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Knee joint forces in the "Serra da Estrela" territory: the Trails4Health project

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ORIGINAL ARTICLE

ABSTRACT

This study aimed to characterize knee joint forces in different trails from the Serra da Estrela with distinct characteristics. Twenty-nine subjects (20 males and 9 females), mean of 28.04±10.79 years, 1.73±0.09 m of height and 69.59±11.00 kg of body mass volunteered for this study. In separate days, all subjects underwent three hikes (trail 1: circular, 10970m; trail 2: linear, 9053m; trail 3: circular, 7536m). A GPS device (Fenix 5, Garmin, USA) was used to ensure a consistent 5 $km.h^{-1}$ pace and tracking the slopes. The knee joint forces, namely the maximum patellofemoral compressive force (MaxPcF), the maximum tibiofemoral shear force (MaxTsF) expressed as times the body weight (xBW) and the load equivalent (LE) were estimated. The MaxPcF was 2.1, 1.8 and 2.1, and the MaxTsF was 0.83, 0.80 and 0.83 for trails 1, 2 and 3, respectively. The MaxPcF for trail 1 is equivalent to a flat 17386 m walk, and MaxTsF is equivalent to a 10980 m walk. The MaxPcF for trail 2 is equivalent to a flat 12605 m walk, and MaxTsF is equivalent to an 8320 m walk. The MaxPcF for trail 3 is equivalent to a flat 12357 m walk, and MaxTsF is equivalent to a 7532 m walk. According to the LE, trail 1 can be classified as "moderate", and trails number 2 and 3 are classified as "pleasant". Main data suggests that trail number 2 elicited less knee compression and shear forces. In contrast, trails number 1 and 3 are less appropriate for those who suffered from previous knee pain.

Keywords: hiking, active tourism, biomechanics, load.

INTRODUCTION

The practice of physical activity using natural resources has been pointed out as a new slope to increase the knowledge of protected green areas, and develop social/economic backgrounds of less populated villages (Brymer and Gray, 2010). This quest for physical activity in natural places seems determined by financial status, seasonality, gender, social conditions and a new trend of practice or mode (Hall and Page, 1999). With this in mind, companies of active tourism, are working strongly with a wide range of outdoor activities, in an attempt to satisfy new groups of people and loyalty their regular customers. Moreover, they are using natural resources from less developed areas to promote geographical wealth and economic development.

One of those areas is the highest mountain in Portugal called "Serra da Estrela". This is the largest protected green space that comprises unique natural characteristics, making it a prime spot for outdoor challenges. The mountain range is situated between the villages of Seia, Manteigas, Gouveia, Guarda and Covilhã comprising about 100km long and 30km across at its widest point. It is formed from a huge granite ridge that once formed the southern frontier of the country. Due to its bizarrely shaped crags and gorges, mountain streams and lakes, beautiful forest and magnificent views, the area rank among Portugal's outstanding scenic attractions. However, it exhibits a seasonal choice because restricts active tourism to winter sports, failing to offer other activities that may be extended to the summer calendar. So, there is a need to find additional strategies giving to the highest mountain of Portugal an annual forecast.

"Hiking" or "rambling" is one of the outdoor activities and has been defined as the act of walking in non-flagged trails through countryside or mountain over a long period (Funollet, 1994).

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Hiking in Portugal is increasing with approximately 34 organized activities each weekend in the national territory (Tovar and Carvalho, 2010). The highest number of activities take place in the North (28%) followed by Coast centre (26%), and only a reduced number of activities arevisible in the Inland centre (21%). Recent reports state that hiking promotes a reasonable improvement in perceived health, fitness level and mood state (Strauss-Blasche et al., 2004). It is also beneficial for elderly with increased cardiac risk (Gatterer et al., 2015) or metabolic syndrome (Mair et al., 2008). However, long-term hiking can sometimes induce postural deficits (Vieira, de Avelar, Silva, Soares, and Lobo da Costa, 2015) and traumatic lower extremity injuries (Loob, 2004). Indeed, previous studies reported that lower extremity joint loads change substantially with slope (e.g., Schwameder, Roithner, Burgstaller, and Muller, 2001).

