Step Frequency and Lower Extremity Loading During Running

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Key words
- tibial stress fracture
- running injury
- step frequency

Abstract

The purpose of the present study was to ascertain whether increase in step frequency at a given velocity during running reduces the lower extremity loading variables, which is associated with tibial stress fracture in runner. We hypothesized that the lower extremity loading variables at a given speed would be minimized at around +15% f_{step}. 10 male subjects were asked to run at 2.5 m/s on a treadmill-mounted force platform. 5 step frequencies were controlled using a metronome: the preferred, below preferred (−15 and −30%) and above preferred (+15 and +30%). From the vertical ground reaction force, we measured following lower extremity loading variables; vertical impact peak (VIP), vertical instantaneous loading rate (VILR) and vertical average loading rate (VALR). We found that there were significant differences in lower extremity loading variables among 5 step frequency conditions. Furthermore, quadratic regression analyses revealed that the minimum loading variable frequencies were 17.25, 17.55, and 18.07% of preferred step frequency for VIP, VILR and VIAR, respectively. Thus, adopting a step frequency greater than one's preferred may be practical in reducing the risk of developing a tibial stress fracture by decreasing lower extremity loading variables.

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Introduction

Tibial stress fractures are one of the most common and potentially serious overuse injuries in runners [13]. The stress fractures are thought to be related, in part, to abnormal lower extremity loading variables, such as vertical impact peak (VIP), vertical instantaneous loading rate (VILR) and vertical average loading rate (VALR). In order to understand associations between loading and the history of tibial stress fracture, several researchers have compared the characteristics of the ground reaction force (GRF) between control and stress fracture group [26]. For example, some studies reported that runners who developed tibial stress fractures had higher VILR and VALR than a group of age and mileage matched control subjects [3, 8, 22, 27]. Furthermore, there was a trend towards higher VIP in the group that had a stress fracture compared to the control group [8, 17]. Thus, modifying these loading mechanics may decrease a runner's risk for stress fractures.
Some studies suggest that adopting a 10–20% increase in step frequency (f_{step}) greater than one's preferred may prove beneficial in reducing the risk of developing a running-related injury or facilitating recovery from an existing injury [5, 6, 10, 12]. However, it is still unknown how the f_{step} manipulations affect overall lower extremity loading during running. The purpose of the present study was to ascertain whether increase in f_{step} at a given velocity during running reduces the lower extremity loading variables. We hypothesized that the lower extremity loading variables at a given speed would be minimized at around +15% of preferred f_{step}.

Methods

Participants

10 male participants with no neuromuscular disorders or functional limitations in their lower extremity participated in the study. Their physical characteristics were: age 28.8 ± 3.0 years, body mass 71.5 ± 9.3 kg, and height 1.75 ± 0.04 m (mean ± SD). They were all moderately active and recreationally trained but not engaged in systematic running training. Our study has been performed in accordance with the ethical standards

of the International Journal of Sports Medicine [11]. The experimental protocol was approved by the local ethical committee and is in accordance with guidelines set out in the Declaration of Helsinki (1964).

Task and procedure

The subjects were asked to run on a treadmill-mounted force platform (ITR3017, Bertec Corporation, Columbus, OH), from which the vertical ground reaction force (GRF) was recorded at 1000 Hz. The natural frequency of vertical vibration of the force platform mounted in the treadmill was 240 Hz. The GRF was then low-pass filtered at 100 Hz. Running speed was set at 2.5 m/s, because this was low enough to allow a larger range of step frequencies above and below the preferred f_{step} of normal subjects. Each subject ran on the treadmill and directed the experimenter to increase or decrease the f_{step} until a comfortable f_{step} was found. On average, the preferred f_{step} was 2.73 ± 0.14 Hz (mean ± standard deviation). Subjects ran with a digital audio metronome to facilitate the appropriate f_{step}. Since a past finding reported that a 10–20% increase in step rate substantially reduces tibial acceleration and energy absorption [5,10], we controlled 5 f_{step}: the preferred, below preferred (−15 and −30%) and above preferred (+15 and +30%). Before data collection, all participants were instructed to practice for as long as they needed until they felt comfortable with the task (it ranged from 3 to 4 min). According to their subjective impression, this practice session was enough to get used to the task. Also, none reported feeling fatigue. Then, they performed running for 30 s at each of the 5 f_{step} in a random order with 5 min rest periods in between.

