The Effects of Triceps Surae Tendon Length Altering Shoe Insoles during Running

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Abstract

Background: *In running, injury risk is related to the magnitude of ground reaction forces (GRF) and cumulative loading. Such loads can be altered by changing the gear ratio.* ***Aim:*** *The aim of this study was to investigate the effects of triceps surae length altering insoles during running.* ***Methods:*** *Kinematic and ground reaction force data was collected from 11 recreational male runners. Participants ran with three different types of insoles: elevated rearfoot, flat, and elevated forefoot. Vertical GRF peaks, braking peak, impact loading rate, and ankle gear ratios were calculated.* ***Results:*** *The forces, gear ratios, and vertical loading rates did not show significant differences among the three insole conditions ($p > 0.05$). In elevated rearfoot condition strong Pearson's correlation was detected between the impact loading rate and gear ration at the impact peak ($r = 0.7$), and strong negative association was calculated between braking force and corresponding gear ratio ($r = -0.73$).* ***Discussion:*** *The magnitude of forces, ankle gear ratios, and impact loading did not show a significant difference among the three insole conditions. The significance of the results in this study might have been affected by a small sample size that reduces the statistical power of the analysis, therefore, the results should be treated with caution. An increased sample size would give more power to the prospective study to detect the possible differences among groups.*

Keywords Running, ground reaction force, Achilles tendon, insoles, gear ratio.

1. Introduction

Approximately 12 % of the people in the EU chose running as their way of physical activity, making it one of the most popular sports in the region. Denmark is at the top of the list with 31% of Danes older than 16 years old that have been regularly running in the past year [1]. Although running has a great benefit in health improvement, it also has a high injury rate, especially the lower limb, and those injuries happen for all types of runners [2, 3, 4]. According to Van Gent et al., lower extremity running injury incidence ranges from 19.4% to 79.3% [5]. Even recreational running is not considered to be a low injury risk activity [6]. Lun et al. state that the most common running related injuries (RRI) occur in the knee joint (42 - 46%) and in the ankle and foot (17 - 30%) [7]. RRI are often linked to overuse, previous injuries, training errors, and experience in running [2]. The systematic review conducted by Lopes et al. matches findings from other authors concluding that most of the RRI occur in the lower limb. The most prevalent injuries were patellofemoral pain (PFP), Achilles tendinopathy, tibial stress syndrome, tibial stress fractures, and plantar fasciitis [4, 8]. Such injuries in running were linked to overuse mechanisms and are thought to be caused by accumulated impact forces. Approximately 500 - 1200 impacts occur after running one kilometer distance with the impact peaks reaching the magnitude of several times higher then the body weight [8]. Researchers concluded that footwear can impact mechanical factors, such as knee angular impulse, related to running injuries [9]. Lewinson et al. conducted a randomized controlled clinical trial on wedged insoles for runners with PFP. The results showed that running with wedged insoles provides clinical benefits by reducing PFP [10]. Another study showed biomechanical alterations influenced by the presence of wedged insoles stay consistent during a prolonged 30 minute run [11]. In walking, heel elevated insoles of viscoelastic material have been show to reduce the strain in the spinal column [12].

Based on literature, Achilles tendon is highly sensitive to overuse injuries, as it gets constantly exposed to the continual loads in both running and walking. According to Giddings et al., during the propulsion phase Achilles tendon load can be as high as eight times the body weight per single step [13, 14]. Such repetitive loads create micro-tears in the collagen fibers, that already are subjected to high tensile forces in running [15]. A study by Sobhani et al. has showed that PFP symptoms in walking and running can be reduced by alternative footwear. They used rocker shoes which altered GRF acting point, and external flexion moment got smaller due to shorter external moment arm. Simultaneously, internal flexion moment was also smaller, which significantly reduced the ankle joint load compared to regular footwear [16].

