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COMPARATIVE STUDY OF SHOE-SURFACE INTERACTION IN TRAIL RUNNING - SUBJECTIVE AND OBJECTIVE EVALUATION

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The purpose of this study is to compare and evaluate different running shoes in various surface conditions in two measurement phases. In the subjective test, fourteen trail runners performed the experiment with three running shoes in distinct surface conditions. Three features, comfort, cushioning and traction, were rated by means of questionnaire. In the objective measurement, a traction tester device was configured to simulate the movement and evaluate the rotational traction of the three shoes on different surfaces. The subjective test showed a significant difference with respect to comfort and cushioning. The objective measurement in dry conditions showed a significant decrease ($P < 0.05$) in rotational traction on different surface types; rotational traction in wet conditions was significantly lower ($P < 0.05$) than in dry conditions.

KEY WORDS: running shoe, rotational traction, comfort, cushioning.

INTRODUCTION: Running as a human activity originated about two million years ago, and is related to the evolution of the human form (Bramble& Lieberman, 2004). While running has long been a core element of sporting activity, the popularity of trail running has grown exponentially in recent years. However, not many studies have focused on injury etiology in trail running. In general, risk factors for running injuries can be classified into two groups, 1) intrinsic factors such as age, gender, weight, genetic profile, and 2) extrinsic factors such as surfaces, shoes, previous injuries (Dvorak, et al., 2004; Korpelainen, et al., 2005; Worp, et al., 2015). The research review shows that experienced runners are prone to lower back, knee joint and plantar surface foot injuries (Hespanhol, et al., 2011; Malliaropoulos, et al., 2015). As trail running takes place on very different natural surfaces (sand, stone, turf or ice),in critical terrain (e.g. narrow paths in mountains) trail running shoes should provide an optimum level of traction, comfort and cushioning to prevent injuries due to falls or overuse. The aim of this study is to compare and evaluate shoe-surface interaction factors in subjective and objective measurements, which will also help arrive at a better understanding of what can be considered “optimal” level.

METHODS: In the first phase, subjective measurement, a total of fourteen semi-professionals trail runners (three women, eleven men) with a mean age of 27 years participated in the experiment. Four trails with distinct surface conditions (gravel, mud, natural grass) and different path shapes were used in the experiment. Trails A (natural grass) and D (gravel) were curved paths (arcs) on flat ground outdoors with a radius of 9m and 5.4m respectively. Trails B (gravel) and D (mud), on the other hand, were simply straight paths. The average distance of the paths was 250 m. Three running shoes on the market which were recommended by project sponsor were utilized in every trail experiment. Participants were asked to run at moderate speed for three minutes on each trail with different shoes. A rate scale questionnaire was conducted to measure three features namely comfort, cushioning and traction on the four different trails after each performance. Rating a higher score (rate scale is between 0 and 50) on the questionnaire shows a higher level of satisfaction with the features. To avoid the influence of shoe brand on results, they were covered with a label. In this phase, as shown in Figure 1.b, the maximum vertical force of the most experienced runner was measured separately with insole pressure sensors via random selection of shoe and surface, namely, shoe 2 and trail B, gravel. The insole pressure sensor (Moticon GmbH, Munich, Germany) consisted of 13 sensors which were distributed across the insole (Figure 1).The plantar force was computed from the pressure distribution at 50 Hz. The sensor measurement range was between 0.00 and 40N/cm^2. In phase 2, the objective measurement, i.e. the rotational traction of the same three shoes (Figure 1.c,d,e), was evaluated on four different surfaces. A tray, 90cm by 80cm, with 34 mm of sand was the first surface type tested. A video camera was located on 45 degree view, between side and front views. The video of the movement and plantar pressure distribution was synchronized through Moticon software. By capturing screen shot of the video once the runner produced the maximum vertical force, the angles of the movement were measured by picture analyzing.

