# Relationship between Ground Reaction Force and Stability Level of the Lower Extremity in Runners

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**Background:** Neuromuscular control is critical for providing protection from injury during dynamic activities. Running injuries have been associated with high ground reaction forces (GRF) which may be related to poor lower extremity stability in runners. **Objective:** To identify the relationship between peak active vertical GRF (VGRF) measured during running and Star Excursion Balance Test (SEBT) scores in a group of recreational runners. **Design and Setting:** Subjects were assessed for lower extremity stability using the SEBT, and for peak active VGRF while running across a force plate in a laboratory setting. Scores were then correlated. **Subjects:** Seventeen healthy adults who ran at least 15 miles/wk were recruited. **Measurements:** The reaching length of the SEBT was measured from 3 directions (anterior, lateral, & posterior) of each foot, and the peak active VGRF was measured from the left foot while running across a force plate. Data were reduced using Pearson correlation coefficient, $p < 0.05$. **Results:** While the previously injured runners produced higher active VGRF (2.48 v 2.24 BW) and lower SEBT scores (45.09 v 51.83cm) as compared to the previously non-injured runners, there was no significant correlation between stability level and peak active VGRF, ($r(14) = -.273$, $p > .05$). **Conclusion:** Lower extremity stability as measured by the SEBT is not related to peak active VGRF in recreational and competitive runners. However, those with previous injury had markedly decreased stability and slightly higher active force than those without injury. **Key Words:** neuromuscular control, dynamic stability, balance

As the number of recreational runners has increased over the last decade, so has the number of running-related injuries.[1] The most common running-related injuries are stress fractures, shin splints, plantar fasciitis, and iliotibial (IT) band syndrome.[2] These conditions are believed to occur from excessive running distance or intensity, running surface type,[3] abnormal anatomical structure (high/low arch)[4] and poor running mechanics.[5] The biomechanical analysis of running mechanics started over 30 yr ago, and since observational study was not reliable enough to identify probable causes of injuries, the force plate has become one of the most popular instruments to measure the impact force and collect reliable data to identify the amount of force the body produces during a foot contact.[3] It was also reported that impact (initial heel contact) or active (push-off phase) vertical ground reaction force (VGRF) during jogging is 2 to 3 times body weight.[3] Recent studies demonstrated that higher VGRF is typically found in runners with longer stride length,[5] older runners,[6] and running downhill.[7] In addition, excessive running distance and intensity may have major contributions to running-related injuries. One study reported that more than half of runners have experienced running-related injuries during their first year of committed running training.[8] These data indicate that novice runners may lack knowledge regarding running routines and proper progression as compared to experienced runners. Moreover, this also indicates that novice runners' lower extremity muscles may not be necessarily adapted properly to run the distance or handle the intensity repetitively. One study stated that novice

Sato K, Butcher-Mokha M. Relationship between ground reaction force and stability level of the lower extremity in runners. In Cleary MA, Eberman LE, Odai ML, eds. *Proceedings of the Fifth Annual College of Education Research Conference: Section on Allied Health Professions.* [online conference proceedings]. April 2006;1:40-44. Miami: Florida International University. http://coeweb.fiu.edu/research_conference/.

runners are increasing distance too rapidly, and they also tend to overly engage in high intensity training.[9]

Anatomical structure has a major role in running mechanics, especially when differentiating mechanics and injury risk between male and female runners.[4] Female runners reported twice as many as running-related injuries as male runners.[1] Greater quadriceps angle is often seen in women, which causes internal rotation of knee joint and tibia during running.[10] This type of abnormal anatomical structure causes high stress in the lower extremity that ultimately leads to overuse injuries.[5] Finally, the findings were reported by Ferber et al that female runners actually produced greater kinetic activities in the lower extremity during running, as compared to male runners.[11]