Tendons units have elastic properties, as they can store and release energy when the muscle is stretched and immediately followed by a concentric contraction [17]. Forces generated by the muscles to produce movement differ dramatically based on the length of the muscle, velocity of shortening and lengthening, and muscle activation timing [18]. In order to produce high forces in the beginning of the voluntary movement, neuromuscular system uses a stretch-shortening cycle (SSC). The tendon SSC is a typical muscle function property activated in daily life activities, such as jumping, kicking or running [19, 20]. As described in literature, during SSC occurs potentiation which is described as greater force output as the muscle contracts concentrically [21]. Edwen et al. researced SSC muscle power in different age groups and genders. They found that men demonstrated significantly higher rates in adult category, however, maximal SSC power showed to coalesce between men and women as they reach old age [22]. Another study by Debenham et al. concludes that subjects with Achilles tendinopathy demonstrate altered SSC in sub-maximal hopping. Compared to healthy volunteers, subjects with injury performed the task in higher degree of dorsiflexion, a larger Achilles tendon stretch amplitude, and delayed muscle activity. This can be an indication of greater load on the Achilles tendon [23].

Gaddy et al. concludes that longer Achilles tendon can impact running by enhancing running economy and reducing physiological effort while running. It was expected, as previous studies of triceps surae tendon length and higher strength potentially improves SCS while running [24]. Similarly, a recent study has shown that longer Achilles tendon, especially of gastrocnemius medialis segment, may be one of the factors linked to higher running performance [25]. Both of the aforementioned studies, however, have not used insoles to impact the length Achilles tendon and rather compared the anatomical tendon lengths of different runners.

Even though this mechanism has been widely studied, there are not many studies on how inclined/declined heel position affects running biomechanics. There is a study conducted by Braunstein et al., where comparisons are made among five different types of running shoes and barefoot running. On this setup all of the shoes' heel height is higher than the forefoot height. The findings suggest that there is a significant difference between barefoot and shoed running, and that ankle extensors generate higher forces when running with shoes compared to barefoot running [26]. Many studies have been published on a variety of shoes and insoles, however, it is not exactly clear what effect heel-inclined, flat, and toe-inclined insoles have on running biomechanics resulting by adjusted triceps surae tendon length. Therefore, the aim of this study was to investigate the effects of triceps surae tendon length altering shoe insoles during running. It is hypothetised that running with different insoles would affect GRF, gear ratios, and, therefore, loading of the ankle joint.

2. Methods

Subjects

The data was gathered from 11 recreational male runners (body mass $75.9 \pm 5kg$, height $1.8 \pm 0.04m$). They ran at a comfortable speed in a biomechanics laboratory. All subjects were informed about the trial procedure and gave their consent to participate.

Interventions

A pair of ECCO shoes (Biom Lite M, ECCO Sko A/S, Bredebro, Denmark) and three different types of insoles were used for this study. The shoe soles were flat and did not have cushioning (Figure 1). The insoles were cut to the appropriate shoe sizes used for the trials.

The insoles were placed in the shoe without any additional support linings. Each subject was provided by the same pair of shoes, and only the non-custom insoles were changed between the trials. This helped eliminate the occurrence of possible biomechanical differences that may arise due to different footwear.

Figure 1: *Ecco shoes used for the running trials.*

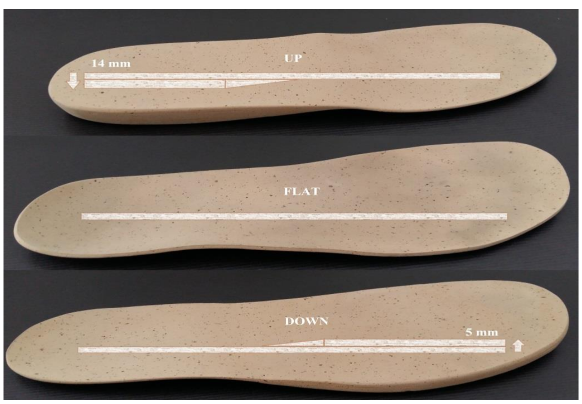

Figure 2: *Custom insoles with 14 mm heel spring ("UP"), flat ("FLAT"), and 5 mm forefoot elevation ("DOWN") [27].*

