SUMMARY

The purpose of this investigation was to compare dynamic postural stability after a fatigue induced exercise when performing a single-leg landing stabilization protocol in healthy subjects. A paired-samples T test was used to compare the effects of fatigue on dynamic postural stability during landing. Ten healthy subjects volunteered to participate in this investigation. Subjects were required to perform a double-leg jump to a height equivalent to 50% of their maximum vertical jump height and land with single-leg and balance for three seconds. Fatigue induced exercise included repeated squatting and toe-raised motions with about one third loading of each subject’s body weight when subjects felt exhausted. Inclination angles, time to stabilization (TTS), joint kinematics and GRF were collected to analyze. The results of the investigation showed that the less time of anterior-posterior TTS, less range of motions at hip and knee and greater peak GRF have found after a fatigue induced exercise. These findings revealed that a stiff landing movement might be explained that the subjects selected a more rapid strategy via reducing the hip and knee motions to achieve balance and this would cause the less time of anterior-posterior TTS.

INTRODUCTION

Lower extremity injuries are common in athletes and are most prevalent in cutting or jump sports such as basketball, volleyball and handball. These kinds of injuries include anterior cruciate ligament (ACL) injuries and lateral ankle sprains which often resulted from direct contact or noncontact mechanisms such as landing from a jump. Generally speaking, a successful landing from a jump requires muscle strength, joint stability, and balance control, which are also critical for providing protection against injuries [5]. Neuromuscular fatigue usually has a greater effect on neuromuscular control and lower extremity joint stability, which is a factor associated with a higher risk of sustaining musculoskeletal injury. Then, a landing movement usually involves the dissipation of kinetic energy and is characterized as soft or stiff. Ground reaction force (GRF) can be used to identify changes in landing stiffness owing to the GRF is greater during a stiffer landing [6]. However, studies have shown that fatigued lower extremity muscles might also change the joint kinematics after landing [3].

In the past, gait stability has been assessed using the motion of the whole body center of mass (CoM) and its relative position to the center of pressure (CoP) of the supporting foot [4] but seldom in other movement (ie. jump-landing). However, the CoM-CoP distances may be affected by a subject’s stature [1] but a method that used CoM-CoP inclination angles could remove the influence of stature differences among subjects [4].

Time to stabilization (TTS) has been used to measure neuromuscular control which incorporates both sensory and mechanical systems to master the complex task after landing [5]. It has also been used to evaluate the effects of fatigue after landing [5]. The definition of TTS, which is calculated by GRF, is the amount of time it takes for a participant to return to baseline after a landing [2,5]. However, we take into account that only used the GRF to evaluate postural stability by TTS might be mislead, because TTS could be totally influenced by the values of GRF and the GRF can’t represent a complete steady state of posture stability. As a result, this current study we attempted to use CoM-CoP inclination angles to access the TTS. Hence, in this study, we assessed peak inclination angles and TTS, peak GRF and joint kinematics as compared to pre-fatigue and post-fatigue after a single-leg landing. We hypothesized that the peak inclination angles, the times for TTS and the peak GRF would increase and the joint kinematics would change after a fatigue induced exercise.

METHODS

Ten healthy males (24.1±1.0 years old; 69.1±8.3 kg; 172.0±3.2 cm) were recruited for this study. To begin jump-landing task, each subject started in a standing position 70 cm away from the center of the force plate. Then we instructed all subjects to jump with double-leg toward the center of the force plate, reach an overhead target which equivalent to 50% of the subject’s maximum vertical jump height [5] and land with single-leg (supporting leg only) on the force plate. When landed with testing leg, subjects were asked to use toe-heel strategy and maintain their balance for 3 seconds with their hands on the waist, look straight ahead as quickly as possible. If the subjects lose balance and step off on the force plate, or if their non-testing leg, or upper extremity sway excessively, all of these trials were defined as failed trails. Fatigue induced exercise included repeated squatting and toe-raised motions with about one third loading of each subject’s body weight until subjects felt exhausted. A barbell loaded with the appropriate weight was positioned along the posterior aspect of the subject’s shoulder; this way was similar to performing a loaded squat maneuver. Each squatting motion was performed through a knee flexion range of zero to ninety degrees, toe-raised motion was performed from neutral standing position to their maximum degrees of plantarflexion. Borg rating of perceived exertion (RPE) was used to assess the level of muscle fatigue (level 17). If the subjects could not reach this level or felt uncomfortable during the experiment, the experiment would be stopped.

