A Thesis

Entitled

Time to Stabilization: Number of Practice Trials
and Measured Trials Needed

By
Ashley VanMeter, ATC, LAT

Submitted as partial fulfillment of the requirements for
The Master of Science degree in
Exercise Science

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College of Health Science and Human Service

College of Graduate Studies

The University of Toledo

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An Abstract of

Time to Stabilization: Number of Practice Trials
and Measured Trials Needed

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Objective: To establish a standard protocol for the number of practice and test trials needed for testing TTS. Design and Setting: Separate trial (1-20) by side (dominant, non-dominant) repeated measures ANOVA was performed for APTTS and MLTTS. A paired samples t-test was performed to determine the number of failed trials between the dominant and non-dominant sides. A Scheffe’s post-hoc test was applied. Significance was set at p<0.05. Subjects: Thirty-one healthy subjects participated in this study. Measurements: Subjects participated in one testing session. Twenty trials of a jump-landing task were performed on each leg. The jump-landing task consisted of a single-leg landing from a double leg jump height equivalent to 50% of the subject’s maximum jump height. Subjects started 70cm away from the center of the forceplate (Bertec, Corp;
Columbus, OH). Subjects jumped off of both feet, reached up and touched the indicated marker, and landed on the forceplate with one foot. The landing leg was randomized.

**Results:** For MLTTS, no significant interaction between side and time existed ($F_{19, 570} = 0.078$, $p = .667$; power = 0.64). A significant main effect for trial existed ($F_{19, 570} = 2.901$, $p< .001$; power = 0.99). There was no significant main effect for Side (dominant (1.61± .03) non-dominant (1.63 ± .03) ($F_{1, 30}= 6.17$, $p = .438$; power = 0.12). For APTTS, there was no significant interaction between Side and Time. ($F_{19, 570}= .973$, $p = .492$; power = 0.73) There was no significant main effect for trial ($F_{19, 570}= 1.34$, $p = .153$; power = 0.89) or side (dominate (1.18 ± .02) vs. non-dominate (1.19 ± .02)) ($F_{1, 30}= .081$, $p = .778$; power = 0.06). For failed trials, there was no significant difference between the dominant (5.90±0.84 trials) and non-dominant (6.00±1.06 trials) ($t=-0.97$, $p = .924$).

**Conclusion:** This study attempted to determine how many practice and test trials are needed to achieve consistency. It appears that either leg can be used during TTS calculations which will help clinicians trying to find a base comparison for the injury leg. However, the primary purpose of this study, which was to determine the number of trials needed to overcome a learning effect, was not realized fully. We can cautiously conclude that three practice trials would allow a healthy subject to become familiar with the task. However, this study brings up the question if there really is a learning effect that is quantifiable associated with TTS assessment in healthy subjects.
Acknowledgments

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Chapter 1

Introduction

Fifty-eight percent of all injured female basketball players were engaged in landing from a jump at their time of injury. [1] To date there have not been any appropriate dynamic stability measures to prescreen athletes to determine if they are at risk for an injury. With the capabilities of the time to stabilization (TTS) measurement this might be a possibility, but first the TTS measurement and protocol has to be standardized.

Various techniques have been used to detect joint instability in pathological subjects. One approach was to measure a static stabilization.[2-4] This approach may not be clinically applicable due to the fact that injuries happen during dynamic movements. The single-leg hop test was developed as a dynamic test to test stabilization[5-10]. This test met the requirement for including sports-related function, but it is hard to obtain reliable measurements. Time to stabilization is another method that may be used to quantify dynamic stability as a subject transitions from a dynamic state into a static state. This procedure has been used to examine deficiencies in ACL-deficient and reconstructed patients during dynamic stabilization[7], differences between functional and isokinetic
fatigue[9], and also recently in examining patients with functional ankle instability (FAI).[10-13]

One area that researchers have not touched on with the TTS protocol is if there is a learning effect associated with this task. Some tasks require practice trials to account for the learning effect that is apparent for that task. A test that assesses dynamic postural control from a different perspective than TTS is the Star Excursion Balance Test (SEBT). Similar to a TTS, the SEBT can be considered a novel task and therefore subjects performing the task would need to gain a level of familiarity with the task when asked to perform the task for the first time. In a previous study it was established that the SEBT requires six practice trials to ensure strong reliability and it was suggested that this allows healthy subjects to overcome the initial learning effect with the test.[14] To our knowledge, there has not been a similar investigation with the assessment of TTS. Using this previous study and also the results of failed trials during piloting we are hypothesizing that seven practice trials would be needed to establish a level of consistency when performing an assessment of TTS.

The focus of this study was to determine how long it takes an individual to obtain accurate TTS measures that characterize a representative and stable performance. Perfection is unrealistic for this task, but it is possible that a learning effect will skew the data if it is not accounted for before trials are analyzed. There is not a set amount of practice trials for every study, each study is different, and therefore the goal of this study was to determine how many practice trials will be needed to obtain accurate trials for TTS for healthy physically active people. This may allow future studies using TTS to be
standardized and provide greater measures of reliability and validity when utilizing this technique.