Experimental design

A total of 55 reflective markers were attached on participant's body based on marker placement protocol and anatomical body landmarks (See Appendix, Figure 10). The motion was captured using eight high-speed infrared cameras with a recording frequency set at 250Hz (ProReflex, Qualisys, Gothenburg, Sweden). GRF and center of pressure recordings were gathered using two AMTI force plates with a frequency set at 1000Hz (Advanced Mechanical Technology, Inc., Watertown, MA, US). The cameras were synchronised with the two force plates in the lab. A trigger button was used to define the start and end of each trial recording.

After all the markers were attached, each subject spent 10 minutes familiarising with the shoes and the insoles every time new pair insoles was introduced. Before conducting the running trials, a subject had to stay in a T-pose for a static trial recording to define each segment and teach the software the dimensions of the subject's body parts (Figure 3).

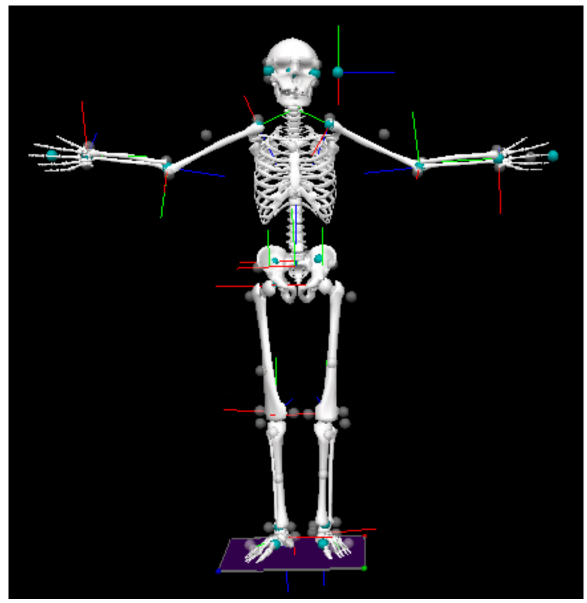

Figure 3: *T-pose model for the static trial recording.*

For the dynamic trials each subject had to run a straight distance of 8.6 m, make a 180 degree turn, come back to the starting point and continue running the same route until all the required amount of contact phases with the force plate were recorded. The distance from the starting point to the force plate was 4.9 m (Figure 4).

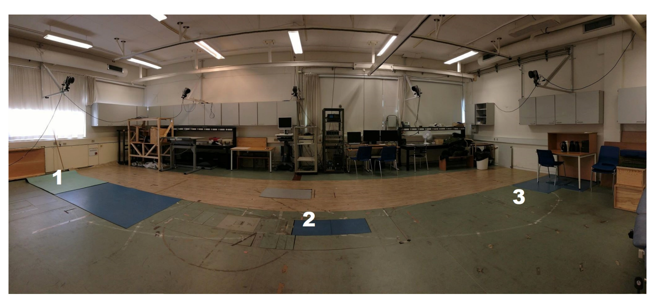

Figure 4: *Panoramic view of the laboratory. Starting point (1) that is 4.9 m away from the force plate (2). Participants ran to the point 3, turned around, came back to the starting position and repeated the trial.*

The whole testing session took a maximum of 2.5 hours. About 50% - 60% of the time was used for subject preparation for the actual trials.

Data processing

Motion capture and force plate data was collected and exported to Visual 3D (V6 Professional) and calculations were processed withing the software. Recorded GRF of each trial was normalised to body mass and used to express maximal vertical impact load, maximal impact peak, and breaking peak (for rearfoot runners only, $n = 8$), also maximal active peak (for all participants). Similarly to Boyer and Nigg's research, the mean value of three force plate measurements of each insole condition was used for further data analysis [28]. Vertical loading rate on impact was calculated based on the method presented in Ueda et al. paper. It was chosen to use the timeframe from foot strike to the impact peak. This method expresses vertical loading rate as "the average slope of the vGRF vs. time curve between foot strike and first vGRF peak" [29]. The vertical loading rate (VLR) calculation is based on the method presented by Ueda et al. and can be expressed as following:

$$VLR = (F_1 - F_0)/t_1 \ ,$$

where VLR is vertical loading rate, F_1 is force at the impact peak, and t_1 is the time at the instance of impact peak [29].
The internal moment arm of Achilles tendon was calculated based on a method described by Maganaris et al. [30].