The Star Excursion Balance Test (SEBT) is a clinical test that has been used to assess lower body stability and dynamic balance in recent years.[12,13] Its' reliability is 0.67 to 0.87.[14] Olmsted et al.[13] reported that when instability of the lower extremity is diagnosed by using the SEBT, those participants generally produce less power, and possess balance and body control which may lead to a higher risk of injuries from athletic activities. Thus, poor stability may cause excessive kinetic forces, fatigue, and faulty movement pattern, which ultimately associate with overuse running-related injuries. Although these reviewed studies discuss the VGRF and its relation to running-related injuries, the direct relationship between the VGRF and the stability level of the lower extremity based on a clinical stability test has not been studied. Therefore, the purpose of this study was to identify the relationship between the peak active VGRF and lower extremity stability level as measured by the SEBT, in a group of recreational runners. Further, scores were examined between those in the group who have sustained a previous running-related injury, and those who have not. We hypothesized there may be a correlation between the high active VGRF and the low stability level of the lower extremity based on the SEBT score in runners. In addition, previously injured runners may display higher active VGRF and lower SEBT scores compared to healthy runners.

## Methods

Seventeen recreational and competitive rear-foot strike runners (6 males, 11 females) volunteered for this study (age = 32.8$\pm$8.9 yrs, height = 166.7$\pm$9.2 cm, mass = 65.6$\pm$16.1 kg). They answered specific questions regarding their training strategies and past history of lower extremity injuries to identify their running background. Based on individual history, this study had 11 previously injured runners and 6 no previous injury runners prior to the test. All data collection was performed at a selected laboratory. The SEBT measured dynamic stability of the lower extremity. Since verbal instruction and visual demonstration increases the reliability of the SEBT, each participant was given these along with 3-5 practice trials.[14] Eight lines, each 75 cm in length, were placed at 45-degree angles (Figure 1). The test was performed without shoes to eliminate influence from shoes according to the past studies.[12–14] After an adequate amount of warm-up by stretching, each participant placed his or her left foot on the center of 0-180 degree line. Then, participants reached their toes as far as possible to the directions of 0, 90, and 180 degree lines while maintaining balance (Figure 2). Participants performed the same sequence with their right foot. All participants followed the same procedure. Each participant performed 3 trials for each foot and their best reaches were recorded manually. The investigator visually observed that participants were in static position for at least 3 s to ensure their ability to stabilize their bodies before recording the data. The lengths of the reaching toes and the toe of the opposite foot were measured manually. The scores of the SEBT were recorded with the longest lengths of all 3 directions averaged to be the total score.

This study simulated the real running speed for all participants to measure the active VGRF (push-off phase of the VGRF). Participants performed at least two trials and made left foot contact on the force plate at a comfortable running speed (2.65-3.35 m/s = 8-10 min per mile pace) after having warmed up for 1 mile outdoors at a self-selected pace. If participants had abnormal steps prior to reaching the force plate, the trial was not recorded and they were asked to perform another trial. The active VGRF were measured by an AMTI force plate (Advanced Medical Technologies, Inc., Watertown, MA) that sampled at 600 Hz. The Peak Motus software (ver. 8.2, ViconPeak, Centennial, CO) was used to reduce the data with Fast Fourier Analysis. The active VGRF were obtained at the push-off phase of foot contact, normalized to body weight (BW), and averaged for the groups. The active VGRF and the SEBT scores were input into SPSS (SPSS Inc. Chicago, IL) and analyzed using Pearson correlation coefficients, $p<.05$.

## Results

A Pearson correlation coefficient was calculated for the relationship between the scores of the SEBT and the peak active VGRF. No significant correlation was found in the relationship between the scores of the SEBT and the active VGRF ($r$ (14) = -.273, $p > .05$), indicating a non-linear relationship between the two variables. The previously injured runners displayed lower average in reaching length of the SEBT, as compared to the previously non-injured runners (45.09 cm vs. 51.83 cm) (Figure 3). The previously injured runners also displayed a higher average in peak active VGRF in average of 2.48 body weight, whereas the previously non-injured runners produced in average of 2.24 body weight (Figure 4).

