Research Paper: Effects of Peroneal Muscle Fatigue on Ground Reaction Force Profile During Lateral Hop Landing

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ABSTRACT

Introduction: Ankle sprain occurs often late in sport competitions consisting of many lateral ankle movements, jumping or landing, where peroneal muscles are fatigued. Changes in Ground Reaction Force (GRF) parameters may also be related to this injury. The present study aimed to assess the effects of peroneal muscles fatigue on GRF profile during lateral hop landing.

Materials and Methods: Twenty-five recreationally active healthy males performed a lateral hop on a force plate before and after a fatigue intervention by a Biodex dynamometer using an isometric eversion at 40% of maximal voluntary isometric contraction until eversion torque decreased to 50% of its initial value. A force plate and an EMG system were used to collect data during lateral hop landing.

Results: Fatigue was confirmed by a significant fall in median frequency (P<0.05). Mean of the normalized peak GRF in the vertical direction, mean of the normalized impulse of the GRF in the vertical direction, and means of the time to peak GRF in the vertical and mediolateral directions decreased significantly after fatigue (P<0.05).

Conclusion: If the peroneal muscles are fatigued, a much more load may transfer to the vertical direction during landing, although the vulnerable part of the ankle is situated on the mediolateral direction.

Keywords:
Hopping, Loading rate, Impulse, Sports injury

1. Introduction

Because of high prevalence of ankle injuries, in particular ankle sprain, researchers have conducted many studies to determine the causes or mechanisms of the injury and in doing so prevent, treat or rehabilitate it [1, 2]. Ankle sprain may be related to muscle fatigue since some studies have reported that it occurs late during sports competitions, where the muscles are fatigued [3]. Moreover, some studies report that this injury is frequently observed in sports with high repetitions of jumping, landing or lateral movements of the ankle region [4, 5].

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Functional tests, therefore, may be useful to assess changes in the lower extremity kinetics and or kinematics with fatigue, and study the relation of these changes with ankle sprain. Some researchers have examined the timing, sequencing or level of electrical activity of the relevant muscles in a fatigued situation [6-8]. They have suggested the peroneal muscles, in particular Peroneus Longus (PL), as the primary defense mechanism which function dynamically to prevent spraining of the ankle [9]. Others have focused on the kinematic changes of the lower extremity with fatigue that may lead to the injury [10]. Change in the kinetic parameters of the Ground Reaction Force (GRF) with fatigue may be another important factor related to the injury [4, 11].

In the current study, we measured variables such as the peak GRF, time to peak GRF, loading rate of the GRF and impulse of the GRF in the vertical, Mediolateral (ML) and Anteroposterior (AP) directions. In addition, peak GRF in the vertical direction divided by peak GRF in the ML direction (V/ML ratio) was assessed. These variables are important for biomechanical analysis during functional activities of the lower extremities [11, 12].

Typical signal of the GRF consists of two phases; the first (passive) phase and the second (active) phase. The second phase was considered for analyses in the present study because of its high relevance to the lower extremity kinematic and muscular function [13]. Some of these parameters have been assessed separately during various activities. However, to our knowledge, no study has examined all parameters of the GRF during a functional task in a fatigued state. The aim of the present study, therefore, was to assess the effect of a peroneal muscle fatigue intervention on the GRF profile during lateral hop landing test. We hypothesized that fatigue would change the GRF parameters during landing from a lateral hop.

2. Materials and Methods

Twenty-five apparently healthy, recreationally active men (Mean±SD age=25.7±3.2 years, Mean±SD mass=70.9±10.2 kg, Mean±SD height=176.1±4.7 cm) were recruited from a School of Physical Education and Sport Sciences to participate in the current study using a convenience non-probability sampling method. We chose males only for the present study since each gender may respond differently to fatigue [14]. They had no history of fracture, joint restriction or deformity in their lower extremities. In addition, they reported no history of ankle sprain, giving way or pain during the previous year. The participants who were unable to perform the lateral hop test, the Maximal Voluntary Isometric Contraction (MVIC) or the fatigue intervention were excluded from the study. In addition, they would be excluded if they had any pain during any part of the tests.