**Operational Definitions**

**Time to stabilization (TTS):** a quantitative force-plate measure that is used to evaluate dynamic postural stability.[8]

**Dynamic postural stability:** the time it takes for the initial components of the GRF of a jump landing to become similar to the components of the GRF in a stabilized single-leg stance.[8]

**Dominant leg:** the leg that one uses to kick a ball

**Statement of the Problem**

The time to stabilization measure has been used to determine deficits in unstable ankles and along with deficits in ACL reconstructed knees.[7, 12, 13, 15, 16] It has been established that this method can detect differences between injured and non-injured legs. Therefore, this study attempted to determine if a learning effect influences this measure. Some studies use three practice trials while others use as many as needed.[7, 15, 16] There is a need to establish a set number of practice trials so that every subject is performing the same protocol with the same amount of exposure to the task. This may allow future studies using TTS to be standardized and provide greater measures of reliability and validity when utilizing this technique.
**Statement of the Purpose**

The purpose of this study was to establish a standard protocol for the number of practice and test trials needed for testing TTS. Prior to this study, there had not been an established protocol on how many trials need to be performed or how many pre-trials need to be performed before initiating test trials. By determining a standard on how many trials need to be performed, the efficiency of dynamic postural control testing with TTS may be improved.

**Significance of the Study**

Time to stabilization has been utilized effectively to study the deficits between injured and non-injured lower extremities. The most recent application of the TTS calculation is to determine an injury prescreening to try to determine who is most likely to have an injury during the season. Before now there were no standard protocols for TTS related to the number of trials needed to achieve consistency. The results of this study may help improve the efficiency of this measurement technique.

**Research Hypotheses**

H₁: There will be no significant differences in TTS between the dominant and non-dominant limbs in both the A/P and M/L directions.

H₂: For APTTS and MLTTS on both the dominant and non-dominant limb, it will take seven trials to gain consistency in TTS, subsequently overcoming the learning effect.
H₃: There will be no significant differences in the number of failed trials between the dominant and non-dominant limbs.
Chapter 2

Review of Literature

**Balance**

Gambetta and Gray state that balance is the single most important component of athletic ability due to its significant involvement in nearly all areas of movement.\[17\] Every task during the day requires balance. Even during simple everyday movements the body has to work hard to stay balanced. There are a few different words used interchangeably for the word balance. Stability, postural control and dynamic postural control are all different descriptors of the word balance. Stability has been defined as the state of a joint remaining or promptly returning to proper alignment through an equalization of forces.\[18\] Stability can be used when describing upper or lower extremity movements. Postural control is a complex series of actions and reactions controlled by many components of the body.\[4\] The body utilizes both sensory and motor components to maintain postural stability. Dynamic postural stability when landing from a jump may be defined as the time it takes for the initial components of the GRF of a jump landing to become similar to the components of the GRF in a stabilized single-leg stance.\[8\]
Neuropathways

Reimann and LePhart describe proprioception as the ability of a joint to determine its position in space; detect movement, kinesthesia, and sense resistance acting on it.[19] Afferent inputs and efferent outputs help contribute to the accuracy of one’s neuromuscular control. Afferent inputs are responsible for the response time of muscular activation and also maintaining the body’s center of balance and are activated by the mechanoreceptors that are located in the joints and muscles. Ruffini’s endings, Pacinian corpuscles, and free nerve endings are all mechanoreceptors located in the joints.[18, 20] These mechanoreceptors relay the joint’s position and detect movement of the joint to the CNS. Muscle spindles and Golgi tendon organs are muscle mechanoreceptors that are located within the muscle or tendon that sense change in the muscle length or tension.

Postural Stability

There are a number of sensory inputs, including visual, vestibular, and somatosensory components, which are sent to the CNS to help maintain postural stability.[21] The somatosensory system detects sensory stimuli including pressure, touch, and pain. The vestibular system uses information it receives from the vestibules and semicircular canals of the ear to maintain balance. This information can be used to control eye musculature to maintain focus on objects when the head is moving, to maintain proper posture, or by contributing to conscious awareness of the body and joint position. Neuromuscular control mechanisms help decrease postural sway through
reactive neural-feedback loops between the CNS and the musculoskeletal system.[18, 20]

A feed-forward mechanism is compiled from previous motor experiences and contributes to decreased postural sway. It is known that an injury to a body part can decrease proprioception as well as anatomical structures.[7, 8, 15, 16, 22]

**Dynamic Postural Stability**

Dynamic postural stability for this study describes the time it takes for the original component of the ground reaction force of a jump landing to become similar to the components of the ground reaction force in a stabilized single-leg stance. [8] Deficits in dynamic postural stability can hinder one’s daily living. Every movement that one does requires dynamic postural stability. This includes the basic getting up in the morning, to brushing teeth, to being able to balance on the balance beam. Dynamic postural control combines every sense and system that postural stability utilizes (as mentioned previously) and aids in movement.

**Time to Stabilization**

Time to stabilization is a quantitative force-plate measurement that is used to evaluate how quickly individuals stabilize after landing from a jump.[8] Individuals with longer TTS times may have decreased neuromuscular control and proprioception.