The missing information about uphill and downhill effects from some territories can lead to overload in knee joints, transducing to pain to daily activities. This justifies the definition of well-planned and scientifically tested hiking trails, to set the most appropriate paths for people's plan their hike, always taking into consideration their fitness level and/or musculoskeletal limitations. Moreover, it is necessary to adopt preventive measures to reduce the gap of the inland territory in terms of demand for hiking practice. In this sense, this study aimed to characterize the knee joint forces in three trails from the Serra da Estrela territory with distinct characteristics.

METHOD

Participants

Twenty-nine subjects (20 males and 9 females), mean of 28.04±10.79 years, 1.73±0.09 m of height, 69.59 ±11.00 kg of body mass volunteered for this study. All the participants signed a consent form after an explanation about the study design. The inclusion criteria were: i) not having any skeletal muscle injury in the previous 6 months; ii) being clinically healthy; iii) have completed at least two hikes in the past year. All procedures were in accordance with the Declaration of Helsinki with respect to Human research. The University Ethics Committee approved the experimental procedures.

Procedures

In separate days, all subjects underwent three hikes corresponding to different trails. The trail 1 called "Tintinolho" was circular, with 10970m length, and was located in the city of Guarda. The trail 2 called "Vale Glaciário do Zêzere" was linear, with 9030m length and located in the village of Manteigas. The trail 3 called "Lapa dos Dinheiros" was circular, with 7536m length and was located in the village of Seia. All trails were divided into stages according to the terrain characteristics. The velocity was continuously set and monitored by an expert hiker, ensuring a consistent 5 $km \cdot h^{-1}$ pace. During the hike, no stops were allowed, and the participants informed that those who stopped for more than one min for any reason, would be removed from the sample. Every subject used a watch with GPS tracking (Fenix 5, Garmin, USA) throughout the hike for tracking the gradient, and to set altimetry information.

The knee joint forces were determined for each stage of the trail computing: (i) the maximum patellofemoral compressive force (MaxPcF), and; (ii) the maximum tibiofemoral shear force (MaxTsF). The MaxPcF was estimated according to the equations proposed by Gabriel, Moreira, and Faria (2010) according to the slope:

$$\mathrm{MaxPcF} = -0.1106 * \mathrm{S} + 1.3, \text{ if slope} < 0 \qquad (1)$$

or

$$\mathrm{MaxPcF} = 0.0786 * \mathrm{S} + 1.3, \text{ if slope} > 0 \qquad (2)$$

where S represents the slope of the stage (in percentage). The MaxTsF was estimated based on the equation (Gabriel et al., 2010):

$$\mathrm{MaxTsF} = -0.0104 * \mathrm{S} + 0.8333 \qquad (3)$$

where S represents the slope of the stage (in percentage). Data were expressed as times the body weight (xBW) for both MaxPcF and MaxTsF. Those values were then converted into multiples of a 5km flat walk in order to set the trail difficulty. This procedure was originally described by Hugo (1999) and adapted by Gabriel, Moreira, and Faria (2011). The retrieved data was then interpreted as the load equivalent (LE). The LE was calculated based on the equations:

$$LE_{MaxPcF} = \sum_i^n \frac{\left(\frac{MaxPcFi * Displi}{6500}\right)}{6500} \qquad (4)$$

$$LE_{MaxTsF} = \sum_{\mathrm{i}}^{\mathrm{n}} \frac{\left(\frac{\mathrm{MaxTsF}i * \mathrm{Displ}i}{4167}\right)}{4167} \qquad (5)$$

where MaxPcF***i*** and MaxTsF***i*** represents all the maximum patellofemoral compressive and maximum tibiofemoral shear forces, and Displ***i*** represents the horizontal displacement in each stage.