## Conclusion

The results did not support the hypothesis that there was no correlation of low scores of the SEBT with higher peak active VGRF. However, the results supported one hypothesis that previously injured runners produced higher active VGRF and lower stability in the lower extremity based on the SEBT. The participants who had multiple running-related injuries in their past scored the lowest. The results related to some reviewed literatures' findings. This study related to the previous study by Olmsted et al.[13] that previous injuries affected SEBT performance and scored poorer than those who have no previous injuries. This study cannot determine how injuries, low stability, nor high peak active VGRF happens to each individual, but running-related injuries may have caused the decrease in stability of the lower extremity which may also lead to the risk of re-injury. Based on the results of this study, we conclude that impairments in stability are not necessarily associated with higher peak active VGRF during running. However, those with previous injuries showed lower stability and higher active VGRF than those without injury. Runners may be able to reduce the active VGRF or improve their stability level in the lower extremity by performing proper training in the long term, and may reduce the risk of injuries from running activities. Further research will be needed to investigate other GRF variables (impact VGRF, medial/lateral GRFs, and posterior/anterior GRFs) and its relation to the stability level of the lower extremity.

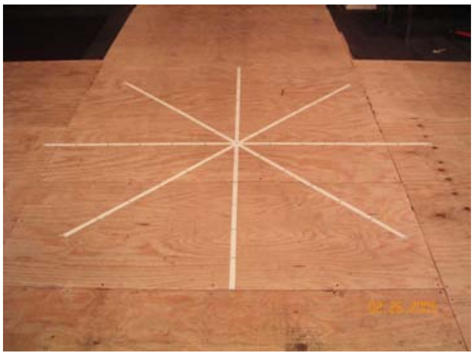

**Figure 1.** Layout of the Star Excursion Balance Test

**Figure 2.** Lateral Reach on the Star Excursion Balance Test

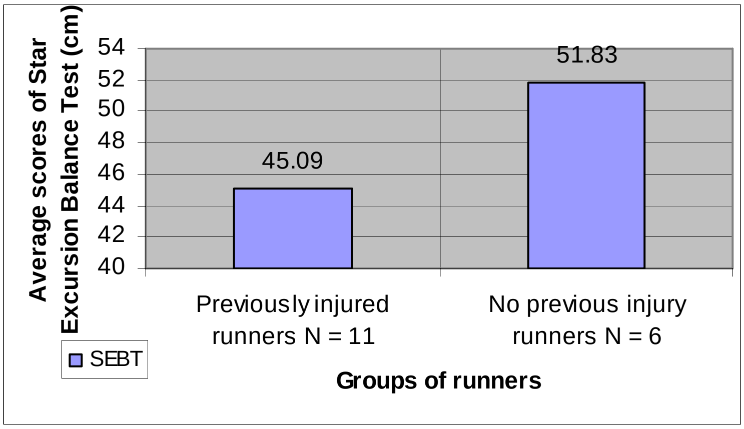


**Figure 3.** Comparison between two characters

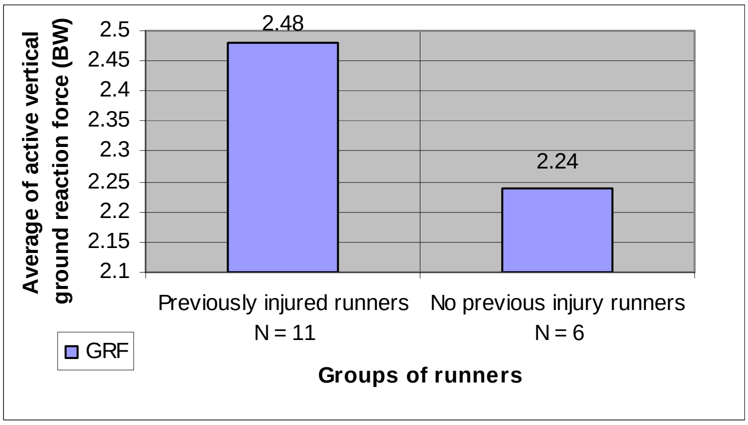


**Figure 4.** Comparison between two characters

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