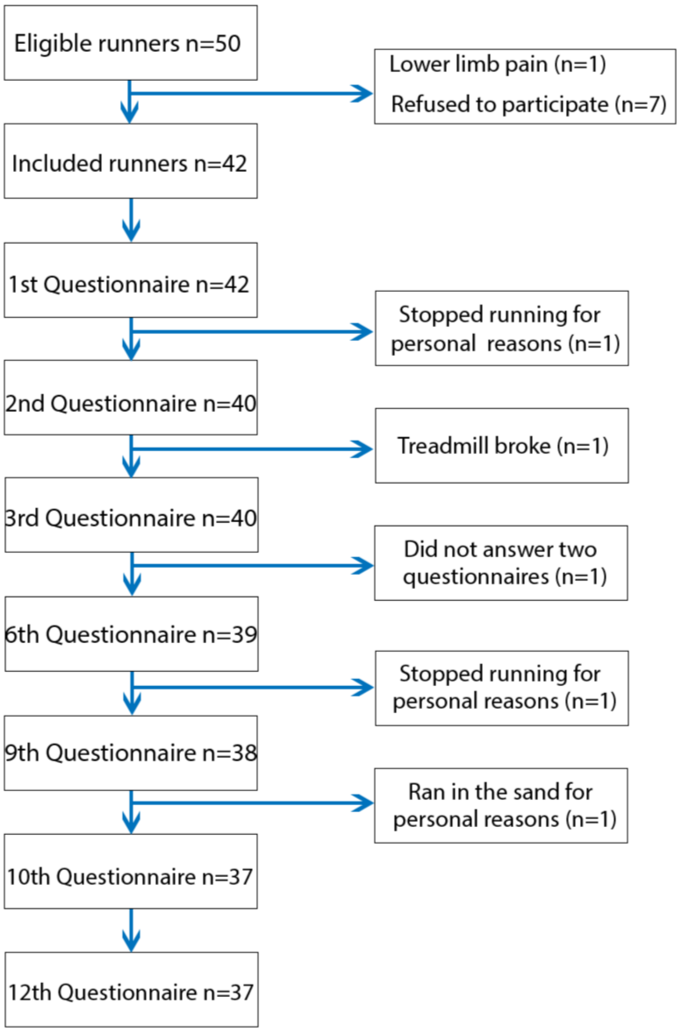

Figure 6 - Flowchart of the inclusion process and follow-up of the study.

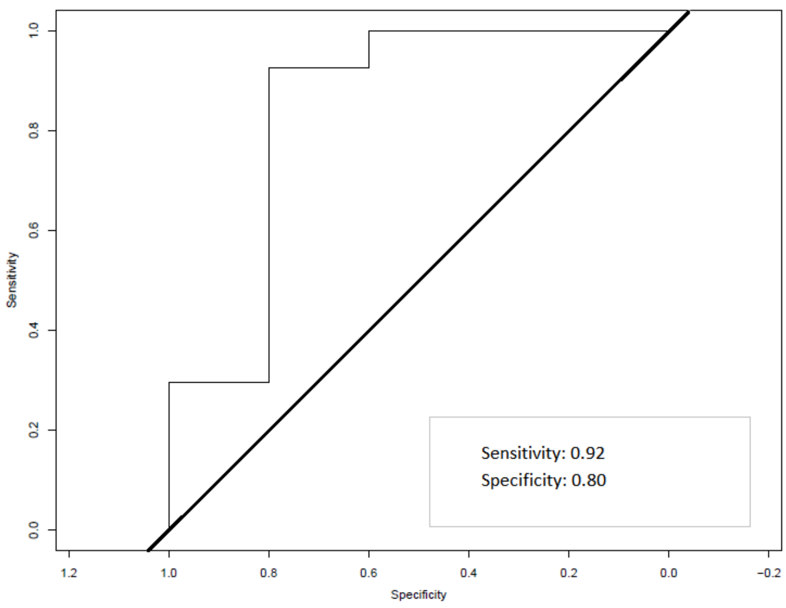

Figure 7 - ROC curve for the final model binary logistic regression analysis.