Ross and Guskiewicz have developed a way to calculate time to stabilization as a measurement of how quickly individuals stabilize after a jump landing.[8] The jump-landing task was selected as the ideal protocol due to its resemblance to athletic movements during competition. The jump-landing protocol is also ideal because it
provides a way to control the jump height of the individuals as well as the horizontal of the jump distance.[8]

Ross and Guskiewicz determined that the key component to calculating TTS is the peak ground reaction force (GRF). The anterior-posterior (AP) and medial-lateral (ML) components of the GRF are analyzed to measure TTS. This study used a software package that scanned two sections of the last 10 seconds of each trial (10-15s, 15-20s).[8] The section with the smallest absolute GRF range is used as the optimal range-variation value, which displays the athlete’s optimal postural stability. The absolute GRF range-variation values for AP and ML directions are superimposed over the respective GRF data, which is done by using horizontal lines. After the values are superimposed they are rectified and then an unbounded third-order polynomial is fit to AP and ML directions beginning at the peak GRF. The point at which the unbounded third-order polynomial transects the horizontal range-variation line is determined the TTS.

Another study tried to determine which landing protocol would be better to determine deficits in subjects with functional ankle instability, either a step down or a jump protocol. Wikstrom et al used healthy and functionally instable individuals during their study to see which protocol was more efficient at finding the deficits in the different ankles.[10] The step down protocol was performed by using the test leg as the step down leg off of a 20-cm-high platform onto a force plate. This is the same protocol used by Colby et al in their study about ACL deficits.[16] The jump landing protocol was taken from the Ross and Guskiewicz study on time to stabilization.[8] Wikstrom et al concluded that the best way to compare healthy ankles to functional instable ankles is to
use the jump protocol and should be analyzed by using the unbounded third order polynomial method.\[10\]

**TTS and Fatigue**

Time to stabilization has been used to test two types of fatigue: isokinetic and functional. Wikstrom, Powers, and Tillman used isokinetic and functional fatigue protocols to determine if an individual could achieve the same amount of fatigue during a functional fatigue protocol as an individual can during an isokinetic protocol.\[9\] This study used TTS due to its ability to assess the effects of fatigue on neuromuscular control and dynamic stability. Ground reaction forces were also measured because the greater the GRF the stiffer the landing from a jump. This is important because it has been suggested that increased muscular stiffness during landing would provide more joint stability and protection against joint injury.\[19\] The fatigue protocol is used to determine if there is a delay or impairment in muscle activity and stiffness, which could lead to excessive motion in the knee or ankle, which could lead to injury. Wilstrom et al noted that there was no difference between isokinetic and functional fatigue protocols when it comes to dynamic stability when landing from a jump.\[9\] Therefore, the findings made during studies using isokinetic fatigue protocols could be generalized to changes occurring during competition.

**TTS and Functionally Unstable Ankles**

Time to stabilization has been used to determine if there was a difference between functionally unstable and stable ankles in a study by Ross et al.\[15\] From previous
studies and experiences it was determined that individuals with functionally unstable ankles have postural control deficits, which could cause greater range-of-variation values with single leg stance. Individuals with stable ankles will have smaller range-of-variation and therefore will take longer to reduce the range-of-variation compared to the unstable ankles with greater ranges. This study developed a way to normalize the range-of-variation to each individual using his or her body weight. This study’s new way to calculate TTS is called vibration magnitude curve-fit which normalizes the reference variable between the groups. This is the way the data will be analyzed in this study. It was determined that there is a difference between individuals with functionally unstable ankles compared to individuals with stable ankles during a single-leg jump landing. This study also determined that the vibration magnitude curve-fit calculation for TTS was more reliable than the traditional way to calculate TTS.

Another study assessed deficits in FAI subjects using joint position sense (JPS), TTS, and electromyography (EMG).[11] Brown et al used a biodex to test JPS in four directions: dorsiflexion, plantar-flexion, inversion, and eversion. EMG of tibialis anterior, peroneals, and the lateral gastrocnemius were measured during jump-stabilization testing. TTS was also measured during jump-stabilization testing. The study results concluded that FAI subjects had deficits in landing stability and soleus muscle activity during landing, with longer anterior-posterior TTS in the unstable ankle group and less soleus EMG amplitude before and after landing compared to stable ankles.[11]

Ross and Guskiewicz developed a study using both static and dynamic task to determine if there were differences between functionally stable and unstable ankles.[12]
Each subject balanced on a force plate with one leg for the static task. Each subject performed one 10-second practice trial and three 20-second test trials. For the dynamic task subjects performed a jump-stabilization maneuver. The subjects performed three practice trials and three testing trials. The results concluded that mean sway was not significantly different between the functionally stable and unstable groups, but the functionally unstable group took significantly longer to stabilize in the anterior/posterior and medial/lateral directions.[12]

**Dynamic Postural Stability Index**

Wikstrom et al believes that TTS has some apparent flaws[6]. The first flaw is that TTS is a force measurement from three directions for each landing giving three separate measures for postural stability. Even though the three directions can show differences between each direction, there is no way to show relationship between the three directions. Wikstrom et al developed a new way of measuring dynamic postural stability: The dynamic postural stability index. This new measurement is a composite of the medial lateral stability indices, anterior posterior stability indices, and the vertical stability indices and is sensitive to changes in all three directions. These measures are mean square deviations assessing discrepancies around a 0 point, unlike TTS which uses SDs assessing discrepancies around a group mean.[6]

This study measured the reliability of both the TTS method and the DPSI and concluded that the DPSI measurements were more reliable than TTS measures.[6] DPSI and TTS are different in the aspect of time. DPSI is not a produce of time, but of overall stability whereas TTS measures how long it takes for one to stabilize. DPSI and TTS are
both great evaluations in their own right: DPSI for directional and global measures and TTS for time based directional measures.