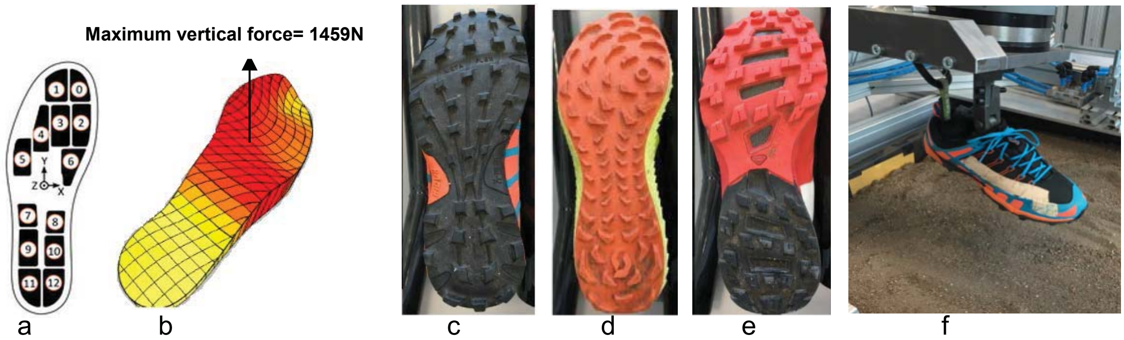

Figure 1. (a) Sensor pressure position (b)Vertical force load in subjective test (c) shoe 1(d) shoe 2 1(d)shoe 3 (f)Traction tester and sand surface in objective test

Particle size distributions of this surface (Figure 1.f) were defined according to DIN 18123, Deutsches Institut für Normunge.V. (German Institute for Standardization).The main part of the surface was 52% medium size sand consisting of particle sizes between 0.2 mm to 0.63mm.The second surface type was a mixture of sand and small stones (sand and surface). A total number of nine small stones with an average weight of 600 grams were embedded under the sand surface, especially in the regions where shoes had contact with surface. Synthetic turf (Astro play ^{TM} outdoor) 90cm by 80cm and a granite surface 40cm by 60cm were used as other types of surface. In this phase, a pneumatic traction tester (Grund, et al., 2007) was used to measure rotational traction. The device consists of an artificial lower leg with 6 degrees of freedom, and a silicon replica human foot derived from computer modeling, which can simulate human lower leg movement with different force and angles. The same three running shoes which were used in the subjective tests were used in the objective test. To simulate the movement of the participants, the vertical force 1459N, which was obtained from the insole sensor in subjective test, was used and applied to the traction tester. The angle of the movement obtained from video synchronization was simulated with the traction tester in the position: flexion 30° and eversion 20°. Rotational traction was measured for four different surfaces; granite, sand, synthetic grass and a mixture of sand and stone. The objective measurement was considered in two surface conditions: dry and wet. In the wet condition, 0.73 liters of water for 1m^2 was applied equally onto the contact area of the four surfaces, sprayed through a nozzle. The data from subjective and objective measurement was analysed by ANOVA and Tukey HSD post-hoc test.

RESULTS: Figure 2 illustrates that there was a significant increase of satisfaction in comfort and cushioning ($p < 0.05$) for shoe 2 on trails B and D.

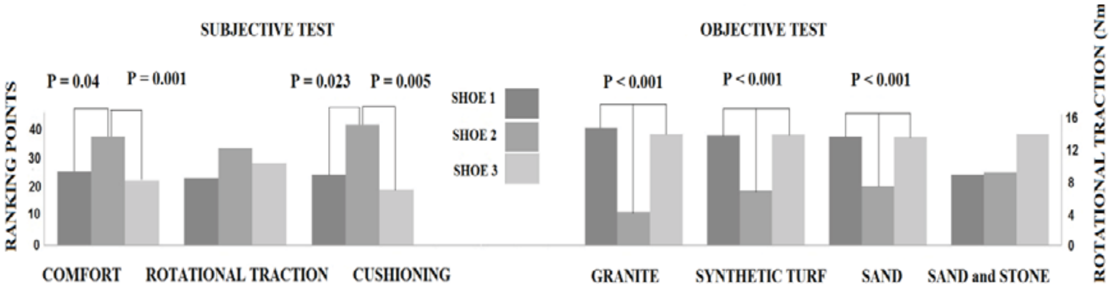

Figure 2. Ranking points (subjective test) and rotational traction (objective test) in dry condition

The results indicated the total ranking points of shoe 2 shows a higher level of cushioning and lower level of discomfort than the other shoes. There was an appreciable difference between the shoes in the four trails in respect of the traction feature. In the objective test, result of shoe-surface traction in dry and wet conditions show that the rotational traction rate of shoe 2 is significantly less than other shoes in the dry condition, except in sand and stone surface. According to the Table 1, rotational traction in the dry condition is greater than for the wet condition.