Statistical analysis

Data were expressed as mean, maximum and minimum for each stage of the three trails. Because this was a recommendation study with a characterization purpose, no inferential statistics were conducted. The qualitative interpretation of the trails difficulty was made using the LE, and interpreted according to the suggestion of Gabriel, Moreira, and Faria (2010) as: (i) "very easy" if -∞ < LE < 1; (ii) "easy" if 1 ≤ LE < 2; (iii) "pleasant" if 2 ≤ LE < 3; (iv) "moderate" if 3 ≤ LE < 4; (v) "hard" if 4 ≤ LE < 5; (vi) "severe" if 5 ≤ LE < 6; and (vii) "extreme" if 6 ≤ LE < +∞.

RESULTS

Figure 1 presents the knee joint forces during each stage from the trail 1 "Tintinolho". The highest MaxPcF was 2.59, and the lowest was 1.38 in stages 6 and 9, respectively. The highest MaxTsF 0.95 and the lowest was 0.73 in the stages 6 and 2, respectively.

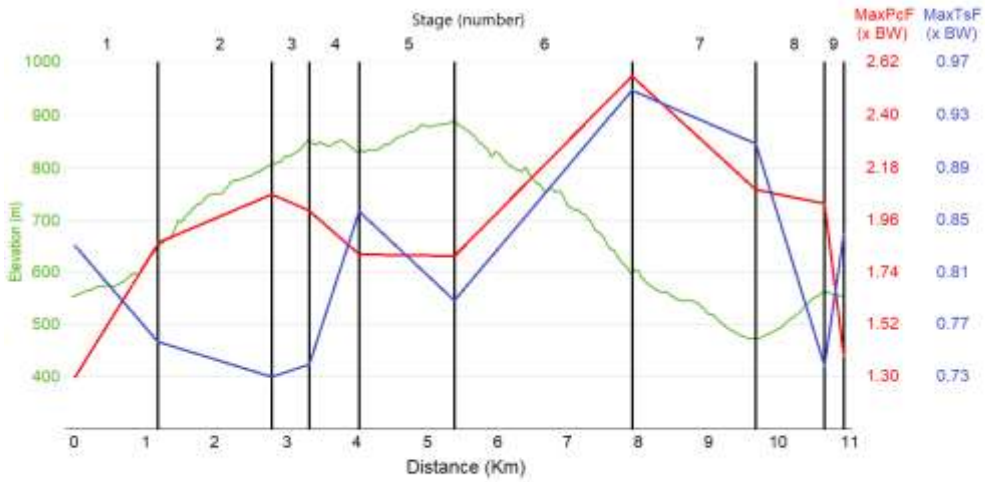

Figure 1. Knee joint forces during each stage from the trail 1 "Tintinolho".

Figure 2 presents the knee joint forces during each stage from the trail 2 "Vale Glaciário do Zêzere". The highest MaxPcF was 2.67, and the lowest was 1.36 in stages 6 and 3, respectively. The highest MaxTsF 0.82 and the lowest was 0.65 in stages 3 and 6, respectively.

Figure 3 presents the knee joint forces during each stage from trail 3 "Lapa dos Dinheiros". The highest MaxPcF was 2.87, and the lowest was 1.50 in stages 2 and 8, respectively. The highest MaxTsF 0.96 and the lowest was 0.63 in stages 1 and 2, respectively.

