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# Dynamic Stabilization During the Landing Phase of Plyometric Exercises

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# DYNAMIC STABILIZATION DURING THE LANDING PHASE OF PLYOMETRIC EXERCISES

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This study examined the differences in and the reliability of time to stabilization (TTS) of several plyometric exercises. Twenty six men performed a variety of plyometric exercises representing a continuum of intensities of landing instability, including line hops, cone hops, squat jumps, tuck jumps, countermovement jumps, dumbbell countermovement jumps, and single leg countermovement jumps on a force platform. A repeated measures ANOVA with Bonferroni post hoc corrections was used to evaluate the differences in TTS between plyometric exercises. Practitioners who use plyometrics to train dynamic stability and balance should create programs that progress the intensity of the exercises based on the results of this study. This study also demonstrates that TTS reliability is fair to excellent for a variety of jumping conditions.

**KEY WORDS**: stretch shortening cycle, reliability, balance, postural control

**INTRODUCTION:** Balance training improves postural stability and may reduce injury (Wikstrom 2009). Plyometric training offers promise as a balance training stimulus, though many aspects of plyometric program design are unclear. Plyometric intensity is among the most important variables for designing a program (Ebben et al., 2008; Jensen & Ebben, 2007). Studies have assessed intensity of plyometric exercises using electromyographic, kinematic, or kinetic analysis (Ebben et al., 2008; Jensen & Ebben, 2007). However, previous research assessing plyometric exercises did not assess their characteristics with respect to postural control or stability. The intensity of the landing phase of plyometric exercises may be measured by the difficulty of dynamic postural stabilization and quantified by time to stabilization (TTS).

Time to stabilization is derived through force plate data and used to evaluate postural stability by measuring the time taken for vertical ground reaction force to reach and stabilize within 5% of the subject's body weight following the landing from a jump (Wikstrom, 2004). Time to stabilization has been used to examine stability during ankle taping and bracing (Jacobs et al., 2006) and to compare the effect of different levels of functional ankle instability (Wikstrom et al., 2004; Ross et al., 2005). Time to stabilization has typically been used with a jump landing protocol that included a bilateral take off from 70 cm away from a forceplate, jumping to approximately 50% of the subjects maximal vertical jump, and landing on a single leg while attempting to stabilize as quickly as possible (Wikstrom et al, 2004; Wikstrom et al., 2005; Ross et al., 2005). Functional ankle instability has also been assessed using TTS after subjects stepped down from a 20 cm box (Wikstrom et al., 2005). Others have used TTS to characterize the differences between dynamic stability of athletes from different sports and to assess gender differences in this variable (Butcher-Mokha et al., 2005). Few studies assessed the reliability of TTS. Flanagan et al. (2008) demonstrated average measures intraclass correlation coefficient values of 0.68 for TTS during the landing from a 30 cm depth jump.

The purpose of this study was to quantify the postural stability demands of the landing phase of a variety of plyometric exercises by assessing vertical TTS. This study also sought to further identify plyometric exercise characteristics with TTS and to assess the reliability of this variable during a variety of jump landing conditions.

**METHODS:** Twenty four athletic or recreationally active adults (mean ± SD; age = 20.23 ± 1.63 years, height = 180.98 ± 6.13 cm; body mass = 79.41 ± 9.03 kg; vertical jump = 63.55 ± 5.80 cm; back squat 5 RM 131.37 ± 25.64 kg) volunteered to serve as subjects for the study. The subjects were informed of the risks associated with the study and provided informed written consent. The study was approved by the institution's internal review board.

All subjects performed a habituation and testing session. Prior to each session, the subject warmed up with 3 minutes of low intensity work on a cycle ergometer and performed dynamic stretching exercises. During the habituation session, subjects performed 2 repetitions of the countermovement jump which was assessed using a Vertec (Sports Imports, Columbus, OH, USA). Subjects then rested for 4 minutes and performed their 5 repetition maximum (RM) back squat test in order to obtain a strength measure that further characterizes the subjects training status. Subjects were instructed and provided a demonstration on the correct performance of the plyometric exercises to be assessed during the test session. Subjects then performed each of these exercises until they demonstrated the correct performance of the technique. The plyometric exercises included the lateral line hop (LH), 15.24 cm lateral cone hop (CH), squat jump (SJ), tuck jump (TJ), countermovement jump (CMJ), loaded countermovement jump with dumbbells equal to 30% of the subjects previously assessed estimated 1 RM squat (DBJ), and the single leg jump (SLJ). After the habituation session, subjects recovered for at least 48 hours and returned for the test session.

