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Abstract

Dynamic stability is often measured by time-to-stabilization (TTS), which is calculated from the dwindling fluctuations of ground reaction force (GRF) components over time. Common protocols of dynamic stability research have involved forward or vertical jumps, neglecting different jump-landing directions. Therefore, the purpose of the present investigation was to examine the influence of different jump-landing directions on TTS. Twenty healthy participants (9 male, 11 female; age = 28 ± 4 years; body mass = 73.3 ± 21.5 kg; body height = 173.4 ± 10.5 cm) completed the Multi-Directional Dynamic Stability Protocol hopping tasks from four different directions: forward, lateral, medial, and backward; landing single-legged onto the force plate. TTS was calculated for each component of the GRF (ap=anterior-posterior; ml=medial-lateral; v=vertical) and was based on a sequential averaging technique. All TTS measures showed a statistically significant main effect for jump-landing direction. TTSml showed significantly longer times for landings from the medial and lateral directions (Medial: 4.10 ± 0.21s, Lateral: 4.24 ± 0.15s, Forward: 1.48 ± 0.59s, Backward: 1.42 ± 0.37s), while TTSap showed significantly longer times for landings from the forward and backward directions (Forward:4.53±0.17s, Backward:4.34 0.35s, Medial:1.18±0.49s, Lateral:1.11±0.43s). TTSv showed a significantly shorter time for the forward direction compared to all other landing directions (Forward: 2.62 ± 0.31s, Backward: 2.82 ± 0.29s, Medial: 2.91 ± 0.31s, Lateral: 2.86 ± 0.32s). Based on these results, multiple jump-landing directions should be considered when assessing dynamic stability.

Keywords: Time-to-stabilization, ground reaction force, multi-directional jumps, landing

Introduction

Time-to-stabilization (TTS) is a force plate-based measure of dynamic stability, which is the ability to maintain balance while transitioning from a dynamic movement to a static state over one’s base of support.[1] In young, athletic populations and in individuals with compromised joint stability, TTS is considered a more functionally relevant assessment of stability than static-based measures.[2] Several methods have been introduced over the past decade for assessing dynamic stability, but TTS, based on the dwindling fluctuations of ground reaction force (GRF) components over time, remains the most common. Experimental studies that use TTS have focused on functional ankle instability[3,4], the effectiveness of ankle bracing[5,6], muscle fatigue[1],and differences between athletic groups[7]. As part of the methodology of this past research, the typical protocol requires jumpers to leave the ground 70 cm away from their landing location, touch an overhead marker (placed at 50% of maximal jump height), land on one foot, and stabilize as quickly as possible with their hands on their hips. Because TTS calculations are based on orthogonal components of the GRF vector, it would seem that jump direction, and therefore landing direction, would influence the assessment.

Few previous studies have examined the influence of different jump-landing directions on TTS. Butcher-Mokha and colleagues calculated TTS for a forward jump landing and lateral drop landings in different types of athletes.[6] Wikstrom and colleagues focused on different jump-landing directions, and used a stability index rather than a measure of TTS.[7] They reported that jump direction had limited influence on stability index scores; only the medial-lateral stability index, a measure based on the medial-lateral GRF, showed differences across three jump directions (forward, diagonal, and lateral). In addition to examining differences between female soccer players and dancers, Gerbino et al. investigated two jump directions: a forward hop after 2 steps, and a "side weight shift" (p. 503).[8] Although not statistically tested, the landing from a weight shift resulted in greater sway index scores, but shorter center acquisition times for both groups (center acquisition time is similar to TTS). Therefore, these jump-landing direction results seem contradictory.

In summary, researchers that use TTS as a dependent variable have participants perform a vertical jump, with little horizontal motion. Side-to-side motion may induce ankle injuries more than forward and/or vertical motions; therefore, it is important to understand multi-directional stability tasks. Studies that include different jump-landing directions did not use TTS, the most common measure of dynamic stability. Therefore, the purpose of the present investigation was to examine the influence of different jump-landing directions on TTS using the Multi-Directional Dynamic Stability Protocol. In addition, for each landing condition, three separate TTS calculations were made using the three orthogonal components of the GRF.

Methods

Participants

Twenty healthy and active participants volunteered for this study (9 men and 11 women, mean age = 28 ± 4 years, mean body mass = 73.3 ± 21.5 kg, mean body height = 173.4 cm ± 10.5 cm). Participants had no history of lower extremity injury 6 months prior to testing, no neurological disorders, and were active at least 4 days a week. Participants were tested during a single test session after their consent was documented in accordance with the university's Institutional Review Board.