**Learning Effect**

In the area of motor behavior many researchers are looking at the effect vision has on task being performed. The researchers want to know how much input vision has on certain task subjects perform. There have been many theories about how practice effects the way task are performed. Pew concluded that with practice the role of vision changes during skill attainment as a transition from closed-loop to open-loop control.[23] So therefore, a performer will become progressively less dependent on afferent sources of information the more one practices.[23] Proteau had a little different theory when it comes to practice.[24] He believes that with practice, subjects develop a more proficient, less time-consuming feedback loop.[24] Ivens and Marteniuk have developed their own version of the specificity of practice hypothesis, which concludes that learning is the development of sensorimotor representations within the central nervous system, as a result of which the CNS becomes increasingly effective at planning and controlling highly practiced movements. [25]

In a study by Van Selst, two different types of tasks were performed with many practice trials to see if practice reduced dual-task interference in psychological refractory period.[26] The first task subjects performed was to discriminate tones into high and low tones by using their voices. This task looked at the audio-vocal responses. In the next task subjects had to watch characters and then perform reaction tasks based on what the characters did. This task looked at the visual-motor responses. Van Selst concluded that
dual-task interference in psychological refractory period dramatically reduced after practice.[26]

During their study on the intratester and intertester reliability on the star excursion balance test (SEBT), Hertel et al discovered a learning effect.[14] During their study they noticed that the best scores were recorded during trials seven through nine. Therefore six practice trials are needed before recording data for the study. Since no instructions were given to teach each individual how to best perform this given task individuals need time to practice to figure out a strategy to complete the given task as efficiently as possible. Since it took six practice trails in the SEBT study before baseline measurements could be calculated, one group in this study will be allowed six practice trials before data will be collected.

Looking at the number of trials and practice trials throughout, these studies show a wide variety of trial numbers. Even with studies by the same authors there are differences in trial numbers. In the Wikstrom et al study each subject needed to complete three successful trials on three different days.[6] Wikstrom et al did not state how many failed trials were performed, but the subjects were allowed to practice as many times as needed.[6] In another Wikstrom et al study on different fatigue protocols, each subject was allowed to practice as many times as needed and then three successful trials were recorded.[9] The subjects in another Wikstrom et al study on stability deficits in functional ankle instability, had to perform three successful trials but it did not state how many practice trials were given.[10] Subjects performed three practice trials and three successful trials during the Ross et al study using functionally stable and unstable ankles.[12] Another study by Ross et al using functionally unstable ankles allowed three
practice trials and seven testing trials. [15] Brown et al had subjects perform four practice trials and five test trials to assess functional ankle instability.[11] These inconsistencies in the number of trials need to be addressed. It is hard to compare the different TTS studies when there is not a standard protocol of practice trials needed to achieve consistency in the measurement and avoid potential learning effects.

TTS is a very useful tool that clinicians can use to help determine if there are any deficits in dynamic stability. Currently, there are different protocols and also ways to calculate TTS as shown above in the studies. TTS has the potential to be a prescreening tool to help determine if individuals are more prone to injury and therefore should go through preventative rehabilitation to help decrease their chances of being injured. The research community needs to determine a standard TTS protocol so that everyone knows the best way to utilize TTS. This study will determine the influence of a learning effect during TTS and also how many trials are actually needed to gain consistency. Knowing how many trials actually need to be performed will help save researchers time by not performing unnecessary trials and improve the reliability and validity of the measurement.
Chapter 3

Methods

Subjects

There were thirty one subjects (Mass: 76.5 ± 13.21, Height (inch): 67.65 ± 3.4, Age: 21.23 ± 2.8) with no previous lower extremity injury in this study (Table 1). All volunteer subjects were recruited from a university setting, signed a University approved consent form, and completed a questionnaire to determine if they qualify for the study. There was only one group in this study. Each subject performed twenty good jump trials on each leg. All subjects were given a random subject number to maintain anonymity. All of the records were filed in a locked filing cabinet in the lab.

Table 1: Subject Demographics

<table>
<thead>
<tr>
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<th>mean ± SD</th>
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<tr>
<td>Mass (kg)</td>
<td>76.5 ± 13.21</td>
</tr>
<tr>
<td>Height (inch)</td>
<td>67.65 ± 3.4</td>
</tr>
<tr>
<td>Age</td>
<td>21.23 ± 2.8</td>
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Procedures

Each subject had his or her vertical reach and maximum vertical jump measured jumping off of two feet. This was done using the Vertec (Sports imports, Columbus, OH). The subject’s vertical reach was assessed by having the subject stand under the Vertec with the hand closest to the Vertec reaching straight up as far as possible. The height was recorded using the plastic height markers. The maximum vertical jump was recorded next. This was assessed by having the subject stand under the Vertec and with two feet jump as high as possible with the hand closest to the Vertex straight in the air, and hit the highest marker that the subject can. This was done three times with the highest jump height being recorded. Once the vertical max was calculated, it was divided by two so that only the marker that is 50% of their max height was shown.

