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Contribution of plantar pressure to the prevention and quantification of the muscle-skeletal injury risk in hiking trails – a pilot study

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Hiking trails have been growing in popularity in the health and well-being promotion. Consequently, the foot became an object of study in order to understand the discomfort and pain in the lower limb. The aims of the work were: 1) to detect tendencies for behaviour of maximum values of plantar pressure (MaxP) during the walk on different slopes, 2) to contribute to the methodology of the difficulty level of hiking trails. Equations show strong tendencies ($R^2 > 0.8$) of behaviour of MaxP in the lateral zones of the heel, 4th and 5th metatarsus as well as in the plantar zone of the hallux. The analysis of the difficulty level of the hiking trails branches deserves a separate presentation, including the technical difficulty analysis (with a compulsory emphasis on the biomechanics) and information on the caloric consumption and on the slopes of each branch.

Key words: biomechanics, locomotion, foot, hiking trails

1. Introduction

Hiking trails have been growing in popularity in the health and well-being promotion. According to MYERS et al. [1], tramp is a kind of physical activity that tends to remain most frequent in several age groups, revealing high levels of participation of the elderly [2]. In biped locomotion, the feet shows three fundamental biomechanics functions [3]: 1) body accommodation to the field irregularities; 2) support and damping of body mass and; 3) propulsive forces transmission. As a result of its location and locomotor associated functions, the feet becomes a fundamental study object in order to understand the adaptations during the hiking trails and consequently the difficulty to perform them [4]. According to MESSIER et al. [5] changes in gait default due to the attempts to avoid or minimize eventual discomfort may be the cause of pain appearance in the lower limb. However, the regular practice of tramp promotes an improvement in tramp biomechanics and a reduction of pain feeling in the knee during the performance of several daily routine tasks of biped locomotion [6]. The aims of the work were: 1) to detect tendencies for behaviour of maximum values of plantar pressure (MaxP) (considered as risk factors of discomfort in the foot) during the walk with natural speed on different slopes and 2) to contribute to the methodology of the difficulty level of hiking trails depending on the biomechanics parameter studied.

2. Materials and methods

The male subject (age: 40 years; height: 1.85 m; mass: 78.6 kg) that volunteered for the study, read and sign the informed consent form in accordance with the

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declaration of Helsinki and ethical approval for procedures obtained from the University of Trás-os-Montes & Alto Douro Ethical Committee. The inclusion in the study respected the following criteria: i) regular practice of pedestrianism (at least 3 sessions of 1 hour per week in the last year); ii) no impairments in the lower limb that might influence locomotion; iii) gait without help of any orthopedic device; and iv) age between 20 and 50 years. The subject made five repetitions of five tasks with different slopes (0% in task 1, 11% in task 2, 21% in task 3, – 11% in task 4 and – 21% in task 5) [7], walking barefoot at a natural cadence, in a 9 m route, located on top of three wood platforms, strict and removable, placed in series: an intermediate platform – 3 m in length, 1 m in width and 0.2 m in height and the other two – 3 m in length, 1.5 m in width and 0.2 m in height. The intermediate platform allows an adjustable slope, supplemented in each extremity by the other 2 platforms. For the data collection in the plantar pressure behaviour we used the Footscan platform (RsScan International, 1 m × 0.4 m, 8192 sensores, 253 Hz) and through the Footscan Software 7.1 (RsScan International) (figure 1) we determined the MaxP in the mean area (HM) and lateral area of the heel (HL), 1º (M1), 2º (M2), 3º (M3), 4º (M4) and 5º (M5) metatarsus, hallux (T1) and the feet toes (T2-5). A trial was discarded if the stance duration was longer than ±5% of that participant average stance duration during the 0% condition, in order to minimize the effect of the walking speed on the data and to ensure that the participant cadence and velocity were consistent during the trials [8], or if the foot contact with the pressure platform was incomplete or if the participant targeted the platform.

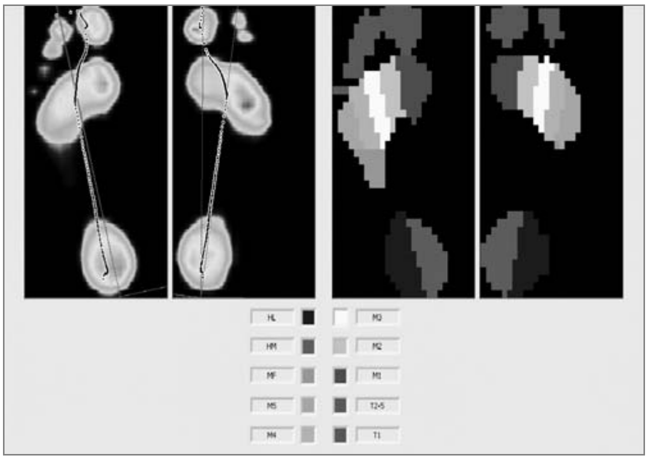

Fig. 1. Identification through the Footscan Software 7.1 (RsScan International) of the mean (HM) and lateral heel (HL), 1º (M1), 2º (M2), 3º (M3), 4º (M4) and 5º (M5) metatarsus, hallux (T1) and plantar pressure zone related to the foot fingers set (T2-5)

For all the tasks, representative values of MaxP in each studied area of plantar support were obtained through the arithmetic mean of their registered MaxP in the five valid repetitions. For each plantar support area linear regressions were obteined, with the determination coefficient, between the ramp slope and the representative values of MaxP. The data analysis was developed with the SPSS (version 13.0, SPSS Inc, Chicago).