Table 1 - Baseline characteristics of treadmill runners.

Variables	Injured (n=10)	Uninjured (n=27)	*p**
Age, years†	34.4 ± 8.4	29.9 ± 7.5	.060
Sex, Female, n (%) ‡	7 (70)	14 (51.9)	.329
Height, cm†	160.0 ± 0.1	160.0 ± 0.9	.892
Bodyweight, kg†	68.4 ± 14.4	71.6 ± 14.7	.557
BMI, kg/m2†	24.3 ± 3.3	25.3 ± 3.4	.446
Schooling, n (%) ‡			
High school	2 (20)	9 (33.3)	.431
Higher education	8 (80)	18 (66.7)	
Non-Smoker, n (%) ‡	10 (100)	27 (100)	
Dominant lower limb, n (%)			
Right	9 (90)	24 (88.9)	.923
Left	1 (10)	3 (11.1)	
Time practicing running, months†	30.1 ± 37.7	44.7 ± 49.6	.215
Mileage, km/week†	13.9 ± 3.3	19.0 ± 14.3	.754
Treadmill speed, km/h†	9.3 ± 1.35	9.6 ± 2.1	.931
Training duration, min†	35 ± 10.5	37.5 ± 11.9	.665
Training frequency, n/week†	3.6 ± 0.9	3.5 ± 1.0	.719
Training orientation, n (%) ‡			
Yes	6 (60)	13 (48.1)	.522
Practiced another modality, n (%) ‡			
Yes	10 (100)	26 (96.3)	.324
Use insole, No, n (%) ‡	10 (100)	27 (100)	
Previous musculoskeletal injury, n(%) ‡			
No	6 (60)	22 (81.5)	.176
Previous skin injury, n (%)‡			
No	9 (90)	17 (63)	.110

Abbreviation: BMI = Body mass index.
*Comparison of injured individuals with uninjured individuals using statistic method according to data distribution.
† Values are expressed as mean ± standard deviation.
‡ Values are expressed as the number of runners and their respective percentages (%).

Table 2 - Tests assessed at baseline

Variables	Injured (n=10)	Uninjured (n=27)	*p**
Hip flexors, Kgf/kg†	12.3 ± 3.3	14.0 ± 2.8	.130
Hip extensors, Kgf/kg†	19.6 ± 4.3	20.2 ± 6.0	.760
Hip abductors, Kgf/kg†	17.8 ± 3.5	20.3 ± 4.1	.094
External hip rotators, Kgf/kg†	11.8 ± 3.8	13.1 ± 3.5	.316
Knee extensors, Kgf/kg†	47.1 ± 16.4	45.3 ± 11.0	.700
Hip stiffness test, degrees †	34.3 ± 8.9	38.2 ± 9.9	.286
Hamstring flexibility, degrees†	131.6 ± 6.7	135.58 ± 8.5	.197

*Comparison of injured individuals with uninjured individuals using statistic the method according to data distribution.
† Values are expressed as mean ± standard deviation.

Table 3 - Multivariate binary logistic regression analysis (n=37).

Variables	Final Model	
	OR (CI)	*P*
Hip flexors, Kgf/kg	4.0 (1.03-16.23)	.045
Hip extensors, Kgf/kg	-	-
Hip abductors, Kgf/kg	-	-
External hip rotators, Kgf/kg	3.0 (.87-10.71)	0.81
Knee extensors, Kgf/kg	.24 (.65-.93)	.039
Hip stiffness test, degrees	-	-
Hamstring flexibility, degrees	4.1 (.91-19.15)	.066

Abbreviation: OR= odds ratio**,** CI = confidence interval.

