Effect of Fatigue on Leg Muscle Activation and Tibial Acceleration during a Jumping Task

Michelle A. Sandrey, Yu-Jen Chang,* Krista Meder,^ Jean L. McCrory^
College of Physical Activity and Sport Sciences, *Division of Physical Therapy and ^Exercise Physiology, West Virginia University, Morgantown, WV.

ABSTRACT

Lower extremity stress fractures are a common occurrence during load bearing activities of jumping and landing. To detect biomechanical changes during jumping while injured, a fatigue model could be used. **PURPOSE:** To evaluate muscle activation and tibial accelerations in the triceps surae complex, anterior compartment and tibia pre-to-post fatigue following a jumping task. **METHODS:** Thirty active college-aged subjects with and without a previous history of stress fractures were recruited (15 male, 15 female, 21.5±5.04 yrs, ht=173.5±12.7cm, wgt =72.65 16.4±kg) resulting in 177 leg trials for evaluation (control, stress fracture injured and stress fracture contralateral). EMG activity and acceleration of the proximal tibia were recorded pre-to-post fatigue. The EMG protocol consisted of surface electrodes placed on the medial gastrocnemius (MG), soleus (SOL), and tibialis anterior (TA) following a standardized placement protocol. A triaxial accelerometer was attached to the proximal anterior surface of the tibia. Subjects performed a maximal vertical jump on one leg 3 times with arms folded across the chest pre-to-post fatigue. Standing heel raises on a custom built platform at a pace controlled by a metronome until task failure was reached was used for the fatiguing protocol. Legs were tested using a randomized testing order. Pre-to-post fatigue measurements included the linear envelopes of the MG, SOL and TA and peak accelerations (resultant acceleration in take-off and landing). **RESULTS:** There was an interaction for leg and test for TA (P=.050) with a difference between stress fracture and control posttest (P=.05). Decreases in EMG linear envelope following fatigue (P<0.01) were evident for the MG (P<0.01) and TA (P=0.12), but not for the soleus (P=.111). There was a significant difference for tibial acceleration for leg (P=.029) in the stress fracture contralateral leg in comparison to the control leg at takeoff (P=.042). At landing, there was a significant difference for test (P<0.01) as tibial acceleration increased post-test (P<0.01) and leg (P=.019) where there was a difference between stress fracture injured with stress fracture contralateral (P=.014). **CONCLUSION:** Attention should be directed to the MG and TA muscles and in providing landing and take-off guidance upon return to activity.

INTRODUCTION

Lower extremity stress fractures are a common occurrence in both athletics and in the general active population. Of the bones affected, the tibia is most frequently studied. (1) There have been studies that have reported on factors associated with tibial stress fractures, (2-6) but studies have been questionable or have analyzed multiple stress fractures. Despite this, there are predictive factors that may be identified specifically to tibial stress fractures, including, muscle activation of the triceps surae and anterior compartment, load bearing capability of the tibia, and activity. (1, 2, 5, 6) Unfortunately, most of the studies have been conducted on runners, with very little emphasis on the load bearing activities such as jumping and landing that occur in other sports.

It is difficult to evaluate biomechanical factors, especially muscle activation and the maximal rate of acceleration on the tibia when an individual has a stress fracture. However, a fatigue model is one that could be used to predict the possible changes that may occur as fatigue may be a risk factor for injury. (7-11) Fatiguing the gastrocnemius muscle by completing heel raises until task fatigue is reached (7-8) may provide the basis of what happens to the muscles in the anterior and posterior compartments and the tibia when the normal function of these muscles or bone are compromised.

PURPOSE

To evaluate muscle activation and tibial accelerations in the triceps surae complex, anterior compartment and tibia pre-to-post fatigue following a jumping task.