Study procedure

Each participant came the biomechanics laboratory two times; the first time for familiarization with the tests and signing the informed consent, and the second time for performing the main tests. The participant performed a 3-minute stationary cycling as a warm-up program. All tests were accomplished using the dominant leg only since the dominant leg is prone to injury more than the other leg [15].

The leg that the participant preferred to kick a ball was considered as the dominant leg. The participant performed a lateral hop on a force plate apparatus (Bertec 9090-15 and Bertec AM-6701 amplifier, Bertec Corporation, Columbus, Ohio, USA) mounted on the ground before and after a fatigue intervention. For this purpose, the participant stood barefoot on the dominant leg lateral to the force plate. Lateral border of the foot was parallel to the edge of the force plate. The participant raised the other leg to clear it from the ground (Figure 1).

The hands were by the sides and he was asked to look at a point on the front wall. Then, we asked the participant to jump laterally and land on the center of the force plate using the dominant limb. The participant had to maintain his stability on the dominant foot until hearing an alarm (after 10 seconds). This test was performed two times more. The horizontal distance for the lateral hop (the distance between the dominant leg and the center of the force plate) was determined before the main test. For this purpose, the participant had performed a lateral hop similar to the main test, but, with the maximum distance that he could hop without losing her stability. The maximum value during three efforts was considered as the maximum horizontal distance for the lateral hop. Seventy percent of the maximum distance was considered for the main test.

The fatigue intervention was executed using a Biodex system 3 dynamometer (Biodex medical, Shirley, NY, USA). Ankle inversion and isometric mode of the Biodex was set after calibration. The participant sat on the seat of the dynamometer which had been reclined to 70 degrees. The tilt of the head of the dynamometer was set at 0 degree. The ankle joint was positioned at neutral angle. The hip and knee joints were adjusted to set the leg in the horizontal position. The ankle was fixed to the relevant attachment using a strap. The other straps support the leg and the trunk. The weight of the leg was supported by an under-leg attachment. At first, the MVIC was measured. The participant was asked to contract evertor muscles isometrically, as strong as possible, against the resistance offered by the ankle attachment of the dynamometer for 6 seconds.

After 2 minutes rest, this process was repeated two times more. The highest value was considered as the MVIC. During fatigue intervention, the participant was asked to evert his ankle isometrically at 40% of the MVIC of the evertor muscles until the eversion torque decreased to 50% of its initial value (20% of the MVIC) and remained below this value for 5 seconds. Similar to the pre-fatigue stage, the lateral hop test was performed three times immediately after the fatigue intervention within two minutes. The electrical activity of the Peroneus Longus (PL) was recorded with a sampling rate of 1000 Hz using a DataLink LS900 apparatus (Biometrics Ltd, Gwent, UK) during measuring the MVIC and performing the fatigue intervention. For these purposes, a bipolar Ag/AgCl electrode (center-2 cm-center) was attached to the PL muscle according to the protocol recommended by the SENIAM [16].

Data analysis

A power spectrum analysis with 500 ms moving windows was performed on the recorded EMG signals of the PL during measuring the MVIC and executing the fatigue intervention. The mean of Median Frequency (MDF) for every two continuous seconds was calculated for the fatigue signal, and then normalized by the MDF calculated during the MVIC. The normalized MDFs were considered for analysis.

The data related to the GRF during landing have been recorded using the software of the force plate with sampling frequency of 500 Hz. Ten percent of the peak GRF in each direction was considered as the onset of the GRF signal for that direction. A GRF signal consists of two phases (two peaks). The second phase was considered for analyses in the present study because it is highly related to the lower extremity kinematic and muscular function [13]. Maximum values of the GRF in the vertical, ML or AP directions were considered as the peak GRF for that direction, respectively. Peak GRF normalized to body mass was considered for all analyses to eliminate any inter-individual difference.