Each subject stood 70cm away from the middle of the force plate (Bertec 4060-NC; Bertec Corp., Columbus, OH) and the Vertec. The subject hit with their hand the target height of 50% of their maximum vertical height during each trial as indicated on the Vertec. The subject was able to swing their arms to jump and reach their 50% mark, but when they landed on the force plate they placed their hands on their hips. The subject was instructed to stick the landing and be as motionless as possible for ten seconds. A trial was rejected if the subject’s other foot hit the ground or the subject hopped during the five seconds. The subject’s trunk position or lower extremity position were not accounted for in this study. Each subject performed twenty trials on each foot. The dominant leg was considered the leg they used to kick a ball with.[27] The order of testing limbs was randomized. (Appendix C)
**Time to Stabilization Calculation**

The data was collected at a sampling rate of 180Hz using the Motion Monitor software (Innovative Sports Technologies, Inc.; Chicago, IL).[15] Before TTS was calculated the data needed to be normalized to the individual’s body weight. Using the method Ross et al 2005 used in their study, optimal range-of-variation values were determined as the smallest absolute ground reaction force ranges for the A/P and M/L elements.[15] Each different element was then divided by the individual’s body weight. A mean range-of-variation value for each component of the ground reaction force was then formed from the twenty trials that were collected for each individual on each foot.

To calculate APTTS and MLTTS, the A/P and M/L components of the ground reaction force were analyzed. The GRF, sampled at 180Hz with the Motion Monitor software from the force plate, was exported and processed in LabView with a customized program file. A third-order polynomial curve fit was applied to the GRF to determine the decay of the data during a landing trial. As a reference value for normalization the range of variation of the GRF ± 3 S.D. was multiplied by the subject’s body mass. This reference value was represented by a horizontal line inserted in the graph superimposed over the graphed component of the GRF and the associated curve fit. The TTS value was determined as the point at which the unbounded curve fit transects the horizontal reference value line. These calculations were performed separately for the APTTS and MLTTS dependant variables using the appropriate A/P and M/L components of the GRF data.
**Statistical Analysis**

The statistical software SPSS (SPSS version 14.0; SPSS Inc, Chicago IL) was used for statistical analyses. The $\alpha$ level was set a priori of .05 to indicate statistical significance. There were three dependent variables: APTTS, MLTTS, and failed trials. To determine the significance of a potential learning effect, separate trial (1-20) by side (dominant, non-dominant) repeated measures ANOVA were performed for APTTS and MLTTS. To determine the number of failed trials between the dominant and non-dominant sides, a paired samples t-test was performed. A Scheffé’s post-hoc test was applied to the statistically significant data.
Chapter 4

Results

Anterior/ Posterior Time to Stabilization

For APTTS, there was no significant interaction between Side and Time. \(F_{19,570}= .973, p = .492; \text{power} = 0.73\) (Figure 1). The means and S.E. values are located in Table 2. Additionally, there was no significant main effect for trial \(F_{19,570}= 1.34, p = .153; \text{power} = 0.89\) (Figure 2) or side (dominate \((1.18 \pm 0.02)\) vs. non-dominate \((1.19 \pm 0.02)\)) \(F_{1,30}= .081, p = .778; \text{power} = 0.06\) (Figure 3).

Medial/Lateral Time to Stabilization

For MLTTS, there was no significant interaction between side and time \(F_{19,570}= .078, p = .667; \text{power} = 0.64\) (Figure 4). The means and S.E. values are located in Table 3. A significant main effect for trial existed \(F_{19,570}= 2.901, p< .001; \text{power} = 0.99\) (Figure 5). There were several trials that were significantly different from one another, but there was no distinct trial in which MLTTS stopped improving. There was no significant main effect for Side (dominant \((1.61\pm 0.03)\) non-dominant \((1.63 \pm 0.03)\) \(F_{1,30}= 6.17, p = .438; \text{power} = 0.12\) (Figure 6).
Failed Trials

When examining the number of failed trials during landing, there was no significant difference between the dominant (5.90±0.84 trials) and non-dominant (6.00±1.06 trials) (t=-0.97, p = .924).
Figure 1: APTTS interaction between side by time ($F_{19, 570} = .973$, $p = .492$)

![Graph showing APTTS interaction between side by time](image-url)
Figure 2: APTTS main effect for Trial ($F_{19, 570} = 1.34, p = .153$)
Figure 3: APTTS main effect for side ($F_{1,30} = .081, p = .778$)
Table 2: APTSS (seconds) mean ± SE for side by time

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<th>Trial</th>
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<td>1</td>
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<td>13</td>
<td>1.18 ± .03</td>
<td>1.16 ± .06</td>
</tr>
<tr>
<td>14</td>
<td>1.14 ± .04</td>
<td>1.14 ± .03</td>
</tr>
<tr>
<td>15</td>
<td>1.10 ± .04</td>
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<tr>
<td>16</td>
<td>1.22 ± .06</td>
<td>1.22 ± .05</td>
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<td>17</td>
<td>1.14 ± .04</td>
<td>1.18 ± .04</td>
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<tr>
<td>18</td>
<td>1.19 ± .09</td>
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<tr>
<td>20</td>
<td>1.11 ± .03</td>
<td>1.12 ± .03</td>
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</tbody>
</table>
Figure 4: MLTSS interaction between side by time ($F_{19.570} = .078$, $p = .667$)
Figure 5: MLTTS main effect for Trial ($F_{19, 570} = 2.901, p<.001$)