During the testing session, subjects warmed up with the same protocol they used prior to the habituation session. Subjects performed 3 repetitions of each of the test plyometric exercises in a randomized order with 1 minute of rest between each exercise, which insures full recovery (Read & Cisar, 2001). Subjects were instructed to stabilize their landing as quickly as possible, with knee and hip flexion, face straight ahead, remain motionless for a period of 5 seconds, and limit upper limb movement upon landing consistent with previous recommendations (Flanagan et al., 2008).

The test exercises were assessed with a 60 x 120 cm force platform (BP6001200, Advanced Mechanical Technologies, Inc., Watertown, MA, USA), which was calibrated with known loads to the voltage recorded prior to the testing session. Data were collected at 1000 Hz, real time displayed and saved with the use of computer software (BioAnalysis 3.1, Advanced Mechanical Technologies, Inc., Watertown, MA, USA) for later analysis. All values were determined as the average of three repetitions for each of the plyometric exercises. Vertical TTS was determined consistent with methods previously used (Flanagan et al., 2008; Wikstrom et al., 2005) as demonstrated in Figure 1.

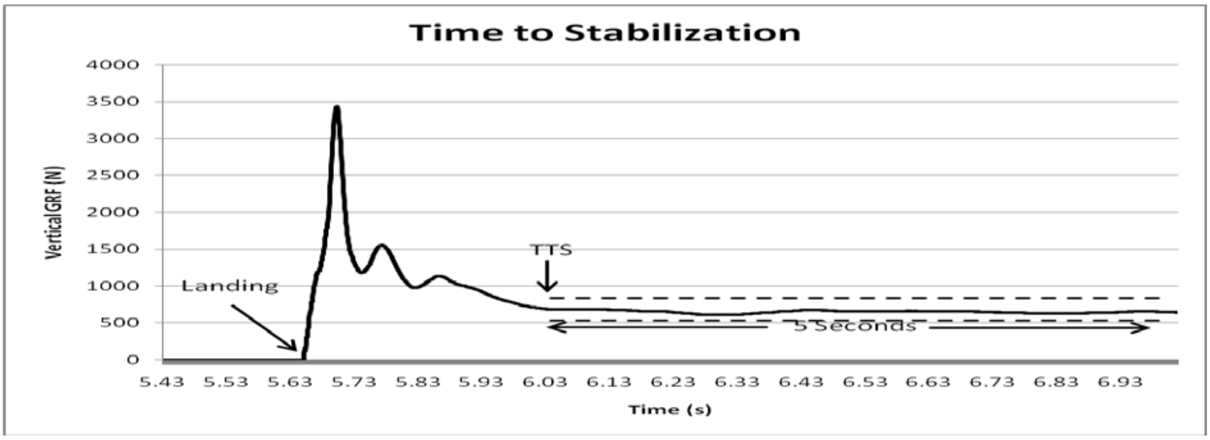


**Figure1. Sample force time record of time to stabilization**

A repeated measures ANOVA with Bonferroni adjusted pairwise comparison was used to evaluate differences in TTS of the plyometric exercises. The trial to trial reliability of TTS was assessed for each plyometric exercise with the intraclass correlation coefficient (ICC). In addition, repeated measures ANOVA was used to confirm that there was no significant difference ($P$ >0.05) between the three trials. The statistical analyses were undertaken with SPSS 17.0. Assumptions for linearity of statistics were tested and met. An *a priori* alpha level of $p \leq 0.05$ was used with effect size and power represented by $\eta_p^2$ and $d$, respectively.

**RESULTS:** The analysis of TTS revealed significant main effects for test condition ($P \leq 0.001$, $\eta_p^2 = 0.41$, $d = 1.00$) and specific differences in TTS between a number of plyometric exercises (Table 1). Results of the reliability analysis show ICC ranging from 0.51 to 0.86 with no significant differences between the trials ($P > 0.05$).