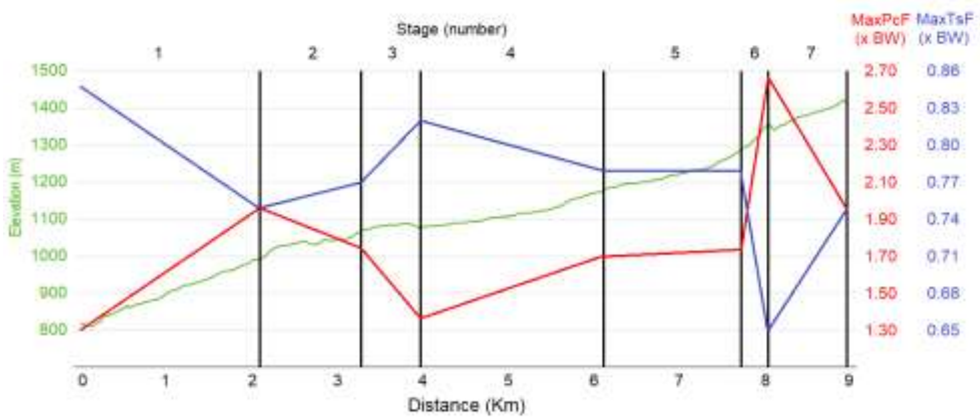

Figure 2. Knee joint forces during each stage from the trail 2 "Vale Glaciário do Zêzere".

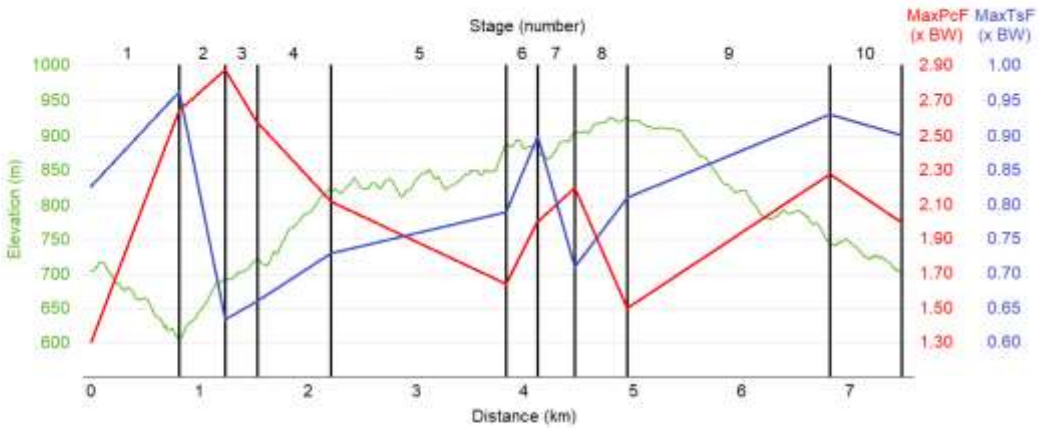

Figure 3. Knee joint forces during each stage from the trail 3 "Lapa dos Dinheiros".

Table 1 presents the qualitative interpretation of the difficulty of the trails considering the LE. The MaxPcF for trail 1 is equivalent to a flat 17386m walk, and MaxTsF is equivalent to a 10980m walk. The MaxPcF for trail 2 is equivalent to a flat 12605m walk, and MaxTsF is equivalent to an 8320m walk. The MaxPcF for trail 3 is equivalent to a flat 12357 m walk, and MaxTsF is equivalent to a 7532 m walk. So, the trail 1 can be classified as having a "pleasant-moderate" difficulty, while the trails number 2 and 3 are classified as "easy-pleasant".

Table 1
Trails qualitative interpretation of trails difficulty according to LE.

		Flat walk Equivalent (m)	LE (x 5000m)	Difficulty Level
Trail 1	MaxPcF	17386	3,48	Moderate
	MaxTsF	10980	2,20	Pleasant
Trail 2	MaxPcF	12605	2,52	Pleasant
	MaxTsF	8320	1,56	Easy
Trail 3	MaxPcF	12357	2,47	Pleasant
	MaxTsF	7532	1,51	Easy

DISCUSSION

The aim of this study was to characterize knee joint forces while walking in Serra da Estrela in trails with distinct characteristics. Overall, the knee joint forces were no higher than 3 xBW which classifies the difficulty of the trails as "easy" or "moderate".