All data were analyzed three seconds after foot initial contact on the force plate at a sampling rate of 1000 Hz. Three-dimensional (3-D) marker trajectory data were collected at 200 Hz with a ten-camera motion analysis system (Vicon, Oxford, UK). A total of 28 reflective markers were placed on bony landmarks of each subject. Whole body CoM position data was calculated using a 13-segment model with the weighted sum method [4]. The CoP position was calculated
using the ground reaction forces and moments measured by the force plates.

**Figure 1:** A typical 3-D trajectory of the CoM and CoP during a landing movement. The CoM-CoP line and its AP inclination angle ($\alpha$) and ML inclination angle ($\beta$) is also represented in the figure.

Instantaneous anterior-posterior and medial-lateral CoM-CoP inclination angles have been defined by Lee and Chou [4] were used in the current study (Figure 1). Then, the AP and ML TTS were determined by using sequential estimation [2,5] via inclination angles (Figure 2). Joint kinematics including hip, knee, and ankle joint angles at sagittal plane were extracted for analysis and were calculated using a joint coordinate system approach. Joint ranges of motion were calculated as the degree of flexion between the point of initial contact and the point of maximal flexion at the hip, knee and ankle during the landing. Peak GRF was normalized by body weight. Paired-Samples T test was used to compare each parameter between pre-fatigue and post-fatigue.

**RESULTS AND DISCUSSION**

All subjects were able to complete the jump-landing task after the fatigue-induced protocol. The typical 3-D trajectories of the CoM and CoP from supporting foot when landing successfully were illustrated in Figure 1. All results were listed in Table 1. Peak inclination angles nearly occurred at initial foot contact (see figure 2), but there were no significant differences after a fatigued exercise. However, the less time of AP TTS was found after a fatigued exercise but not at ML TTS. Although these results didn’t support our hypothesis, we still believed that it might alter our postural stability after an fatigue induced exercise. Therefore, we attempted to observe joint kinematics, yet, the range of motions at hip and knee were significant less than pre-fatigue. The smaller range of motion at the hip and knee as compared to pre-fatigue task seemed to indicate a stiffness landing strategy and this might result in greater GRF. A stiff single-leg landing strategy might cause greater balance demands of the supporting limb where reducing the anterior-posterior excursions of the trunk might become critical for posture control [3]. A stiff landing strategy could be explained that subjects selected a more rapid strategy via reducing the hip and knee motions to achieve balance and this causes the less time of AP TTS.

**CONCLUSIONS**

Fatigue induced exercise might have an effect on landing strategy while maintained the same level of shock attenuation. Post fatigue results revealed that inclination angle didn’t change but the AP TTS did change when compared to pre test, and this might attribute to the altered body position and use of the hip and knee to succeed balance.

![Figure 2](image)

**Figure 2:** A representative TTS sample calculated by CoM-CoP inclination angles.

**REFERENCES**


**Table 1:** Results of biomechanical parameters (*represented significant differences among pre- and post- fatigue exercise, $p<.05$)

<table>
<thead>
<tr>
<th>Inclination angle(deg)</th>
<th>TTS(sec)</th>
<th>GRF(BW)</th>
<th>Range of motion(deg)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>AP</td>
<td>ML</td>
<td>AP*</td>
</tr>
<tr>
<td>Pre</td>
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<tr>
<td>post</td>
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<td>2.0 ± 1.1</td>
<td>1.8 ± 0.2</td>
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