Procedures

After a 10 min warm up jog at a self-selected speed on a treadmill, each participant performed various hopping tasks with their dominant leg, barefoot, onto a force plate to determine TTS. The dominant leg was determined based on the leg that the participant would choose to kick a ball. Four hopping tasks for the Multi-Directional Dynamic Stability Protocol were: forward hop, lateral hop, medial hop, and backwards hop (Figure 1). The different hops are described by the direction of the hop with respect to the participant (i.e., a medial hop for a right-leg dominant person was directed to the left). All hopping tasks were assigned in a randomized order.

For the forward hop, participants were asked to take two preparatory steps leading with the dominant leg and landing single legged on the dominant leg over a 15 cm hurdle placed at a distance of 100% of the leg length from the center of the force plate. The leg length was measured as the length from the anterior superior iliac spine to the medial malleolus. For the medial, lateral, and backward hops, participants were instructed to stand single-legged on their dominant leg only and hop over a 5 cm hurdle placed directly next to the force plate, landing single-legged onto the force plate with the dominant leg. All participants were instructed to land in the middle of the force plate on a single leg with eyes focused forward and hands placed on their hips. They were asked to stabilize as quickly as possible on a single leg and remain as motionless as possible for 10 sec. Hurdles were placed for a minimum jump height among participants. Participants were allowed to familiarize themselves with the procedure and practice this motion three times before three trials were collected for each of the four hops. If the participant lost balance or touched the floor with the contralateral leg the trial was discarded and another one was performed.

Data Collection and Analysis

Data were collected using an AMTI force plate (model OR6-6-2000; Advanced Medical Technology Inc., Watertown, MA) mounted to the lab floor in accordance with the manufacturer's guidelines. A walkway was built up around the force plate so that the surface of the platform was flush with the surface of the walkway. GRF data were collected at a sampling rate of 100 Hz for a duration of 10 sec. Sampling rates as low as 60 Hz have been found to be sensitive.[9,10] GRF data collection began when the vertical force output from the platform amplifier exceeded 0.5 V (approximately 140 N). Signals from the force plate were processed using the Peak Motus software (version 9.2.1; Vicon, Englewood, CO). All force and torque data were filtered using a low-pass Butterworth digital filter with a cutoff frequency of 12 Hz. Processed data were then exported to Microsoft Excel (Microsoft Corp., Redmond, WA) where TTS measures were calculated.

TTS measures were based on the work of Colby and colleagues.[2] The medial-lateral GRF component (Fx), the anterior-posterior component (Fy), and the vertical component (Fz) were used for separate TTS calculations. For each component, an overall average force value and standard deviation were calculated over the entire 10-sec data collection window. Then, for each force component, sequential average values were calculated for each data point (100 Hz over 10 sec = 1000 data points):

$$\text{SeqAvgx}(n) = \frac{\sum_{n=1}^{1000} Fx}{n} \quad (1)$$

$$\text{SeqAvgy}(n) = \frac{\sum_{n=1}^{1000} Fy}{n} \quad (2)$$

$$\text{SeqAvgz}(n) = \frac{\sum_{n=1}^{1000} Fz}{n} \quad (3)$$

TTS was determined as the time when the sequential average diminished to within one-quarter of the overall signal's standard deviation. For each orthogonal GRF component, TTS values are labeled TTSml, TTSap, TTSv respectively.

Statistical Analysis

Single factor within-subjects repeated measures analyses of variance (ANOVA) were conducted to test for differences between the four jump-landing directions for all three dependent variables (SPSS 18.0 for Windows, SPSS Inc, Chicago, IL). When appropriate, pairwise comparisons were made to identify where differences occurred in the data. The probability of a Type I error (α) was set at 0.01 for all statistical tests.

Results

All TTS measures showed a statistically significant main effect for jump-landing direction ($F=662.53$, $P<0.001$). Follow-up pairwise comparisons showed statistically significant differences for each TTS measure (Table 1). TTSml showed significantly longer times for landings from the medial and lateral directions as compared to the forward and backward directions (Figure 2, left panel). Conversely, TTSap showed significantly longer times for landings from the anterior and posterior directions as compared with medial and lateral directions (Figure 2, middle panel). TTSv showed a significantly faster time for the forward direction compared to all other landing directions (Figure 2, right panel).