- * sig diff than trial 1 & 2
- # sig diff than trial 3
- + sig diff than trial 5 & 7
- $ sig diff than trial 4, 5, 8 & 11
- % sig diff than trial 5 & 8
- ^ sig diff than trial 13
- ! sig diff than trial 7 & 13
- † sig diff than trial 5, 8, 13, 15 & 17
- ¥ sig diff than trial 4, 5 & 17
- @ sig diff than trial 7, 13, 14, 18 & 20
Figure 6: MLTTS main effect for side ($F_{1,30} = 6.17 \ p = .438$)
Table 3: MLTSS mean ± SE side by time

<table>
<thead>
<tr>
<th>Trial</th>
<th>Dominant</th>
<th>Non-Dominant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.76±.08</td>
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<tr>
<td>2</td>
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<td>1.62±.11</td>
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<td>4</td>
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<td>1.64±.06</td>
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<tr>
<td>20</td>
<td>1.55±.05</td>
<td>1.55±.05</td>
</tr>
</tbody>
</table>
Chapter 5

Discussion

The purpose of this study was to establish a standard protocol for the number of practice and test trials needed for testing TTS. By determining a standard on how many trials need to be performed, the efficiency of dynamic postural control testing with TTS may be improved. Based on our results, it is difficult to conclude that a standard number of practice trials were established during this study. It was hypothesized that it would take seven trials to gain consistency in TTS in all directions. This was based on the premise that during another dynamic postural control test, the Start Excursion Balance Test, healthy subjects required six practice trials to gain consistency.[14] Due to the results of this study, this hypothesis was rejected. There were differences observed in TTS as subjects progressed through the protocol of twenty trials, but there did not appear to be a clear number of trials that were performed after which no additional improvements were observed. It was also hypothesized that there would be no significant differences between the dominant and non-dominant sides for TTS in both the A/P and M/L directions. Due to the results of this study this hypothesis was accepted.
MLTTS

In the M/L direction there was a statistically significant main effect for trials. We expected to observe a decline in TTS from the beginning to the end of the twenty trials and that at some point during these trials, there would cease to be any additional significant improvement in dynamic stability. However, there were multiple significant differences among the twenty trials. Our purpose was to use the expected finding to describe the number of trials needed to overcome the learning effect during this task. There was not a significant difference in MLTTS between each of the first three trials, but there were multiple significant differences between trials 4-20 and the majority of trials 4-20 were significantly different from trials 1-3. This leads us to cautiously conclude that three trials are needed to overcome the learning effect. Unfortunately, because there were several trials beyond the three trials in which MLTTS significantly increased or decreased, this does not allow us to conclude for certain that there is a specific number of trials needed to establish consistency during this task.

There are a few possibilities for the peaks and valleys observed in the data of the main effect for trial for MLTTS. One possibility could be that the subjects lost focus throughout the course of performing twenty trials. In the beginning of the study the subjects perhaps were focused and tried to improve with each jump; but after the initial handful of trials perhaps they just wanted to complete the study as soon as possible and did not concentrate on the task at a consistent level. We did provide an adequate amount of rest in between each trial. However, while the subjects did not report that they felt any
physical fatigue and were able to complete all the trials without reported difficulty, it is possible that they experienced some level of mental fatigue.

As we hypothesized, there was no significant main effect for side meaning there was no significant difference between the dominant and non-dominant leg during TTS in either of the directions. Therefore, we do conclude that either side of a healthy subject can be used during TTS as a consistent representation for doing this task. This knowledge is of great benefit for clinicians who are working with subjects with lower extremity pathology such as ankle instability or ACL injury. This could mean that the patient’s healthy ankle can be used as a standard to use in comparison to the injured ankle. More importantly, because there is not an influence of limb dominance on this task, it will be easy to match the performance of a pathological subject’s injured limb to a limb of a healthy subject to examine the influence of the pathology on performance without becoming concerned about the influence of limb dominance.

**APTTS**

In the A/P direction there was no significant main effect for Trial, unlike the M/L direction. In examining the data, the progression of APTTS during the twenty trials was similar to the results of the MLTTS, but it was not statistically significant. A reason for the difference between the A/P and M/L directions could be that perhaps gaining stability in the A/P direction is easier than in the MLTTS and therefore healthy subjects could perform task almost immediately and will perform the task consistently throughout consecutive trials as our results demonstrated during all twenty trials. It would seem logical that gaining stability in the A/P direction would be more difficult and would take
longer than in the M/L direction because the task involves a forward hop and subsequently more momentum in the A/P plane. However, consistent with previously published papers, APTTS measured in our study was shorter than MLTTS.[9, 11, 15] Perhaps because APTTS seems to involve shorter stability times, the range of variability is lower and therefore it is difficult to detect differences between trials during the performance of healthy subjects.

There was also no main effect for side or a significant interaction between side by time for APTTS. These results could be due to the same factors as for MLTTS.

**Failed Trials**

When reviewing the number of failed trials, there was not a significant difference between the dominant and non-dominant legs just like in the MLTTS and APTTS. Both sides had on average approximately six failed trials. This supports the conclusion that both legs are equal when it comes to TTS. When examining the main effect for Trials in both A/P and M/L directions it appears as if there is a large decrease in TTS between trials 1-3 and then there is a pattern of fluctuation throughout the remainder of the trials. This would suggest that there needs to be three practice trials before test trials are performed.