Discussion

Injuries incidence in treadmill runners was 6.8 per 1,000 hours of running, and the main associated factors were hip flexor and knee extensor isometric muscle force output.

Although running is not a physical contact sport, the incidence of injuries was high compared to other modalities. A study conducted with 268 athletes found an incidence of 4.4 in basketball, 5.3 in soccer, and 1.7 in volleyball for 1,000 hours of exposure to the sport. The definition of injury in the study included those that caused the interruption of participation in the current session and those that caused the interruption of participation the day after the start[28]. We postulate that the challenge of improving performance, associated with a repetitive gesture, as well as inadequate load management, may demand more from the capacity of individuals, contributing to the high number of injuries. Conversely, exclusive treadmill runners have lower injury rates when compared with runners on other surfaces 7.7 [23] to 10[24]/1,000 hours, however, these studies had a 12 weeks follow-up and did not report integumental lesions.

It is believed that particular characteristics of treadmill running, such as shorter step length and increased cadence, reduces patellofemoral joint stress[29], and decreases peak ground reaction force[30] reducing the amount of mechanical energy transferred to the lower limbs, due to the longer duration of plantar flexion[30], which can help with greater absorption and dissipation of impacts by the ankle joint[30,31].

The knee was the most affected anatomical region, which aligns with a recent systematic review[32], which covers several types of runners with low to high mileage training characteristics per week. The high index of knee injuries is related to the magnitude of the impact forces on the lower limbs during running, which can reach 2.5 times body weight[33]. Skin injuries, in turn, accounted for 15% of the injuries, being all blisters, which are the most common integumental injuries in runners[34,35], occurring due to humidity, inadequate footwear adjustment, and increased running volume[35].

To not underestimate the results, we choose a rigorous definition of injury widely used in the literature[22–24] and included integumental injuries, which frequently appear in runners[36], despite the lack of studies on this subject. The sample characteristics may also have influenced our findings. At baseline, both groups had lower flexor, extensor, and abductor force output than[37]. Another point is that uninjured runners were overweight and injured runners were at the limit of normal BMI. According to a study by Clermont et al.[38], recreational runners had an average BMI of 25.03 which was significantly different from competitive runners, we conjecture that recreational runners may not be committed to following a systematic training routine.

Regarding the associated factors, the regression model showed a significant association between hip flexor and knee extensor force outputs. When running on the treadmill, the moving belt reduces energy demands of propelling the body by moving the foot and support leg backwards[39], performing greater hip extension during the swing phase[40], so the flexors would act eccentrically, by breaking the lower limb. Luedke et al.[41] also noted the strength associated with injuries in cross country runners, runners who had lower strength from hip abductors, knee flexors, and extensors had a higher incidence of anterior knee pain. Sports injuries are complex and with several interaction factors, we postulate that the muscular condition associated with increased demand may overload structures and favor injuries. Detecting risk factors are relevant, as it can help researchers and health professionals to better understand the etiology of injuries, as well as methods of treatment and prevention.

Study limitations include the sample size due to difficulty recruiting exclusively treadmill runners, as a portion of them run during the week in gyms and sporadically on other surfaces during the weekend. However, the number of treadmill runners has been increasing and there are few studies on the topic. Further prospective studies should be conducted to investigate biomechanical risk factors as well as training load (weekly frequency and distance/week) in treadmill runners.

Conclusion

The incidence of injuries in treadmill runners was 6.8 per 1,000 hours of running, with hip flexor and knee extensor force output being the main associated factors.

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Corresponding author:

Priscila Monteiro Veras Department Graduate Program in Rehabilitation Sciences and Physical Functional Performance Department, Federal University of Juiz de Fora (UFJF), Minas Gerais, Juiz de Fora, Brazil. Av. Eugênio do Nascimento, s/n, Bairro Dom Bosco, Juiz de Fora, MG, Brazil. 36038-330. Email: priscilaveras@gmail.com

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