Most of the previous approaches used a standard trails classification as "easy", "medium" or "hard". Despite this qualitative interpretation, previous interventions just used geographical and/or spatial-temporal information to set the trail difficulty. With this in mind, we tried to go deeper and set difficulty by quantifying knee aggression. Some successful attempts were already made in other regions of Portugal, such as Douro International (p.e. Gabriel et al., 2011), but not in the Serra da Estrela territory.

The patellofemoral compressive forces happen when two body sections are aligned into each other. Those are expected to increase continuously with the slope both in uphill and downhill walking (Schwameder et al., 2001). However, on the same slope, the patellofemoral compressive forces tend to be more aggressive in downhill. In this study, the participants experienced near 3 xBW when downhill at 12%. For our group, with a mean of 69.59 of body weight, this represents approximately 210 kg of force experienced at each step during the descent. Schwameder et al. (2001) found patellofemoral compressive forces of 2.3 xBW when downhill at a 10.5% grade. Normally, the high patellofemoral compression forces are dominant in the entire stance phase at downhill. Those tend to increase when considering the effect of body weight (as higher the body weight, higher is the compression force), which may require some attention from hikers when choosing their paths. In practical terms, each hiker should multiply his body weight by the downhill factor (i.e., 3xBW) to know the exact compression force that will be induced in that specific joint.

The tibiofemoral shear forces are unaligned forces pushing tibia and femur in the opposite direction. Those are expected to decrease as the grade increases. The more challenging uphill was found in stage 2 of the trail 3 "Lapa dos Dinheiros", showing tibiofemoral shear forces of 0.63 xBW at a 20% climb. Schwameder et al. (2001) found values near 0.7 at slopes near 20% grade. At uphill, the stance phase happens step by step at higher ground promoting a lower relative knee angle and range of motion. Although most of the structures are highly loaded at uphill, there is only a little stress in the inner knee as the shear forces are small. That is the reason why there are recommending uphill walking for hikers that finished recovering from an anterior cruciate ligament injury.

The non-uniform distribution of joint forces during up and downhill may require learning new walking patterns. Using kinematics analysis, Lay, Hass, and Gregor (2006) found several postural changes during locomotion in sloped surfaces. The authors reported the need to raise the limb for toe clearance and heel strike, and to lift the body during uphill walking, and to control the descent of the body during downhill walking. So, people that want to begin hiking in mountain paths should be aware of adaptations in critical aspects of posture for a more efficient and less aggressive walk.

Considering a healthy outcome, hikers must have information about the overall knee aggression that each path will trigger. With that in mind, previous studies started to use the load equivalent as a measure to rate the trails difficulty considering the energetic expenditure (Hugo, 1999) and knee joint loads (Gabriel et al., 2010). The load equivalent represents the overall load in the knee during the hike and its equivalent in a 5000 m flat walk. For instance, a 10000 m hike that elicits an overall load of three times the load predicted to a 5000 m walk in flat terrain, has a load equivalent of three points (being classified as moderate). It means that, for an extent of 10000 m mountain hike, the knee load will represent a 15000 m flat walk. Therefore, participants are free to choose, if a "15000 m flat walk" is suitable for them according to their health status, or choose another path accordingly. In the present study, the trail 1, "Tintinolho", presented the highest load equivalent, being the overall MaxPcF equivalent to a 17386 m flat walk (LE = 3.48), and the overall MaxTsF equivalent to a 10980 m flat walk (LE = 2.20).

CONCLUSION

Our findings suggest that trail 2 "Vale Glaciário do Zêzere" elicited less knee compression and shear forces. In contrast, trails number 1 "Tintinolho" and 3 "Lapa dos Dinheiros" are less appropriate for those who suffered from previous knee pain or are in a recovery process. This approach can help participants making the most appropriate choice about hikes, taking into consideration their physical level and/or history of skeletal muscle injury.

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Conflict of interests:
Nothing to declare.

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