Data collection and analyses

10 consecutive steps from both legs were used for the analysis. Foot-ground contact was determined at a vertical GRF threshold of 20 N. From the measurement of GRF, the VIP, VILR and VALR were determined (Fig. 1). VILR was the peak sample-to-sample loading rate occurring during 20–80% of VIP for this period [1,18]. VALR was calculated as the total change in force divided by the total change in time over this period. When no distinct impact transient was present, the same parameters were measured using the average percentage of stance as determined for each condition in trials [15].

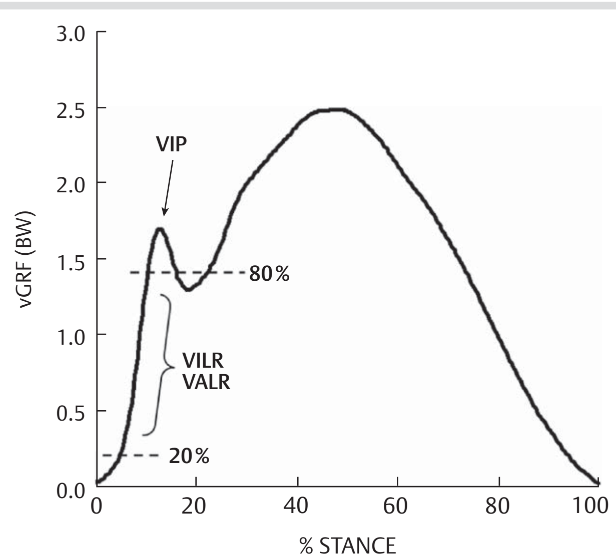

Fig. 1 Vertical ground reaction force (vGRF) during the stance, recorded from a single subject in preferred f_{step} conditions. Lower extremity loading variables (VIP, VILR and VALR) were determined at early stance phase.

Statistics

One-way repeated measures ANOVA and Bonferroni post-hoc multiple comparison test were performed to compare the loading variables among 5 frequencies. Further, we performed quadratic regression analyses by the least square method to each loading variable for obtaining the minimum value frequency. Statistical significance was set at $P < 0.05$. SPSS for Windows software (Version 13.0, SPSS Inc.) was used for all statistical analyses. All data are presented as the mean ± the standard deviation (SD).

Results

In all conditions, actual performed f_{step} was within 5% of the designated metronome frequency. Statistical analyses revealed that there were significant differences in VIP, VILR and VALR among 5 f_{step} conditions (Fig. 2). The results of the regression analyses were as follows: VIP, $y = 0.0002x^2 - 0.0069x + 1.7033$, $R^2 = 0.982$; VILR, $y = 0.0277x^2 - 0.9725x + 99.623$, $R^2 = 0.997$; VALR, $y = 0.0239x^2 - 0.8642x + 77.121$, $R^2 = 0.997$, where x is step frequency (%) and y is the loading variables. According to these equations, the minimum loading variable frequencies were 17.25, 17.55, and 18.07% of f_{step} for VIP, VILR and VALR, respectively.

Discussion

Since a 10–20% increase in step rate substantially reduces joint loading, adopting an f_{step} greater than one's preferred may prove

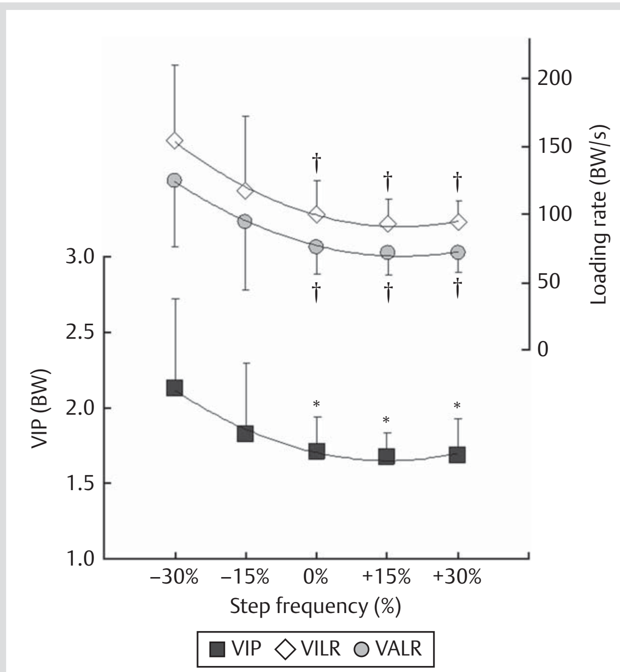

Fig. 2 Comparison of VIP, VILR and VALR among 5 f_{step} conditions. A dagger and asterisk indicates significant differences from value for the −30% f_{step}; $P < 0.01$, $P < 0.05$, respectively.