Discussion

The results of the present investigation clearly show that TTS measures, based on orthogonal components of the GRF vector, are dependent on the direction of jump and subsequent landing. Thus, dynamic postural stability is influenced by the task-specific demands placed on a person. For jump-landings taking place predominantly in the sagittal plane (i.e., forward- and backward-directed jumps or hops), TTS based on the anterior-posterior component of the GRF will result in larger values. Likewise, TTS based on the medial-lateral component of the GRF will result in longer times when evaluating jump-landings in the frontal plane. In the two directions of forward and lateral jumps, Butcher-Mokha and colleagues also reported similar findings of larger values in the direction of the jump to the same directional component of the GRF.[6]

The results of the present study lead to the suggestion that multiple jump-landing conditions should be examined when assessing dynamic stability. The four jump-landing directions considered in the present study yielded drastically different results, especially when the TTSml and TTSap measures are considered. These two measures discriminated well between sagittal and frontal plane jump-landing directions (e.g., TTSml for medial and lateral directions were 2-3 times greater than the forward and backwards directions). No TTS result distinguished between a medially directed and laterally directed jump-landing. Therefore, these two tasks, represented by a jump to one's inside and to one's outside, are repetitive. Likewise, the anterior-posterior and medial-lateral TTS measures did not distinguish forward- and backward-directed jump-landings. Again, for TTSap and TTSml, these two tasks are repetitive. Taken collectively, however, it is useful to insure different jump-landing directions are considered in dynamic stability studies. Our current jumping protocol involves jumping from four different directions over a small hurdle. Previously mentioned jump protocols differ in that their participants are required to jump to 50% of a maximum vertical jump with no side to side motion. The focus of our multi-directional jumps was to mimic some sporting activities, such as a forward jump after a couple of steps, as well as acknowledging the multiple directions of ankle injury mechanisms.

This suggestion will be useful for those studying lower extremity injuries because so much emphasis is placed on post-injury joint stabilization, especially at the ankle. It will also be useful to examine different jump-landing directions in individuals with functional ankle instability.

In a study similar to the present one, Wikstrom and colleagues examined three directions of jump-landings: forward, diagonal, and lateral.[7] They used a stability index rather than a measure of TTS, but also calculated a stability index for each orthogonal component of the GRF vector. The medial-lateral index showed a pattern consistent with the results of the present experiment. This medial-lateral index was greatest for the lateral direction (higher index is worse stability) and was smallest for the forward direction. The diagonal direction displayed values between these extremes and all were statistically different. The values of the other two indices, anterior-posterior and vertical, were inconsistent with the results of the present study. The anterior-posterior index showed no differences between jump-landing directions and the vertical index showed a greater value for the forward direction compared to the lateral direction.

Although GRF-based measures of TTS are the most common measures of dynamic stability, researchers are beginning to introduce revisions. As mentioned, Wikstrom and colleagues[6] use a stability index and Gerbino and colleagues[8] reported center acquisition times based on center of pressure calculations taken from a pressure mat. Ross and colleagues reported TTS, but used a slightly different calculation.[3,10] In the present investigation, the condition-measure combination that resulted in the highest TTS values (TTSap for forward and backward jump-landings and TTSml for medial and lateral jump-landings) are considerably higher than those reported by others.[1,3] The TTS values based on the vertical GRF for all jump-landing directions and those based on anterior-posterior and medial-lateral GRF components for jump-directions in the respective orthogonal planes, however, are consistent with previously reported values.

Overall, the results of the present study strongly suggest that multiple directions of jump-landings should be used when assessing dynamic stability. It is also clear from these results that small jumps, essentially one-legged hops, are sufficient to tax the postural systems of young, active adults such that it takes 4.0-5.0 s to achieve stability when considering jump-landing directions and GRF components. These more demanding conditions may prove useful when attempting to determine stable and unstable populations. In conclusion, TTS was influenced by jump-landing direction. Specifically, TTSap was greater for jump-landings in the anterior-posterior directions and likewise, TTSml was greater for jump-landing directions in the medial-lateral directions.