While it is possible to advocate that three practice trials are needed to overcome a learning effect when performing TTS, there are no significant statistics that supports the idea. One reason could be that there were too many trials utilized for this study. Looking at the main effect for trials and also the interaction between the side by time there is a marked decrease in the TTS for about the first three trials and then the times start to have
peaks and valleys. Even though physical fatigue was accounted for during this study, there might be some mental fatigue. As previously discussed, it is possible that that during the course of performing the twenty trials on each limb, the subjects may have lost focus and this could be a possible reason for the peaks and valleys.

The results in this study are very comparable to previous studies.[9, 11, 12, 15] (Table 4) Originally, TTS was calculated differently than it was in our current study and as a result the TTS was higher in the earlier studies. In 2004, Wikstrom et al[9], determined that the jump protocol and unbound third order polynomial method of calculation as the most effective was to calculate TTS. This method reduced the TTS measure compared to the previous method as can be seen in Table 4. Our study’s comparable results to previous studies leads to the possibility that the TTS measure will always vary during testing. There may not be a definitive trial in which there will be no longer a quicker TTS. It is possible that the peaks and valleys are going to happen and is just part of this test’s design.

<table>
<thead>
<tr>
<th>Research</th>
<th>A/P TTS</th>
<th>M/L TTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Study</strong></td>
<td>1.19±.10</td>
<td>1.62±.15</td>
</tr>
<tr>
<td>Brown et al [11]</td>
<td>2.30±.46</td>
<td>2.31±.70</td>
</tr>
<tr>
<td>Ross et al [12]</td>
<td>2.33±.33</td>
<td>2.00±.65</td>
</tr>
<tr>
<td>Wikstrom et al [9]</td>
<td>1.562±.35</td>
<td>1.560±.38</td>
</tr>
<tr>
<td>Ross et al [15]</td>
<td>1.35±.30</td>
<td>1.56±.28</td>
</tr>
</tbody>
</table>

Another explanation could be that TTS is not precise enough to detect the very small differences between trials. This study only used healthy subjects and our results may be demonstrating that there is very little variability in the performance of healthy subjects during this task. Additionally, there might be less of a learning effect when
compared to pathological subjects and therefore no significance was noted. Future studies should examine the learning effect when comparing subjects with and without lower extremity pathologies.

Even though a power analysis was calculated before beginning the study, the power in this study was perhaps low for some of our results. For our two interaction models, the observed power for the APTTS and MLTTS was 0.73 and 0.64, respectively, while the observed power for the Side main effect comparisons for the APTSS and MLTTS were 0.06 and 0.12, respectively. Therefore, an increase in the number of subjects may be warranted to adequately examine these relationships. However, for the main effect comparisons of Trial, the observed power values were quite high, 0.89 and 0.99, indicating that our findings related to this variable seem to be associated with an adequate sample size.

The biggest reason why our second hypothesis was rejected is that there might not be a major learning effect in this task. Therefore a set number of practice trials might not be needed. The TTS jump landing task might be a simple enough task for healthy subjects that the learning effect is really short even though most people do not jump and land on one foot and hold it for five seconds. The daily activities that people do might be enough to prepare subjects for this sort of jumping task. During walking and running you are landing on one foot and have to stabilize. Jump landing might be just a little more intense than the walking and running of daily activity and therefore it take a very short time for the body to learn how to perform the task efficiently.
Limitations

There were a few limitations to this study. The largest limitation was that only healthy subjects were used in this study. As mentioned earlier, this might have limited the ability to find significant differences between the trials and subjects. It has to be assumed that the subjects were truthful in answering the injury questionnaire and that the subjects are trying their hardest to perform this task at the best of their ability. Another limitation in this study was that each subject had different shoes. Their shoes might not have been in the best condition to stabilize after landing from a jump, but they also might have been motion control shoes, which could have helped with stabilizing. This study did not have the resources to put the subjects into the same shoes to account for the effect that the shoes might have on TTS.

This study also did not standardize the jump distance for each subject. The jump distance was set at 70cm for all subjects. This distance has been the standard in previous studies, but may affect the angle at which the subject lands on the force plate. Standardizing the jump distance to a subject’s height could increase the reliability of this protocol.

A limitation in this study was that even though the total failed trials were recorded, the time at which they happened was not recorded. Therefore, we are not able to determine if most of the failed trials happened in the beginning and therefore more practice trials would be needed. Clinicians and researchers will have to keep in mind that there may be a need to consider and account for the number of failed trials when assessing TTS.
The last limitation to this study would be that the subjects that are left-handed had to use their right hand to touch the marker which could have made it a little awkward for them. Each of the left-handed subject commented on how awkward it was to use their right hand. This study wanted to make all aspects of the study the same for everyone, so everyone jumped from the same direction. It did not appear that this awkwardness of the left-handed subjects affected their performance even though they felt uncomfortable in the beginning.

This study could be a stepping stone to another study that could be performed by splitting up the twenty trials on different days. The object of this study would be to reduce the possibility of fatigue even more, and also to try to prevent the subjects from getting bored throughout the study. Another addition to this study could be to use pathological subjects instead of healthy subjects. It would be interesting to see if there are significant differences over time using pathological subjects in both directions.

