Time to Contact Measures Demonstrate Modulation of Postural Stability during a Lower Extremity Dynamic Movement Task

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INTRODUCTION

Traditional measures of postural stability rely on averaged center of pressure (CoP) motion over an extended period of quiet standing, making it difficult to draw conclusions from these tests to the dynamic situations that individuals experience in daily life. Moreover, these measures may not be sensitive enough to discriminate between healthy individuals or between the later stages of recovery and lower-extremity injury, when the goal of rehabilitation is to restore symmetry.

Unlike traditional measures of postural stability, postural time to contact (TtC) provides a measure of the time for the CoP to contact a stability boundary defined by the base of support, given its instantaneous trajectory. By tracking CoP changes over time, TtC allows for detection of instantaneous modifications in postural stability during dynamic tasks [1].

Previous studies have analyzed TtC during quiet single leg stance [2, 3] and a dynamic upper extremity task [1]. However, no study has used TtC to evaluate postural stability during dynamic lower extremity movement. Therefore, the purpose of this study was to determine the changes in postural stability that occur during the Star Excursion Balance Test (SEBT) [4] using TtC analysis.

METHODS

Eight 3D motion capture cameras (Vicon, Los Angeles, CA) and one force plate (Bertec, Columbus, OH) were used to calculate the position of the feet and the CoP of 47 athletes (39M/8F, 22.9±4.96yrs, 13.9±0.8kg, 1.75±0.09m) as they performed the SEBT barefoot in three directions, anterior (ANT), posterolateral (POL) and posteromedial (POM). After 4 practice trials in each direction per leg, nine valid trials per direction per stance leg were recorded for TtC calculations. A trial was valid if the subject kept hands on hips and the heel of the stance foot flat on the floor.

TtC was calculated in MATLAB based on equations developed by Slobounov et al. [5]. The base of support was defined by markers on the big toe, lateral malleolus, medial malleolus, and heel of the subject’s stance foot (Figure 1).

For each trial, the time between toe off and toe touch was divided into five epochs of equal duration. Toe off was defined as the point at which the subject’s reaching foot was completely off the force plate and movement was initiated. Toe touch was the first moment the subject’s reaching toe made contact with the floor. TtC was averaged over each epoch. To evaluate differences in TtC an unbalanced 3-way mixed effects ANOVA was used.

Figure 1: A) Base of support for the right foot showing a sample trajectory from the instantaneous center of pressure. B) Right foot with the 4 markers used to define the base of support.
including subject as a random effect and epoch, side, and epoch*side interaction as fixed effects, with post-hoc Tukey’s HSD comparisons ($\alpha$=0.05) to compare individual epochs to each other.

RESULTS AND DISCUSSION

Epoch was a significant main effect ($p<0.001$). TtC for Epochs 2, 3, 4, and 5 were significantly different from each other ($p<0.01$), but Epoch 1 and Epoch 3 were not significantly different. TtC decreased from Epoch 1 to Epoch 2, and then increased between each of the next three epochs (Figure 2). The TtC of the left leg was significantly higher (more stable) than the TtC of the right leg ($p<0.001$) (Figure 2). The interaction between side and epoch was also significant ($p<0.05$).

![Figure 2: Average time to contact (TtC) during the SEBT for left stance, right stance, and the average of the two. Error bars indicate the 95% confidence intervals of the means.](image)

This study is the first to our knowledge to demonstrate that healthy individuals modulate their postural stability during dynamic lower extremity tasks. Haddad et al. observed a similar TtC pattern when measuring changes in TtC during a precision fitting task where the participants picked a block off a table and then pushed it through a hole with their hand while standing comfortably on a force plate with both feet [1]. The initial decrease in TtC is associated with a decrease in postural stability. This period of less stability may be associated with less need for the subject to maintain strict postural stability while the reaching foot is held close to the body. The progressive increase in TtC from Epoch 2 to Epoch 5 represents a progressive increase in postural stability as the subject’s reach foot nears the point of toe touch. These results suggest that the task becomes progressively more difficult, both due to the requirement to touch the toe at a single point without applying any weight and because the reaching foot is being extended further from the body.

This study also observed that subjects exercised greater postural stability on their left leg. Reach distance asymmetries with the SEBT have previously been associated with increased injury risk [4]. Further research is necessary to evaluate the utility of this test in identifying side-to-side asymmetries. Side to side differences in TtC could potentially indicate increased risk for injury.

CONCLUSION

TtC may prove to be a useful tool to examine neurological or orthopedic pathologies in the future, because it quantifies instantaneous postural stability through more challenging tasks than traditional quiet standing protocols, which may increase its ability to discriminate between subtle differences in pathology. Future studies should evaluate the efficacy of using TtC analysis during the SEBT in individuals following acute injury to monitor rehabilitation and evaluate side to side asymmetries, as well as during other single-leg lower extremity tasks to better understand balance deficits in individuals with neuropathologies such as Parkinson’s Disease or stroke.

REFERENCES


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