References

1. Wikstrom E, Powers M, Tillman M. Dynamic stabilization time after isokinetic and functional fatigue. *J Athl Train.* 2004:39(3);247–253.
2. Colby S, Hintermeister R, Torry M, Steadman J. Lower limb stability with ACL impairment. *J Orthop Sports Phys Ther.* 1999:29(8);444-454.
3. Ross S, Guskiewicz K, Yu B. Single-leg jump-landing stabilization times in subjects with functionally unstable ankles. *J Athl Train.* 2005:40(4)298-304.
4. Wikstrom E, Arrigenna M, Tillman M, Borsa P. Dynamic postural stability in subjects with braced, functionally unstable ankles. *J Athl Train*. 2006:41(3);245-250.
5. Shaw M, Gribble P, Frye J. Ankle bracing, fatigue, and time to stabilization in collegiate volleyball athletes. *J Athl Train.* 2008:43(2);164–171.
6. Butcher-Mokha M, Jacobs N, Sato K, Ludwig K. Pre-season dynamic stabilization measures in five collegiate teams. In *Proceedings of XXIV International Symposium on Biomechanics in Sports.* 2006;422-425.
7. Wikstrom E, Tillman M, Schenker S, Borsa P. Jump-landing direction influences dynamic postural stability scores. *J Sci Med Sport.* 2008:11(2);106-111.
8. Gerbino P, Griffin E, Zurakowski D. Comparison of standing balance between female collegiate dancers and soccer players. *Gait Posture.* 2007:26(4);501-507.
9. Wikstrom E, Tillman M, Smith A, Borsa P. A new force-plate technology measure of dynamic postural stability: The dynamic postural stability index. *J Athl Train.* 2005:40(4);305-309.
10. Ross S, Guskiewicz K. Time to stabilization: A method for analyzing dynamic postural stability. *Athl Ther Today*. 2003:8(3);37–39.