**Conclusion**

This study attempted to determine how many practice and test trials are needed to achieve consistency. It appears that either leg can be used during TTS calculations which will help clinicians trying to find a base comparison for the injury leg. However, the primary purpose of this study, which was to determine the number of trials needed to overcome a learning effect, was not realized fully. We can cautiously conclude that three practice trials would allow a healthy subject to become familiar with the task. However, this study brings up the question if there really is a learning effect that is quantifiable associated with TTS assessment in healthy subjects.
References


Appendix A: Informed Consent Form for Human Research Study
INFORMED CONSENT FORM FOR HUMAN RESEARCH STUDY
University of Toledo

Title of Project: Time to Stabilization: Number of Practice Trials and Measured Trials Needed

Person in Charge: Ashley VanMeter
(517) 262-2164
ameter55@hotmail.com

Phillip Gribble
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HHS 2505-H
Mailstop #119
Toledo, Oh 43606
(w) (419) 530-2691
Phillip.gribble@utoledo.edu

1. This section provides an explanation of the study in which you will be participating:

A. The study in which I am participating is part of research intended to assess performance of the lower extremity during a jump-landing task.

B. I will be asked to complete two separate bouts of multiple trials of jumping and landing each using a different landing leg. I will be asked to complete a series of maximum and sub-maximal jumps consisting of jumping off two feet and landing on one foot.

C. My participation will include one session for a total of approximately 45 minutes.

D. I may experience slight soreness or tiredness following the jump-landing protocol. Additionally, there is a slight chance of falling during the jump-landing testing. However, I am free to terminate the testing session at any time.

E. The testing session will consist of the following protocols.

1) **Maximum Jump Height**- At the beginning of the testing session, the investigator will measure my maximum jump height by asking me to jump off two feet, reach as high as possible with one hand to touch a point on a height measurement device, and land on a designated test leg. At the time of the testing session, I will be told if I will perform the first set of jumps using my right or left leg first. I will be asked to perform three trials of this task. The highest level that I can reach and land successfully will be called my maximum jump height. After
completing my maximum jump trials, I will be allowed a 10-minute break during which I will sit down and rest quietly.

2) **Sub-Maximal Jump Analysis**- Based on my maximal jump height, the height measurement device will be adjusted to a height equal to 50% of my maximum jump height. I will perform trials during which I will jump off both feet, reach and touch the designated 50% height level and land on the designated test leg. A 60 second rest period will be allowed between test trials. After 20 trials are completed using one leg I will be allowed a 10-minute break period during which I will sit and rest quietly. After the rest break, I will repeat the same procedures as before this time using the other leg as the landing leg.

2. This section describes **your rights as a research participant**:

   A. I understand that I may ask the investigator any questions about the research procedures, and these questions will be answered.

   B. My participation in this research is **confidential**. Only the people in charge will have access to my identity and information that can be associated with my identity. In the event of publication of this research, no personally identifying information will be disclosed. To make sure my participation is confidential, only a code number will appear on the data collection sheet. Only the researchers can match my name with my code number.

   C. My participation is voluntary. I am free to stop participating in the research at any time, or to decline to answer any specific questions without penalty.

   D. I may contact the Office for Research, 2300 University Hall, University of Toledo, Toledo, OH 43606, (419)530-2844, for additional information concerning my rights as a research participant.

3. This section indicates that you are giving your **informed consent to participate in the research**:

   **Participant**:

   I agree to participate in the scientific investigation described above, as an authorized part of the education and research program of The University of Toledo.
I understand the information given to me, and I have received answers to any questions I may have had about the research procedure. I understand and agree to the conditions of this study as described.

To the best of my knowledge and belief, I have no physical or mental illness or difficulties that would increase the risk to me of participation in this study.

I understand that my participation in this study does not entitle me to any compensation, financial or otherwise.

I understand that my participation in this research is voluntary, and that I may withdraw from this study at any time by notifying the person in charge.

I am 18 years of age or older.

I understand that medical care is available in the event of injury resulting from research but that neither financial compensation nor free medical treatment is provided. I also understand that I am not waiving any rights that I may have against the University for injury resulting from negligence of the University or investigators.

I understand that I will receive a signed copy of this consent form.

_______________________________________                              _______________
Signature                     Date

Researcher:
I certify that the informed consent procedure has been followed, and that I have answered any questions from the participant above as fully possible.

______________________________________   ________________
Signature         Date
Appendix B: Health History Questionnaire
Subject #

Name___________________________________________________________

Date of Birth_____________  Height_________  Weight___________

Sex: M    F   Kicking Leg: R    L  Age________

1. Have you ever experienced a head injury?    Y    N
   If yes when? _______________
   What was the injury? ________________

2. Have you ever suffered a significant back injury?   Y    N
   If yes when?________________
   What was the injury? ________________

3. Have you ever suffered a fracture to any part of your leg, ankle, or foot?    Y    N
   If yes, which bone (s) was fractured? ________
   When did the fracture occur? __________

4. Have you ever suffered a significant knee injury?   Y    N
   If yes what injury?_________
   If yes when?_________

5. Have you ever suffered a significant ankle injury?    Y    N
   If yes what injury?_________
   If yes when?_________

6. Have you ever suffered a significant hip injury?   Y    N
   If yes what injury?_________
   If yes when?_________

_________________________________________________________________

Subject’s name (Print)

_________________________________________________________________

Subject’s signature
Appendix C: Picture of Vertec and Forceplate