Statistical analyses

The sample normality was checked using Shapiro-Wilk test [31]. For each force and gear ratio variable separately a repeated measures ANOVA was chosen to compare the values at each insole condition. The same method was also used to investigate the vertical impact loads. Such method is equivalent to the one-way ANOVA, but is designed for related, not independent, groups [32, 33]. Pearson correlation coefficient was used to express the association between the chosen two variables [32]. The interval of confidence was 95% with a statistical significance level set at $\alpha = 0.05$. Statistical analysis was conducted using SPSS 25 (SPSS Inc., Chicago, IL, USA) and Microsoft Office 365 ProPlus (Version 1803).

3. Results

The means among the corresponding variables were similar with only a slightly higher values of active peak and breaking force gear ratio observed in elevated forefoot ("Down") condition (Table 1). However, all measured forces, gear ratios, and vertical loading rates did not show significant differences among the three insole conditions ($p > 0.05$). Highest Pearson's correlation coefficients between the variables were calculated for the elevated heel insole condition, with strong positive association between impact peak gear ratio and impact load ($r = 0.7$), as well as strong negative correlation between breaking force and its corresponding gear ratio ($r = -0.73$). Most of the correlation strengths were found to be low and very low (Table 2) [34].

Table 1: *The mean and (SD) of ground reaction forces (N/kg), gear ratios and impact loading rate (N/kg/s).*

Variables	Insole type		
	Down	Flat	Up
Active peak	24.23(3.57)	23.73(3.41)	23.75(2.78)
Active peak gear ratio	2.48(0.59)	2.49(0.67)	2.42(0.71)
Impact peak	16.34(4.67)	15.7(2.16)	16.13(4.47)
Impact peak gear ratio	0.21(0.1)	0.24(0.11)	0.27(0.07)
Braking force	2.77(0.86)	2.72(0.6)	2.69(1.04)
Braking force gear ratio	0.79(0.49)	0.57(0.49)	0.63(0.49)
Impact loading rate	229.35(79.79)	232.30(68.92)	209.32(98.31)

4. Discussion

In running, injury risk is related to magnitudes of GRF [8]. It has also been shown that gear ratios indicate the magnitude of the joint load [35]. However, the is not much information on how GRFs and impact loading rates change when foot position relatively to the ground is altered due to shoe insoles, which might provide a better insight into the injury prevention. As gear ratio is a modifiable variable in running [16, 35], this study introduced how this measure changes together

Table 2: *Correlation coefficients of ground reaction forces, gear ratios and impact loading rate.*

Variables	Insole type		
	Down	Flat	Up
Active peak and active peak gear ratio	0.35	0.34	0.11
Impact peak and impact peak gear ratio	0.31	0.42	0.68
Braking force and braking force gear ratio	−0.28	−0.05	−0.73
Impact loading rate and impact peak gear ratio	0.28	0.34	0.7

with GRFs and impact loading rate in three different insole conditions. The findings are different from what was expected, as repeated measures ANOVA analysis has shown no significant difference among the corresponding variables in all three conditions. Therefore, null hypothesis has to be retained, stating that running with different insoles would not affect GRF, gear ratios, and, therefore, loading of the ankle joint. Null hypothesis has to be accepted based on "insufficient evidence to reject it" [36]. Even though such outcomes were not expected, it is common in research studies not to find statistical significance [37, 38, 39].