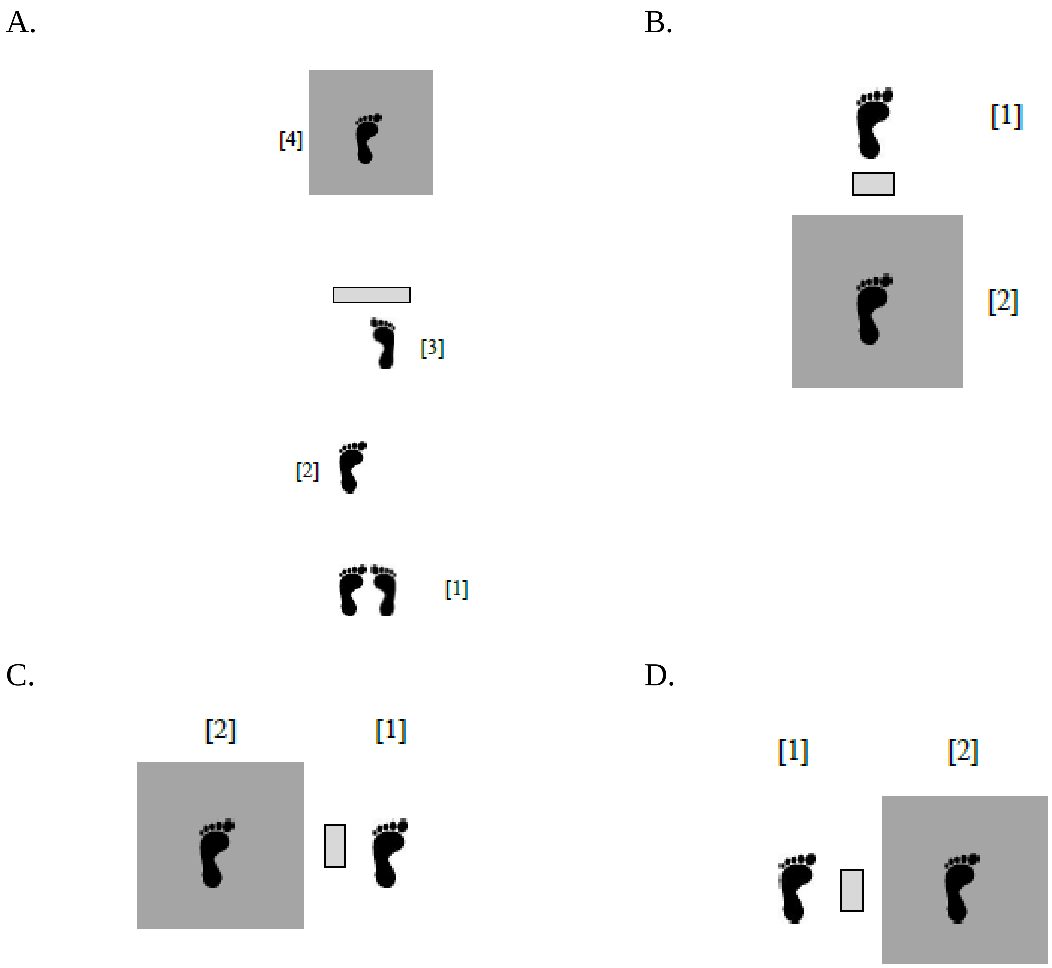

Figure 1. A: A diagram of the Multi-Directional Dynamic Stability Protocol forward jump with the "step, step, hop" method. The rectangle represents a 15 cm hurdle placed at 100% of the participant's leg length from the center of the force platform (depicted by the gray square). The participant was instructed to start with feet together [1], take one step with the test leg [2], followed by another step with the other leg [3], hop over the hurdle and landed on the test leg [4], all in one fluid motion. **B:** A diagram of the Multi-Directional Dynamic Stability Protocol backward jump. The participant starts single-legged in front of the force platform [1] (as depicted by the gray square) and jumps backward over the 5 cm hurdle (as depicted by the rectangle), landing single-legged on the force platform [2]. **C:** A diagram of the Multi-Directional Dynamic Stability Protocol lateral jump. The participant starts single-legged [1] and jumps laterally onto the force platform (as depicted by the gray square) over the 5 cm hurdle (as depicted by the rectangle), landing single-legged on the force platform [2]. **D:** A diagram of the Multi-Directional Dynamic Stability Protocol medial jump. The participant starts single-legged [1] and jumps medially onto the force platform (as depicted by the gray square) over the 5 cm hurdle (as depicted by the rectangle), landing single-legged on the force platform [2].

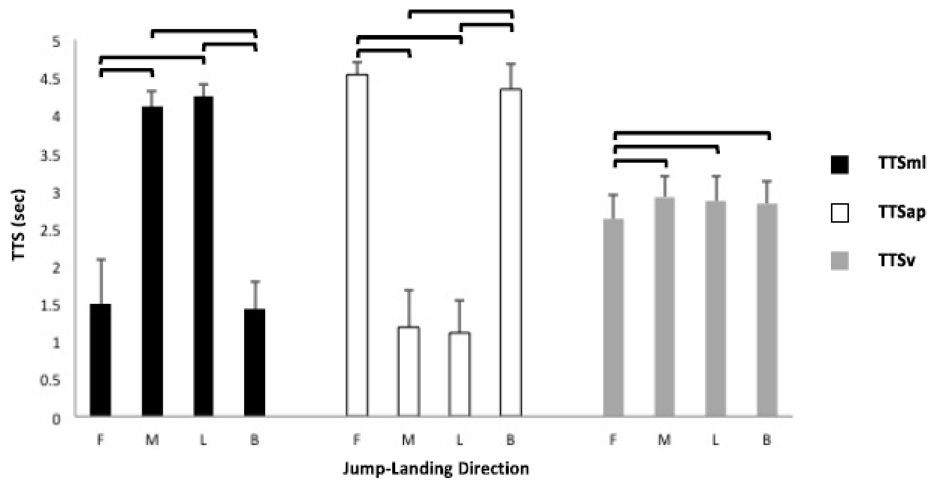

Figure 2. Mean time-to-stabilization values based on medial-lateral (TTSml), anterior-posterior (TTSap), and vertical (TTSv) components of the ground reaction force. Jump-landing directions: F=forward; M=medial; L=lateral; B=backwards. Error bars represent standard deviations and brackets show statistically significant differences between jump-landing directions. Specific p-values are shown in Table 1.

Table 1 Resulting p-values from Pairwise Comparisons Between Jump-Landing Directions

Jump-Landing Directions	TTSml	TTSap	TTSv
Forward to Medial	< .001	< .001	< .001
Forward to Lateral	< .001	< .001	.003
Forward to Backward	.686	.015	.008
Medial to Lateral	.012	.594	.296
Medial to Backward	< .001	< .001	.077
Lateral to Backward	< .001	< .001	.325

Note. Time-to-stabilization values in the medial-lateral, anterior-posterior, and vertical directions are indicated by TTSml, TTSap, and TTSv, respectively.