METHODS

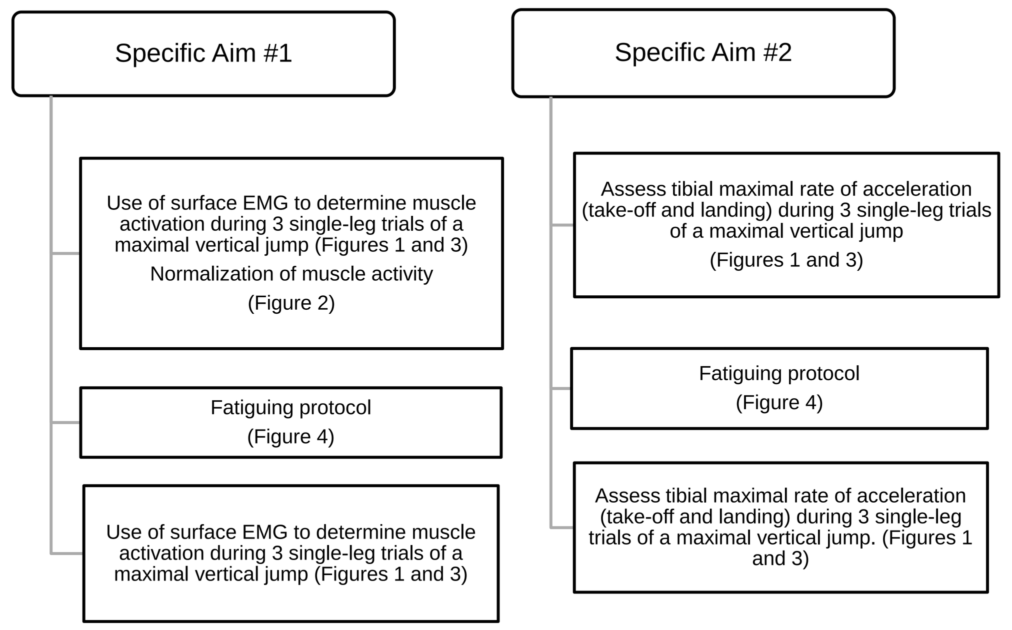
❑ Subjects

▪30 active college-aged participants with and without a previous history of stress fractures were recruited (15 male, 15 female, 21.5±5.04 yrs, ht=173.5±12.7cm, mass =72.65 16.4±kg) resulting in 177 leg trials for evaluation (control, stress fracture injured and stress fracture contralateral).

▪Of those 30 participants, 15 were in the control group, and 15 in the stress fracture group.

▪This study was approved by the Institutions Office of Research Compliance.

PROCEDURES



EMG and Accelerometer Protocol

- ❑ Surface self-adhesive bi-polar Ag/AgCl electrodes were attached bilaterally to the muscle belly of tibialis anterior (TA), gastrocnemius medial head (MG), and soleus (SOL), following a standardized placement protocol.
- ❑ A triaxial accelerometer (1000 Hz, Model TSD109C, BIOPAC Systems, Inc., Goleta, CA) was placed on the distal anteromedial aspect of the tibia.
- ❑ EMG signals and tibial acceleration data were transmitted through MP160 receiver (BIOPAC Systems, Inc., Goleta, CA) to the data collection computer to be analyzed using AcqKnowledge 5 software (BIOPAC Systems, Inc., Goleta, CA).
- ❑ The linear envelopes of the TA, MG and SOL and tibial acceleration data (12) were processed in Matlab (Mathworks, Inc., Natick, MA) .

Fatiguing Protocol

- ❑ Standing heel raises were completed until task fatigue using a custom built apparatus with an adjustable rod and foot positioning device.
- ❑ Shod participants stood with the knee of the testing leg extended on the platform with the other leg bent. One hand was placed on the wall only to maintain balance. Heel raises were completed following the cadence (7, 8) dictated by the metronome and continued until the pace was no longer maintained or the determined height was not reached for 3 sequential heel raises.