Throughout all three conditions, running with heel-elevated insoles showed a slightly smaller mean impact loading rate (Table 1). Even though this difference is not considered to be statistically significant, the findings still suggest that vertical impact loading rate is approximately 8.7% and 9.89% lower than with heel-elevated and flat insoles respectively. Clansey et al. investigated the effects of real-time feedback training on its capability to reduce stress tibial stress inducing factors, one of them being impact loading. They found that such training strategy can reduce impact loading ($p < 0.05$) without affecting running economy. However, such alterations were not sustained one month post-training. The authors suggest there has to be more research done on long terms impact loading reduction [40]. As impact loading rate is one of the factors for stress fracture occurrence [29, 40, 41], it is important to run more analyses in our study design to ascertain whether the results would disprove or still support the outcomes of this study. In case of disapproval, certain insoles might be an approach for vertical impact loading reduction in running.

A higher than calculated correlation was expected between the active peak and gear ratio at the instance of active peak. Such outcome was assumed based on the idea that high gear ratio during propulsion phase, when the foot is in quick movement, enhances the force output based on force-velocity relationship [35]. Even though the results showed positive correlation, the strength of it was either low or very low in all three conditions (Table 2) [34]. These findings, however, can not be generalised to conclude that this correlation would be weak in larger data set. Therefore, is highly probable that such outcomes were influenced by the small sample size [42].

Based on the literature, breaking force should be very small in order not to lose running speed during braking before propulsion phase [15]. Another important feature at braking peak is low ankle gear ratio. While braking, low gear ratio enhances the Achilles tendon stretch, thus potentially increasing the force output during propulsion phase [35]. Our results show strong negative correlation between the braking force and the corresponding gear ratio for the elevated heel insole (Table 2). Based on that, when breaking peak was higher, gear ratios appeared to be smaller and vice versa. In this study design both aforementioned desirable small values did not occur at the same instance.

Given that our findings are based on a limited number of participants, the results from the analyses should, therefore, be treated with considerable caution. The question arises whether an insufficient study design might have caused an effect to be unnoticed [43]. Statistical assumptions are based on the concept that the results of a sample can be used to represent the overall population [36]. The significance of the results in this study might have been affected by a small sample size that reduces the statistical power of the analysis [42]. An increased sample size would give more power to the study to detect the differences among groups. Despite the fact that there are cases of strong correlation between the variables, it is unclear whether they would remain similar in a comparable prospective study. There is a probability both high and low coefficients were estimated by chance, for this reason more studies are needed to improve the quality of the results.

Failing to detect significance in this study allows for future adjustments and implementations. There are multiple reasons possibly responsible for the defied expectations. An important issue to resolve for future studies is the small sample size. When sample size is small, the statistical power of the method is also low. Therefore, one of the most important improvements of this study would be increasing the number of participants. Another possible implementation could be calculating additional or different set of variables, such as triceps surae tendon length for each condition. This way a possible relationship between the tendon length and other biomechanical variables could be detected. It might provide a better insight not only in RRI mechanisms, but also running performance, based on the force-length relationship and SSC.

This approach of using insoles with different elevation could be elaborated even more in the prospective research. This study included both elevated rearfoot and elevated forefoot conditions. It could potentially be expanded to having either insoles with a greater elevation difference between the rearfoot and forefoot or using more types of insoles with different heel or toe elevation heights. Hence, the latter might require more resources and would be more time consuming.

Unfortunately, we were unable to identify the significant relationships of the chosen variables. This was probably a result of the previosly mentioned limitations. The intervention of running with different types of insoles has a potential to be researched more in the future. The prospective studies might apply and expand our methods, also implement additional calculations to show possible biomechanical differences in relation to different types of insoles.

5. Conclusion

This paper has investigated the effects of flat, rearfoot inclined, and forefoot inclined insole effects on running mechanics. The results of this study indicate that there were no statistically significant differences among the variables calculated in three different insole conditions. A strong correlation in the forefoot elevated condition were detected, however, given the small sample size, caution must be applied and the results might not be generalised to describe a bigger population. Although there are limitations due to small sample size, we believe this approach together with additional methodological implementations might potentially find mechanical alterations conditioned by wearing different insoles while running.

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