MUSCLE ACTIVITY AND TIBIAL SHOCK DURING THE INITIAL TRANSITION FROM SHOD TO BAREFOOT RUNNING

[1] Gregory M. Gutierrez, PhD and [2]Evan Olin
[1]Arthur J. Nelson Human Performance Laboratory, Department of Physical Therapy, New York University, New York, NY
[2]Science Research Program, Ossining High School, Ossining, NY
email: gmgutierrez@nyu.edu, web: www.steinhardt.nyu.edu/pt/labs/human

INTRODUCTION

Barefoot running has become increasingly popular among distance runners. While modern running shoes provide protection for the foot, it has been speculated that footwear has a negative effect on intrinsic foot function.[1] A large majority of habitually shod (with shoes) runners land on their rear-foot first (rear-foot or heel strike).[2] This pattern manifests itself in shod runners due to the substantial cushioning under the heel of modern running shoes, meant to dissipate impact, which effectively places the foot in a plantar flexed position, making a fore-foot landing difficult and unstable. Habitually barefoot runners run with a remarkably different strategy than shod runners.[3,4] Specifically, they tend to land either on their fore-foot first (fore-foot or toe strike) or flat footed (mid-foot strike).[3] This pattern allows them to utilize the eccentric action of the plantar flexors to dissipate impact.

It follows that the differences in foot-strike patterns are commonly associated with differences in impact forces. In the loading phase of early stance, runners who rear-foot strike produce an impact transient.[3] These forces are sudden and strong, and have been associated injuries such as tibial stress fractures and plantar fasciitis.[5] Those who rear-foot strike also have a peak vertical force that is three times greater than those who fore-foot strike.[3] Runners who fore-foot strike, however, do not have a distinct ground reaction force impact transient, which may be a less potentially injurious style of running.[3] However, the fore-foot strike technique does cause an increase in the pressure under the metatarsal heads.[6] Further, impact may be higher in barefoot running until the runner has acclimated to the absence of footwear and acquired proper fore-foot strike technique.[4]

No research could be located comparing muscle activity between shod, rear-foot strike running and barefoot, fore-foot strike running. More research including muscle activity is necessary to develop a better understanding of the differences between barefoot and shod running. Further, since all of these conclusions regarding barefoot and shod running were made either in habitually barefoot populations or after a complete transition from shod to barefoot, examining the actual transition is important to understanding the risks associated with a change in running style. Therefore, this study aimed to examine tibial shock and muscle activation in the initial transition from shod to barefoot running both before and after instruction on proper fore-foot strike technique.

METHODS

Eight habitually shod recreational runners gave informed consent and participated in the study (Demographics in Table 1). All subjects were free of any conditions and/or injury that may have influenced movement patterns and ran a minimum of 10 mi/16 km per week**.** All data were collected from the subject's dominant leg. EMG electrodes (Bagnoli-8, Delsys, Inc., Boston, MA, USA) were placed over the tibialis anterior (TA), peroneus longus (PL), medial gastrocnemius (MG), and soleus (SOL) muscles using standard techniques and placement sites. Foot switch leads were positioned directly under the calcaneal tuberosity and the first metatarsal head to determine ground contact. An accelerometer (Type 8690C5, Kistler Instrument Corp., Amherst, NY) was firmly mounted on the skin directly over the tibial crest. A custom electrogoniometer was attached to the lateral side of the knee, with the potentiometer aligned with the knee joint axis, to monitor knee joint angle.

Demographic	Mean±SD
N	8
Male/Female	2/6
Age (yrs)	27.0 ± 6.9
Height (m)	1.68 ± 0.07
Weight (kg)	68.1 ± 14.9
Distance (km/wk)	22.0 ± 5.6
Test Speed (mph)	5.8 ± 0.9

Table 1. Subject demographics.

Subjects performed a five minute warm-up on a stationary bicycle, then were asked to self-select a comfortable speed on the treadmill that they would choose for an easy distance run. This speed would be maintained throughout the testing protocol. The running protocol consisted of three different running trials; each 7 minutes long, with 5 min rests between trials. Analog data were collected during the 2nd, 4th, and 6th minutes. In the first trial, subjects ran with their current running shoes (shod, heel strike [SHS]). After taking off their shoes, subjects performed the second running trial using the same rear-foot strike technique (barefoot heel strike [BHS]). Subjects were then instructed on proper fore-foot strike technique for barefoot running and performed the third running trial using that technique (barefoot toe strike [BTS]).

EMG data were band-pass filtered (2nd order, zero-lag Butterworth filter, with cut-off frequencies of 20 and 300 Hz), rectified, smoothed with a low-pass filter (2nd order, zero-lag Butterworth filter, with a cut-off frequency of 7 Hz), and normalized to maximum dynamic activity. Foot switch data were used to crop the data between touchdown and toe-off for each stride, as well as to calculate ground contact time (GCt).

Foot switch data were also used to assure that the toe struck the ground before the heel during the BTS trials (strides were discarded otherwise). Average EMG activity (MG/PL/SOL/TA avg) was then calculated over each stance phase. Tibial shock was determined as the peak acceleration during the dynamic trials (PkShk). Time to peak shock (tPkShk) and average shock (AvgShk) were also calculated from the accelerometer data. Finally, knee flexion angle at touchdown (KFA@TD) and minimum knee flexion angle during stance (MinKFA) were calculated from the electrogoniometer data. All data were visually inspected and averaged across all strides and measurement times (2nd, 4th, and 6th minutes) for each condition. A one-way MANOVA with repeated measures (Condition – SHS, BHS, and BTS) was conducted. Tukey HSD post-hoc tests determined where significance lied.