Figure 1

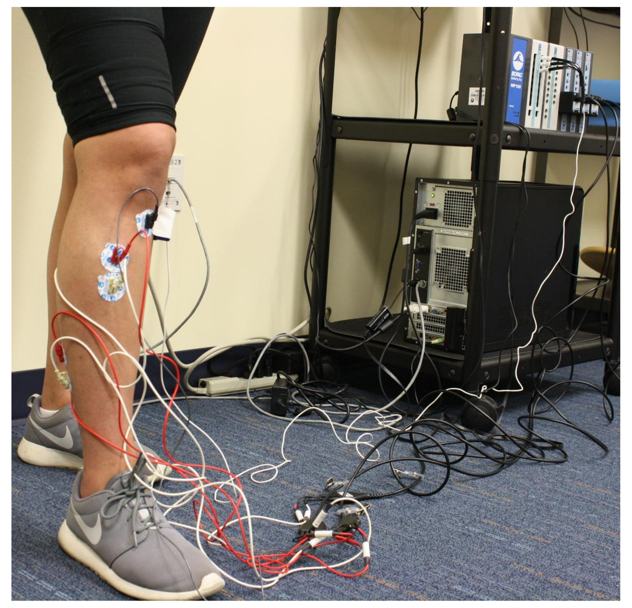
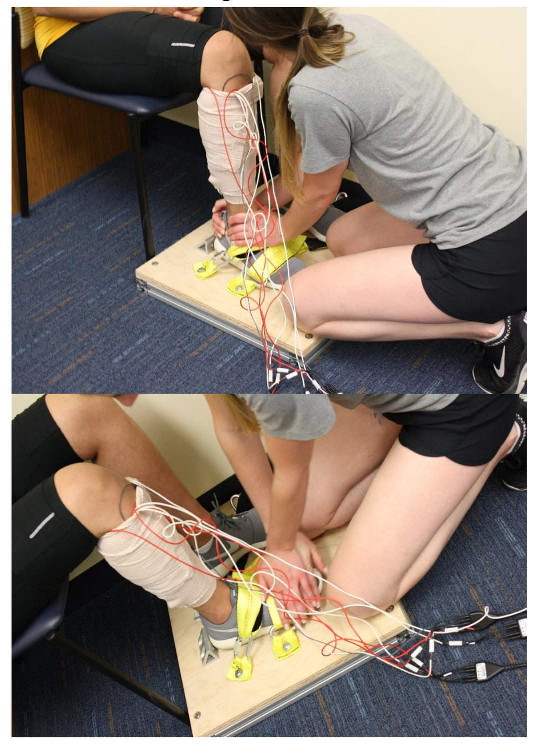


Figure 2



RESULTS

Figure 3

Figure 4

Linear Envelopes of the TA, MG and SOL:

- ❑ There was an interaction for leg and test for TA (P=.050) with a difference between stress fracture and control posttest (P=.05).
- ❑ Decreases in EMG linear envelope following fatigue (P<0.01) were evident for the MG (P<0.01) and TA (P=.12), but not for the soleus (P=.111).

Table 1. Mean and SD Values for Muscle Linear Envelopes (%mvc*sec)

	Pre-Fatigue	Post-Fatigue
TA Control	.222 ± .358	.184 ± .310
TA Stress Fx	.112 ± .091	.106 ± .068
TA SFx Contralateral	.126 ± .066	.119 ± .079
MG Control	.402 ± .898	.364 ± .700
MG Stress Fx	.555 ± .647	.460 ± .539
MG SFx Contralateral	.318 ± .178	.263± .132
SOL Control	.216 ± .136	.210 ± .180
SOL Stress Fx	.233 ± .180	.202 ± .143
SOL SFx Contralateral	.182 ± .112	.180± .157

Key: TA = tibialis anterior; MG = medial gastrocnemius; SOL = soleus; Fx = fracture; SFx= stress fracture

Tibial Acceleration during Take-off and Landing:

- ❑ There was a significant difference for tibial acceleration for leg (P=.029) in the stress fracture contralateral leg in comparison to the control leg at takeoff (P=.042).
- ❑ At landing, there was a significant difference for test (P<0.01) as tibial acceleration increased post-test (P<0.01) and leg (P=.019) where there was a difference between stress fracture injured with stress fracture contralateral (P=.014).