**Table 1. Time to stabilization expressed in seconds of men subjects during a variety of plyometric exercises (N=26)**

| LH | CH | SJ | DBJ | CMJ | TJ | SLJ |
|---|---|---|---|---|---|---|
| 0.50[a] ± 0.09 | 0.57[a] ± 0.15 | 0.67[b] ± 0.14 | 0.73[c] ± 0.18 | 0.73[d] ± 0.21 | 0.77[b] ± 0.16 | 0.99[a] ± 0.39 |

LH = line hop, CH = 15.24 cm cone hop, SJ = squat jump, DBJ = dumbbell countermovement jump, CMJ = countermovement jump, TJ = tuck jump, SLJ = single leg jump
[a] Significantly different than all other plyometrics
[b] Significantly different than all other plyometrics except for DBJ and CMJ.
[c] Significantly different than all other plyometrics except for SJ, CMJ, TJ
[d] Significantly different than all other plyometrics except for SJ, DBJ, TJ

**DISCUSSION:** This is the first study to assess the TTS of a variety of plyometric exercises demonstrating a number of differences with respect to this variable. Practitioners can use this knowledge to create performance enhancement and rehabilitation programs that progress instability, and thus the intensity of plyometric exercises. This study is also the first to demonstrate that TTS is fair to good, to excellent, based on the classifications of Fleiss (1986) (less than 0.4 was poor, between 0.4 and 0.75 was fair to good, and greater than 0.75 was excellent).

The SLJ produced the highest TTS of the plyometric exercises assessed. This finding is likely due to the smaller base of support associated with SLJ landing since the size of the base of support has been thought to affect postural control (Wikstrom et al., 2006). Previous research has demonstrated SLJ ground reaction forces and knee joint reaction force values that were considerably more than half of the values demonstrated for all other plyometric exercises performed in a bilateral condition (Jensen & Ebben, 2007). These findings confirm that the SLJ is the most intense plyometric exercise, and should be prescribed later in plyometric programs that seek to progress the exercise intensity.

Tuck jumps produced relatively high TTS demonstrating that this is a high intensity plyometric exercise, consistent with previous research assessing peak ground and knee joint reaction forces (Jensen & Ebben, 2007). This finding shows that not all “jumps in place” are low intensity plyometric exercises as previously suggested (Potach & Chu, 2008). The TJ requires hip flexion during ascent and consequently considerable hip extension during the descent phase in order to reposition the legs for landing. This action decreases the time to prepare for landing and likely increases the TTS. Pike jumps are likely to be similar since this exercise and the TJ share similar characteristics of active hip flexion followed by extension and a reduction in landing preparation and has been shown to be similar (Jensen & Ebben, 2007). Dumbbell countermovement jumps demonstrate moderate mean TTS values compared to the other exercises potentially due to the dumbbells decreasing extraneous hand movements which has been thought to increase TTS (Flanagan et al., 2008).

The SJ mean TTS was only higher than LH and CH, potentially due to the fact that the SJ does not activate the stretch-shortening cycle resulting in lower jump heights and consequently lower TTS compared to most exercises which may be why LH and CH TTS values are low.

The specific TTS values attained for the plyometric exercises in the present study (0.52 to 0.88 seconds) were shorter than other studies where values ranged from 0.65 to 2.7 seconds (Butcher et al., 2006; Flanagan et al., 2008; Jacobs et al., 2006; Ross et al., 2005; Wikstrom et al., 2004). Shorter mean vertical TTS in the present study may be a function of the subject training status, habituation, and differences in landing tasks between the studies. Reliability of the exercises in the present study may also have been affected by the requirement that subjects skillfully and reliably perform 7 different plyometric exercises, unlike previous studies where subjects performed only one or two (Butcher et al, 2006; Flanagan et al., 2008; Jacobs et al., 2006; Ross et al., 2005; Wikstrom et al., 2004).
Only one known study examined the reliability of vertical TTS (Flanagan et al., 2008). Finding high levels of reliability for repeated trials of dynamic postural stability measures of jump landings is inherently difficult. Any outcome measure that is dependent on proprioceptive and kinesthetic feedback, as well as reflexive and voluntary muscle responses (Wikstron et al., 2006) is likely to be rife with variability. On the other hand, any outcome measure that reduces the integrative sensorimotor complexity may be more internally controlled and potentially more reproducible, but at the cost of external validity. Ground reaction force derived measures of dynamic stability remain more reliable than other options including stabilometery techniques such as center of pressure measurements (Wikstrom, 2006). In the present study, TTS was consistently, moderately reliable, and in some cases, highly reliable, while providing strong external validity.

**CONCLUSION:** Practitioners should create plyometric programs that progress the intensity of the stability stimulus based on the results of this study. The plyometric exercises that produce the shortest TTS should be prescribed early in the program since these exercises provide the lowest challenge to dynamic stability. Plyometric exercises with increasingly higher TTS should be added as the program progresses. This study also demonstrates that TTS is moderately to highly reliable for a variety of jumping conditions.

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