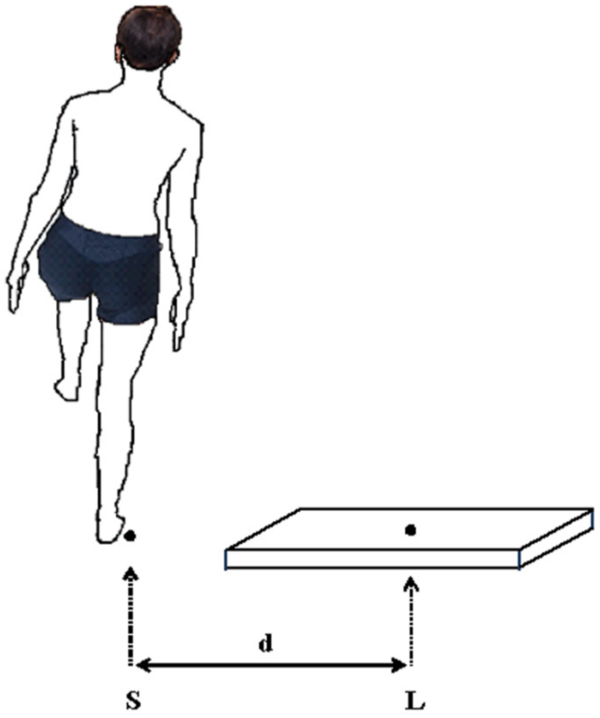

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Figure 1. Illustration of the lateral hop test set-up

S: Starting point; L: Landing point; and d: Calculated lateral hop distance for the main test. (d equals to 75% of the maximum lateral hop distance measured before the main test)

Time to peak GFR was calculated as the time between the onset of the GRF signal and the peak GRF for the vertical, ML or AP directions, separately. Integral of the time with the peak GRF in each direction was considered as the GRF impulse for that direction. The impulse was then normalized to body mass for analysis. Loading rate in each direction was calculated as the normalized peak GRF divided by the time to peak GFR for that direction. The V/ML ratio was also calculated for further analysis. The average of each of the above variables across three trials was considered for analyses to decrease the effect of performance variability.

Statistical analysis

A linear regression analysis was used to assess the rate of the decline in the MDF during the fatigue. Results of the Kolmogorov-Smirnov statistical tests indicated that the distributions of all the data were in accordance with the normal distribution. Thus, the mean of the normalized peak GRF, the time to peak GRF, the normalized loading rate of the GRF, the normalized impulse of the GRF in various directions, and the V/ML ratio during landing were compared before and after fatigue using separate dependent t tests. SPSS version 19 (SPSS Inc., Chicago, Illinois, USA) was used for all statistical analyses. A significant level of 0.05 was considered for these analyses.

3. Results

Mean±SD fatigue intervention lasted 309.06±24.04 seconds. The linear regression analysis showed a significant fall in the MDF of the PL during fatigue, with a Mean±SD slope of -0.132±0.02 $Hz.s^{-1}$, which confirmed that the intervention had been effective (P<0.05).

Mean of the normalized peak GRF in the ML or AP directions did not change significantly due to fatigue (P>0.05, Power=0.77 for the ML direction, and power=0.67 for the AP direction). However, Mean±SD of the normalized peak GRF in the vertical direction decreased significantly from 2.99±0.13 $N.kg^{-1}$ before fatigue to 2.87±0.13 $N.kg^{-1}$ after fatigue (P=0.013) (Figure 2). Also, the Mean±SD of the time to peak GRF in the vertical direction decreased significantly from 73.71±3.58 ms before fatigue to 69.77±2.79 ms after fatigue (P=0.016).

In this regard, the Mean±SD of the time to peak GRF in the ML direction decreased significantly from 71.08±2.62 ms before fatigue to 66.96±2.53 ms after fatigue (P=0.00). However, this measure in the AP direction did not differ significantly (P=0.75, Power=0.75) (Figure 3). Also, mean of the normalized loading rate of the GRF in the vertical, ML or AP directions did not change significantly due to fatigue (P>0.05, power were equal to 0.83, 0.68 and 0.72 for the vertical, ML and AP directions, respectively).

Mean±SD of the normalized impulse of the GRF in the vertical direction decreased significantly from 20.86±0.79 $N.ms.kg^{-1}$ before fatigue to 20.24±0.76 $N.ms.kg^{-1}$ after fatigue (P=0.008); However, this measure in the ML or AP direction did not change significantly (P>0.05, Power=0.83 for the ML and Power=0.71 for the AP direction) (Figure 4). Finally, mean of the V/ML ratio did not change significantly after fatigue (P=0.27, Power=0.82).