Table 1
Average Rotational Traction in Objective Test

	Wet				*dry*			
Surface	Granit	Syn.Turf**	Sand	SS*	Granit	Syn. Turf**	sand	SS*
Shoe 1	10.8	11.2	3.4	5.6	15.5	14.5	14.37	9.35
Shoe 2	9.6	11.1	4.9	4	4.5	7.2	7.8	9.6
Shoe 3	16.5	13.4	6.8	7.8	14.7	14.6	14.3	14.7

* Mixture of sand and stone ** Synthetic Turf

However, shoe 2 and shoe 3 on the synthetic turfs, and the granite in the wet condition show greater rotational traction rate as compared to dry conditions. The result revealed a distinct difference ($p = 0.031$) between rotational traction rate in wet and dry conditions. Additionally, there is a significant ($p = 0.015$) interaction effect between shoe type and surface condition.

DISCUSSION: Comfort, cushioning and traction are the most important features of shoe-surface interaction (Hennig, 2011) all tested in our subjective measurement. Comfort is the most significant and desirable feature of athletic footwear and it is considered a basic customer need by footwear manufacturers. Korpelainen and his team (2001) demonstrated that perceived comfort of the shoe, which is related to pressure distribution (Che, et al., 1994), can affect stress fracture and overuse injuries. In the subjective measurement, shoe 2 was awarded the lowest level of discomfort amongst all the shoes. Impact force during running has been studied for many years, with some studies indicating that increased impact forces are linked to running injuries (Creby&Dixson, 2008; Zifchock,et al.,2006). As trail running takes place on different surface conditions, three types of surfaces, mud, grass and gravel were investigated to evaluate the effect of surface on cushioning. In our subjective measurement, shoe 2 was significantly distinguished from other running shoes, showing greater levels of cushioning. The most distinct difference between the shoes in the terms of comfort and cushioning was demonstrated in trails B and D with gravel surfaces.

Traction is another significant factor influencing performance and injury. According to the American Society for Testing Material (ASTM F2333, 2011), traction is defined as ‘resistance to relative motion between a shoe outsole and sport surface which is not followed by classical law of friction’. Rotational traction is important for rapid changes in direction in every sport. In the objective measurement, the statistical results indicated that rotational traction in wet conditions is lower as compared with dry conditions. According rotational traction rate in both wet and dry conditions, the risk of foot fixation among three shoes is most likely than slip risk due to low range of rotational traction. Shoe 2 indicated an optimum level of rotational traction by minimizing risk of the rotational traction. Furthermore, evaluating rotational traction in curved paths (subjective test) indicated that there was an appreciable difference between shoe 2 and the other shoes in terms of perceived rotational traction. On the other hand, shoe 3 showed the highest rotational traction which can increase the risk of foot fixation and is linked to the anterior cruciate ligament (Lambson, et al., 1996). In our study, three trail running shoes with different cleat designs (numbers, shape, area and length) were compared in both objective and subjective tests. Our results confirmed the findings of Stefanyshyn, et al. (2009) and Lambson et al (1996), who measured the effect of different cleat design on rotational traction in football boots. However; this study suggests a systematic experiment with a focus on cleat design effects on rotational traction for especially trail running shoes.

CONCLUSION: This study indicates it is important to combine subjective and objective measurements with respect to shoe traction. Very few studies have attempted to identify the relationship between rotational traction measured by a mechanical device and perceived rotational traction assessed by participants for a range of commercially available running footwear. In the subjective study, the participants ranked shoe 2 as the one which generates the most grip on curved paths. On the other hand, objective measurement indicated a minimum rotational traction of shoe 2 as compared to the other shoes. Thus, in the dry surface condition, greater grip while changing direction on the curved paths in the subjective measurement most likely meant lower rotational traction in objective measurement. Another interesting observation for the sand and the mixture of sand and stone surfaces was made for this shoe compared to the others; it showed the lowest variation of rotational traction in wet and dry conditions, which was positively rated by the subjects. This may be associated with reducing the risk of losing grip under varying conditions.This study may be useful for practitioners, coach and trainers as well as boot manufactures. It also suggests that more focus should be put on achieving an optimal compromise for different conditions, either by an optimized stud/material configuration or even by a future “sole manipulator” that allows the athlete to switch easily between two outsole patterns.

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