RESULTS AND DISCUSSION

A significant main effect was noted for condition ($F_{(10,6)}$ = 6.015, p=.02). Univariate tests revealed significant differences in nine of the ten variables analyzed (Table 2).

Variable	SHS	BHS	BTS
MGAvg (% Max) *ǂ	15.1±3.5	15.0±4.5	13.4±3.6
PLAvg (% Max) *	28.1±2.4	30.5±5.0	33.5±4.3
SOLAvg (% Max) *ǂ	31.6±3.3	36.1±5.9	37.6±5.0
TAAvg (% Max)	27.9±4.0	32.3±4.2	33.2±3.8
PkShk (g) *	3.6±1.1	6.2±2.5	4.8±2.0
tPkShk (ms) *	47.4±22.9	19.0±4.2	35.4±21.0
AvgShk (g) ǂ	0.25±0.21	0.33±0.20	0.37±0.23
KFA@TD (°) ǂ	13.2±6.5	16.5±7.1	18.9±9.4
MinKFA (°) *ǂ	9.4±7.4	13.5±9.8	13.9±10.1
GCt (ms) *ǂ	322.0±50.8	265.8±53.1	260.6±51.0

Table 2. All data (Mean±SD). * indicates SHS was significantly different than BHS, while ǂ indicates SHS was significantly different than BTS.

Muscle activity in the MG, PL, and SOL muscles significantly increased (p<.01) from shod to barefoot running. In general, the SHS condition had the lowest average EMG for those muscles, while the BTS condition had the highest. These findings are not surprising in that these individuals are habitually shod, rear-foot striking recreational runners. Therefore, that technique should be the easiest to perform and thus should demonstrate the lowest muscle activity. Since greater muscle activation is associated with stronger muscle contractions, during the initial transition from shod to barefoot running, the risk of muscle damage (soreness, strains, tears, etc.) is increased, especially in muscles which are eccentrically absorbing much of the load during a fore-foot strike technique (plantar flexors). Further, greater activation of the PL may lead to a more rapid rate of fatigue. Since the PL is the primary lateral stabilizer of the ankle, if this muscle is fatigued, combined with a more plantarflexed (open-packed) position of the ankle, runners making the transition may be at a greater risk of suffering injuries such as lateral ankle sprains.

These results show that tibial shock occurred quickest and to the highest magnitude (p=.03) in the BHS condition, indicating a much greater loading rate. This emphasizes the importance of the substantial cushioning provided by the modern running shoe, should a rear-foot strike technique be the preferred running style. However, the BHS technique is rarely, if ever, recommended for running. More relevant are the differences between the SHS and BTS conditions. Specifically, PkShk and AvgShk were greater, and tPkShk was quicker (only AvgShk was significantly higher) in BTS than SHS. While it has been suggested that a BTS running style may result in lower shock along the kinetic chain than SHS, these results demonstrate that during the initial transition into BTS running the opposite is true. This is likely due to the absence of cushioning from the shoe in runners accustomed to that cushioning being present, as well as inexperience with proper fore-foot strike mechanics. If runners do not properly acclimate to the new running style, this higher shock and more rapid loading rate may result in more stress related overuse injuries (stress fractures, medial tibial stress syndrome, etc.).

GCt was significantly longer in shod vs. barefoot conditions (p<.01). This supports previous findings that barefoot running is associated with shorter ground contact and flight times, and thus an increased stride rate, than shod running.[4,6] Interestingly, the metabolic cost of barefoot running is still less than that of shod running because the weight of the shoe requires more energy expenditure, even though the increased stride rate results in more mechanical work.[7]

KFA@TD was significantly higher in the BTS condition than the SHS condition (p=.04), while the BHS condition was between those two (although not significantly different than either). Further, the MinKFA was significantly greater in the barefoot vs. shod conditions, indicating the knee was more flexed in the barefoot conditions than the shod conditions. This follows with the tibial shock findings and suggests that while running, barefoot runners accommodate for the increased shock by adjusting at other joints (more knee flexion) to manage the additional stress on the kinetic chain.

CONCLUSIONS

This study aimed to evaluate the initial transition from shod to barefoot running. Taken together, the findings indicate that habitually shod, rear-foot striking runners who chose to transition into a barefoot, fore-foot strike technique should undertake the process cautiously and patiently, as the initial change in mechanics may be detrimental.

REFERENCES

1. Zipfel B & Berger L. *The Foot* **17**, 205-213, 2007.
2. Hasegawa H et al. *J Strength Cond Res* **21**, 888-93, 2007.
3. Lieberman DE et al. *Nature* **463**, 531-535, 2010.
4. Divert C et al. *Int J Sports Med* **26**, 593,598, 2005.
5. Van Gent RN et al. *Brit J Sport Med* **41**, 469 -480, 2007.
6. Squadrone R & Gallozzi C. *J Sports Med Phys Fitness* **49**, 6-13, 2009.
7. Divert C et al. *Int J Sports Med* **29**, 512,518, 2008.