4. Discussion

The current study was designed to assess the effect of peroneal muscle fatigue intervention on the GRF-related parameters in various directions during lateral hop landing test. We hypothesized that fatigue would change the GRF parameters during landing. The results indicate that PL muscle fatigue, which may be confirmed by a decreasing gradient in MDF, decreases the normalized peak GRF in the vertical direction, also the time to peak GFR in the vertical and ML directions, and the normalized impulse of the GRF in the vertical direction. However, the normalized peak GRF in the ML or AP directions, the normalized loading rate of the GRF in the vertical, ML or AP directions, the time to peak GRF in the AP direction and the normalized impulse of the GRF in the ML or AP directions do not change with fatigue.

The current study focused on the PL because of its importance in the prevention of ankle sprain [6, 9]. The lateral hop landing test was chosen for the present study since it imposes a stress on the lateral and vulnerable part

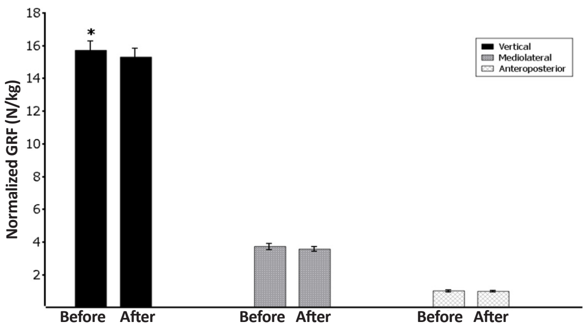

Figure 2. Normalized GRF before and after fatigue in each direction

Values are presented as Mean±SEM.

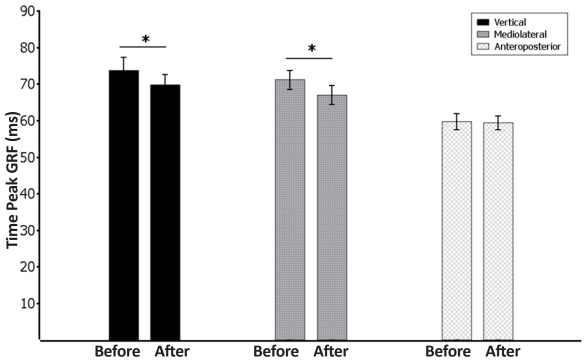

Figure 3. Time to peak GRF before and after fatigue in each direction

Values are presented as Mean±SEM.

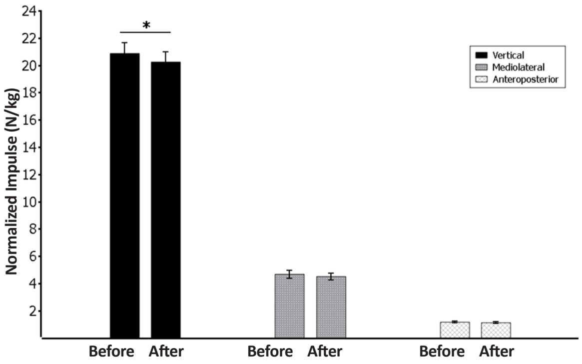

Figure 4. Normalized GRF impulse before and after fatigue in each direction

Values are presented as Mean±SEM.

of the ankle. The demand on the peroneal muscles, thus, increases [17]. Besides, lateral hop test has been used effectively to measure ankle dynamics, including the GRF profile [18, 19]. It is valuable, therefore, to study the changes in the GRF profile in a functional situation while the peroneal muscles are fatigued. It is difficult to compare the findings of the present study with other studies since no study was found which assessed changes in the GRF-related parameters after peroneal muscles fatigue during a lateral hop landing test. However, the decrease in the normalized peak GRF in the vertical direction is in agreement with the study by Madigan et al. (2003) that assessed changes in the sagittal landing biomechanics after fatigue and found that the peak GRF decreased due to fatigue [20].

There are two opposing views about the change in the GRF magnitude with fatigue; some studies have reported an increase in the peak GRF during fatigued landing or hopping [21, 22]. Increasing stiffness or impedance due to increased pre-activation has been suggested as an explanatory mechanism in these circumstances [23, 24]. On the other hand, Augustsson et al. reported a decrease in the peak GRF during fatigued landing [25]. This change may be due to a reduction in stiffness [26]. The decrease in the peak GRF due to stiffness reduction may be controlled by feedback mechanisms [12]. In the present study, the peak GRF was met at about 65 ms through 75 ms after landing. This time frame coincides with the time domain incidence of the medium latency stretch reflexes [26].