Taking into account only the regression equations with $R^2 > 0.8$ and those that express strong trends of behaviour of the representative MaxP values, we established a classification of the difficulty level associated with each section of the routes based on the criteria of the *International Trail Marking System* [7] and usually used in the marking of the mountain bicycle and Alpine sky tracks. Five levels were established (level 1 – easiest, level 2 – easy, level 3 – more difficult, level 4 – very difficult and level 5 – extremely difficult) where the higher degrees of difficulty start in the higher value within the representative MaxP values, in the interval between –20% and 20%. The remaining 4 levels of difficulty (easy, accessible, moderate and hard), considering the biomechanic parameters, resulted from the division into 4 groups of the variation interval of the maximum and minimum level, between –20% and 20%.

3. Results and discussion

Based on the data collection (table), linear regression was obtained, with the respective determination coefficients (R^2),between the slope (%) of the ramp and the MaxP values in T1, T2-5, M1, M2, M3, M4, M5, HL and HM (figure 2). Only T1, M4, M5 and HL have shown linear regression that expresses strong tendencies ($R^2 > 0.8$) of behaviour in the respective values of MaxP. The negative slope for the linear regression between the ramp and the representative values of the MaxP1, compared with the positive slopes of the congenerous linear regression obtained in MaxPHL, MaxPM4 and MaxPM5, can mean that T1 has different functions of HL, M4 and M5 during the plantar support.

The quasi-linear behaviour tendencies identified in MaxPT1, MaxPHL, MaxPM4 and MaxPM5 show that the slope intensity increases in the ascent and in the descent causing proportional behaviour of these parameters, but in opposite directions, more precisely: the slope intensity increasing in the ascent implies a behaviour inversely proportional to MaxPT1 and directly proportional to MaxPHL, MaxPM4 and MaxPM5, while the slope intensity increasing in the descent implies a behaviour directly proportional to

Maximum pressure values in each plantar pressure area (T1, T2-5, M1, M2, M3, M4, M5, HM and HL) in accordance to the route slope

Slope (%)	Maximum pressure values (N/cm^2) in each plantar pressure areas (M±DP)								
	T1	T2-5	M1	M2	M3	M4	M5	HM	HL
–21	24.68 ± 4.52	2.30 ± 0.56	7.80 ± 1.81	8.18 ± 0.86	8.86 ± 1.53	10.12 ± 3.18	5.10 ± 1.37	15.12 ± 1.72	8.86 ± 1.01
–11	16.18 ±1.76	1.76 ± 0.25	9.92 ± 1.50	11.16 ± 1.45	12.10 ± 0.95	12.70 ± 1.81	5.64 ± 0.77	15.60 ± 1.10	9.92 ± 0.36
0	11.22 ± 1.25	1.30 ± 0.38	8.86 ± 0.48	12.02 ± 1.16	18.50 ± 2.55	18.96 ± 2.24	7.10 ± 0.81	19.80 ± 1.86	12.18 ± 1.74
11	10.16 ± 2.84	2.36 ± 1.45	10.86 ± 3.41	12.94 ± 0.99	17.12 ± 1.26	18.62 ± 4.52	6.88 ± 1.82	20.84 ± 3.34	12.46 ± 1.63
21	8.38 ± 1.89	2.44 ± 0.58	7.040 ± 1.30	9.56 ± 0.51	17.58 ± 2.58	21.14 ± 4.11	10.24 ± 4.91	20.06 ± 3.86	12.32 ± 1.52