Table 2. Mean and SD Values for Tibial Accelerations (Take-off and Land) (G)

	Pre-Fatigue	Post-Fatigue
TO Control	5.19 ± 1.61	5.34 ± 1.58
TO Stress Fx	4.69 ± 1.17	4.92 ± 1.26
TO SFx Contralateral	4.61 ± 1.65	4.59 ± 1.56
Land Control	5.82 ± 1.70	6.65 ± 1.96
Land Stress Fx	6.22 ± 1.60	6.96 ± 1.78
Land SFx Contralateral	5.34 ± 1.78	5.82 ± 1.66

Key: TO = take-off; Land = landing; G = units of gravity; Fx = fracture; SFx= stress fracture

CONCLUSIONS

- ❑ Although the stress fracture participants were not currently experiencing symptoms, there was a difference between the stress fracture and control limbs following the fatiguing protocol, which indicated that muscle activity was still limited in the stress fracture limb.
- ❑ Decreases in EMG activity were noted for the MG and TA, but not for SOL. It was surmised that MG would be affected and not SOL based on the fatiguing protocol with the knee in extension throughout. However, another cause for concern is that the TA muscle, one of the major muscles to maintain balance, was affected.
  - ❑ Although not evaluated, upon return to activity the MG and AT muscles should undergo muscle strengthening and endurance.
  - ❑ As a single-limb maximal vertical jump was performed, activities that relate to single-limb balance and single-limb hop to stabilization that would activate the TA muscle and other distal kinetic chain muscles should be incorporated in a rehabilitation program.
- ❑ Differences were noted for take-off and landing for tibial acceleration following a fatiguing protocol of the gastrocnemius.
  - ❑ Why there was a increase in tibial acceleration for the stress fracture contralateral limb at take-off in relation to the control limb may be that subjects were still placing more weight on this limb, even though the stress fracture was healed.
  - ❑ Upon landing, tibial acceleration increased post-fatigue with the stress fracture limb experiencing more than the contralateral stress fracture limb. Because of this, more emphasis should be placed on softer landings following a single-limb maximal vertical jump.
- ❑ Future research should evaluate whether the results of this study, as was noted following a gastrocnemius fatiguing protocol, should be a consideration when determining a rehabilitation program and return to activity following a tibial stress fracture.

REFERENCES

1. Beck BR, Rudolph K, Matheson GO, Bergman AG, Norling TL. Risk factors for tibial stress injuries: a case-control study. *Clin J Sport Med*. 2015;25:230-236..
2. Barnes A, Wheat J, Milner C. Association between foot type and tibial stress injuries: a systematic review. *Br J Sports Med*. 2008;42:93–98.
3. Milner CE, Ferber R, Pollard CD, et al. Biomechanical factors associated with tibial stress fracture in female runners. *Med Sci Sports Exerc*. 2006;38:323–328..
4. Yagi S, Muneta T, Sekiya I. Incidence and risk factors for medial tibial stress syndrome and tibial stress fracture in high school runners. *Knee Surg Sports Traumatol Arthrosc*. 2013;21:556–563.
5. Korpelainen R, Orava S, Karpakka J,Siira P, Hulkko A. Risk factors for recurrent stress fractures in athletes. *Am J Sports Med.* 2001;29(3):304-310.
6. Nattiv A, Kennedy G, Barrack MT, Abdelkerim A, Goolsby MA, Arends JC, Seeger LL. Correlation of MRI grading of bone stress injuries with clinical risk factors and return to play: a 5 year prospective study in collegiate track and field athletes. *Am J Sports Med.* 2013;41(8):1930-1941.
7. Haber M, Golan E, Azoulay L, Kahn SR, Shrier I. Reliability of a device measuring triceps surae muscle fatigability. *Br J Sports Med.* 2004;38:163-167.
8. Pereira R, Schettino L, Machado M, da Silva PAV, Neto OP. Task failure during standing heel raises is associated with increased power from 13 to 50 Hz in the activation of triceps surae. *Eur J Appl Physiol.* 2010;110:255-265.
9. Moran KS, Marshall BM. Effects of fatigue on tibial impact accelerations and knee kinematics in drop jumps. *Med Sci Sports Exerc.* 2006;38(10):1836-1842.
10. Flynn JM, Holmes JD, Andrews DM. The effect of localized leg muscle fatigue on tibial impact acceleration. *Clin Biomech.* 2004;19(7):726-732.
11. Coventry E, O'Connor KM, Hart BA, Earl JE, Ebersole KT. The effect of lower extremity fatigue on shock attenuation during single-leg landing. *Clin Biomech.* 2006;21:1090-1097.
12. Sell TC, Akins JS, Opp AR, Lephart SM. Relationship between tibial acceleration and proximal anterior tibia shear force across increasing jump distance. *J Applied Biomech*. 2014;30:75-81