The decrease in stiffness may be due to the change in the force production capability of active components [26]. The decline in the force production of the peroneal muscles with fatigue may decrease stiffness and then the GRF. Stiffness reduction may place a stress on the passive structures of the lateral side of the ankle and expose them to injury if landings are performed repeatedly during an exercise or sport competition. The time to peak GFR decreases along with the decrease in the peak GRF. Decrease in the eccentric function of the PL may explain the shorter time to peak GRF.

Reduction of efficacy of the PL and more activation or early activation of the antagonists to the PL may position the foot rapidly on the contact surface. Release of the body load, thus, may be completed immediately, rather than distributed gradually, after foot contact. As was cited, increasing pre-activation may decrease the time to peak GRF as well. In this way, impulse, which is a product of the peak GRF and the time to peak GFR, would show a decrease. Our findings point to a decrease in the impulse likewise. Impulse may be related to energy dissipation during landing [27].

Energy dissipation capability of the lower extremity, therefore, decreases which may expose it to injury [4, 5]. Consistency of the loading rate after fatigue may be comparable with the findings of Coventry et al., who observed that loading rate did not change during single leg sagittal landing, after a functional fatigue protocol [28]. Consistent loading rate in the vertical direction are expected because both the peak GRF and time to peak GFR decrease together. The slope of the GRF, therefore, remains unchanged with time. Loading rate is more important than the peak GRF in terms of the landing force absorption [29]. Risk of the injury, therefore, would be lower with the fatigue intensity used in the present study. Although the loading rate and the GRF impulse decreased in the ML direction, these changes were not statistically meaningful.

A more strenuous fatigue intervention might significantly change these measures. Consistency of the V/ML ratio after fatigue points out that the load on one plane did not shift to the other. Thus, the control system may have considered the vertical and sagittal planes independently in terms of the GRF control. None of the measures in the AP direction changed with fatigue. These finding may seem rational, since both the fatigue intervention and lateral hop landing test have focused more on the ML direction rather than the AP direction.

As was observed, in general, GRF-related parameters changed more in the vertical direction, somewhat in the ML direction, but remained unchanged in the AP direction. This means that prolonged lateral movements performed in the frontal plane, during exercises and competitions, may impose loads mainly on the vertical direction although the vulnerable part of the ankle is on the frontal plane. In this regard, Monteleone et al. considered vertical force as the primary component of the lateral hop landing [18]. More degrees of freedom in the vertical direction in the lower extremity may make it more flexible than the ML direction to compensate for the changes induced by fatigue. Training and rehabilitation for the structures located in one plane may affect the function of the structures of another plane. Any deficiency in the elements of one plane, on the other hand, may impose load on the structures of the other plane and may expose it to injury.

It is impossible to link the findings of the present study to injury, but it has been reported that changes in the parameters of the GRF due to fatigue may be related to injury [4, 11]. Unfortunately, it was impossible to control voluntary attempt of the participants to control impact force during landing. In addition, kinematic characteristics of the lower extremity joints and trunk, which may be affected by fatigue, were not monitored in the present study. The findings of the present study may be more interpretable if the electromyographic activity of the ankle musculatures was provided together with the GRF information. In addition, fatigue induced by isokinetic dynamometer may be considered to be non-functional. It is suggested, therefore, to continue the present study using a functional fatigue intervention. Finally, the findings may not be applied to participants outside the young recreationally active healthy males participated in the present study.

Briefly, GRF profile was assessed during a lateral hop landing test before and after a peroneal fatigue intervention. The normalized peak GRF in the vertical direction, the time to peak GFR in the vertical and ML directions, and normalized impulse of the GRF in the vertical direction decreased. Other variables had not changed. Most of the changes due to fatigue occurred in the vertical direction although the fatigue intervention had focused on the lateral vulnerable part of the ankle. Both pre-activation and feedback mechanisms may have led to these findings. These changes during prolonged exercise or sports activity may expose the ankle to injury.

Ethical Considerations

Compliance with ethical guidelines

The participants read and signed an informed consent approved by the Ethics Committee of our University Institutional Review Board (Ethic code: 93/04/159/28041/142126).

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Authors contributions

All authors contributed in preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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