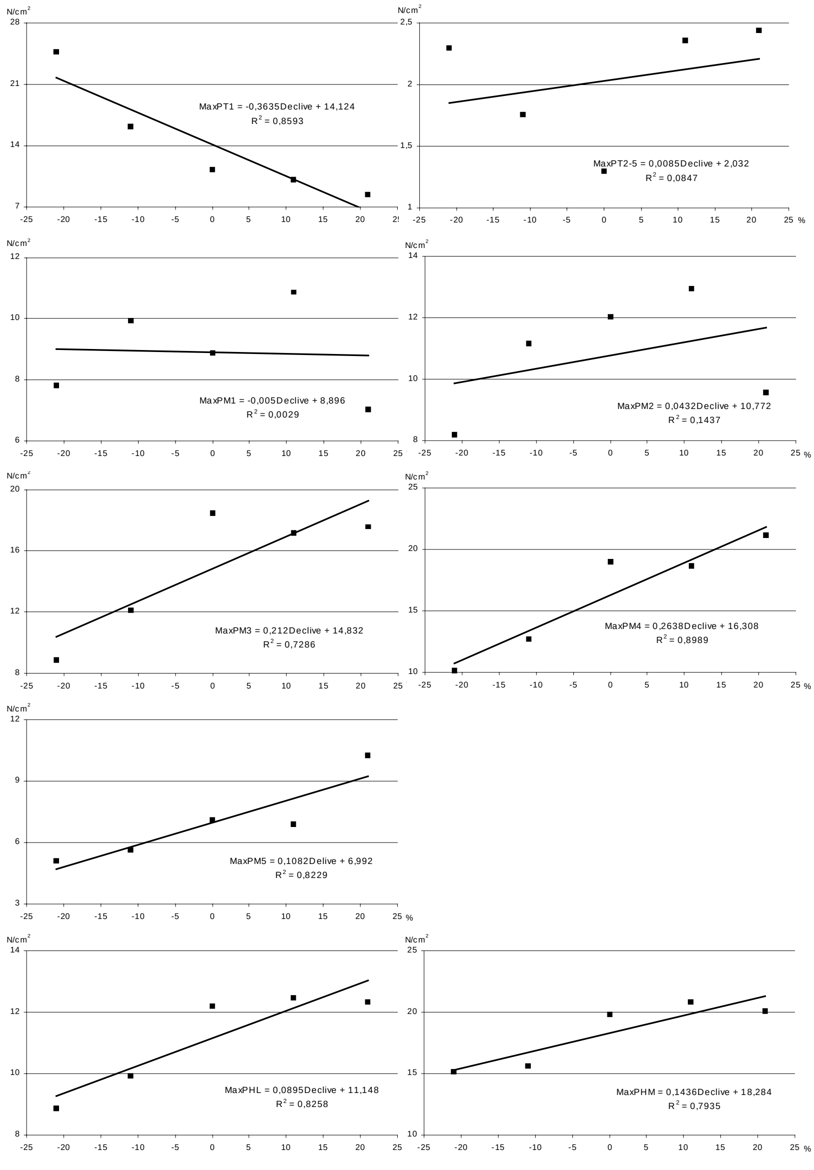

Fig. 2. Linear regressions between the ramp slope and the representative values of the maximum pressure in each area of plantar support (T1, T2-5, M1, M2, M3, M4, M5, HM e HL); R^2 – determination coefficient; Declive = Slope

MaxPT1 and inversely proportional to MaxPT1, MaxPHL, MaxPM4 and MaxPM5. These changes in the proportionality direction can be associated with the differences in the adaptation strategies of the muscle-skeletal system depending on whether it is an ascent or a descent, namely those related to postural adaptations made during the tramp in inclined plane surfaces [9]. The perception that the highest adaptations of the lower limb to the slope variations are made in the ankle during the ascent and in the knee during the descent [10] can also be associated with the change in the behaviour. However, this association hypothesis needs further research that will also include the control variable that identifies the adaptation strategies of the muscle-skeletal system during the tramping of plane surfaces.

Due to the variation of the proportionality direction of MaxPT1 in what concerns the route slope relatively to the homologous behaviour observed in MaxPHL, MaxPM4 and MaxPM5, a parity of the difficulty level for MaxPT1 was established considered in relation to the slope of the route sections (figure 3a) different from those established for the group made by MaxPHL, MaxPM4 and MaxPM5 (figure 3b). The effort intensity developed by the pedestrian in physiological terms was not considered in the difficulty level identification of the routes of each section. The methodology developed by us and used to achieve the aim of this work considers only the behaviour of the representative values of MaxP in 9 feet areas whose behaviours are related to the discomfort/pain in the lower limb and consequent changes in the pattern of the pedestrian tramp.

(a)		(b)
[10%, +∞[	Easiest	]–∞, +10%[
[0%, 10%[	Easy	[–10%, 0%[
[–10%, 0%[	More difficult	[0%, 10%[
[–20%, –10%[	Very difficult	[10%, 20%[
]–∞, –20%[	Extremely difficult	[20%, +∞[

Fig. 3. Five difficulty levels cast in accordance with the slope route section and related to the maximum pressure values behaviour in T1 (a) and M4, M5 and HL (b)

Therefore, it is possible that a section classified by us as easy, according to the methodology developed in this work, can be very difficult in a physiological perspective due to its extent and/or the presence of the pronounced slopes.

4. Concluding remarks

The problem of identifying the difficulty level of routes can be solved by separate presentations, although simultaneously, by the methodologies of technical difficulty analysis of the results obtained (with emphasis on biomechanics) with information related to the caloric expenditure and to the need to surpass the slopes of each section. This approach is not exhaustive however, which justifies the development of other analysis procedures.

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