beneficial in reducing the risk of developing a running-related injury [5,6,10,12]. We found that there were significant differences in lower extremity loading variables among 5 f_{step} conditions (Fig. 2). Furthermore, the minimum loading variable frequencies were 17.25, 17.55, and 18.07% of f_{step} for VIP, VILR and VALR, respectively. Thus, the results of the present study support our null hypothesis that the lower extremity loading variables at a given speed would be minimized at around +15% of preferred f_{step}.

One possible explanation for reduced lower extremity loading variables in +15% f_{step} may be a change in the foot strike pattern. Indeed, Laughton et al. [14] and Lieberman et al. [15] demonstrated that as compared to rearfoot strike, forefoot landing pattern diminishes impact transient in early stance phase during running. A second explanation for the reduced lower extremity loading variables may be knee angle at foot strike. Derrick et al. [4] showed that increased knee flexion at contact could reduce the forces experienced by the body and therefore decrease injury potential. Furthermore, the changes in knee contact angle could increase perpendicular distance from the line of action of the resultant GRF to the knee joint center, which played a role in increased energy absorption [4]. Thus, reduced lower extremity loading variables in +15% f_{step} may be attributed to foot strike pattern and knee angle at foot strike, or combinations of these changes. The mechanisms of reduced lower extremity loading variables should be the subject of future investigation.

Stress fractures are thought to be related, in part, to abnormal lower extremity loading in runners [3,8,17,26,27]. Recently, some studies demonstrated reduced impact loading during running by using a real-time visual feedback gait retraining system [1,2]. However, the methodologies of these studies required very specialized materials or apparatus (e.g. treadmill, accelerometer, computer, and monitor). Adopting a f_{step} greater than one's preferred is practical not only in reducing the risk of developing a running-related injury, but also no materials or apparatus are needed.

Since increased f_{step} at a given speed results in an increase in loading cycle, the running technique could lead to another problem. First, if increase in the f_{step} were to increase the metabolic cost of running, the muscle fatigue is likely to onset sooner in comparison to a preferred one. Indeed, Milgrom et al. [16] suggested that the fatigue state increases bone strains well above those recorded in rested individuals and may be a major factor in the stress fracture etiology. However, a previous study suggested that a 10% reduction in stride length does not significantly change oxygen consumption and heart rate from a preferred stride frequency [10]. Consequently, Edwards et al. [6] concluded that the change in metabolic cost from a 10% reduction in stride length is negligible and that this type of kinematic adjustment would not accelerate the bone microdamage process through fatiguing muscles. Second, an increase in loading cycle will increase running mileage for the probability of tibial stress fracture at the tibia. However, Edwards et al. [6] suggested that strain magnitude plays a more important role in stress fracture development than the total number of loading cycles. Thus, adopting a f_{step} greater than one's preferred is unlikely to induce another running-related injury.

In the present study, a treadmill-mounted force platform was used for our experiment. It is relatively well-established that the biomechanical characteristics of running on a treadmill are quite different from the characteristics of actual overground running [7,9,19,20]. This might be attributed to the differences in air resistance, visual and auditory surroundings, and running surfaces [23]. On the other hand, some studies reported overall similarities between treadmill and overground running [21,24,25]. Thus, future studies should attempt to confirm whether our results are applicable to actual overground running.

In summary, the purpose of the present study was to ascertain whether an increase in f_{step} at a given velocity during running reduces the lower extremity loading variables. The results of the present study suggest that a 15% increase in f_{step} minimizes the lower extremity loading, such as VIP, VILR and VALR. Thus, adopting an f_{step} greater than one's preferred may be practical in reducing the risk of developing a tibial stress fracture without additional use of materials or apparatus.

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Conflict of Interest: None of the authors have any conflicts of interest associated with this study.

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