The Influence of Initial Bipedal Stance Width on the Clinical Measurement of Unipedal Balance Time

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Objective: To determine the effect of varying initial bipedal stance width (ISW) on the clinical measurement of unipedal balance time (UBT).

Design: Observational, cross-sectional study.

Setting: Academic physiatric outpatient facility.

Subjects: Thirty-one clinic subjects with neuromuscular and/or musculoskeletal conditions known to influence mobility and 30 similarly-aged healthy subjects.

Methods: Demographic and clinical information were recorded. UBT was determined under 3 distinct conditions by varying bipedal intermalleolar distance: (1) ISW of 0.3 body height; (2) ISW of 0.05 body height; and (3) ISW of 0 body height. The last was accomplished by subjects assuming unipedal balance while using the hands on a horizontal surface for stabilization. Subjects lifted the contralateral foot (or hands in the case of 0 body height condition) in response to a cadenced command to minimize variation in rate of weight transfer.

Main Outcome Measure: UBT under each of the 3 ISW conditions.

Results: Mean UBT increased with decreasing ISW, and the differences were significant when comparing each ISW with the next smaller. Healthy subjects demonstrated greater UBT than clinic subjects at each ISW, but the magnitude of these group differences were similar across ISW condition. A UBT >10 seconds in the 0.3 body height ISW was the best discriminator between clinic and healthy subjects.

Conclusion: Because UBT varies with ISW, standardization of ISW is necessary for accurate within-subject, and between-subject, comparisons in UBT. Healthy subjects were best differentiated from clinic subjects by UBT >10 seconds in the 0.3 body height ISW condition.

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INTRODUCTION

Measuring unipedal balance time (UBT) has appeal as a clinical measure of balance because it is easy to perform, does not take much time, and is challenging [1]. Moreover, unipedal balance requires frontal plane control, which is particularly important given that lateral instability is associated with falls [2,3] and lateral falls are strongly associated with injury [4]. Additionally, studies have suggested that UBT is associated with age [5] and is a marker for frailty [6]. It can also discriminate between groups of clinical importance. For example, UBT has been found to differentiate between patients who are at low and high risk of falls [7-9], patients with and without peripheral neuropathy [10,11], and patients with multiple sclerosis [12].

Despite these advantages, clinical measurement of UBT is less than ideal. One drawback is that there is often significant within-group variability in UBT. For example the mean ± SD UBT in older subjects without neuropathy was 16.2 ± 11.2 seconds, whereas the same value for older subjects with neuropathy was 5.9 ± 6.2 seconds [10]. Similarly, in a study of 100 older subjects, Maki et al [13] found that the mean ± SD UBT of nonfallers and fallers was 6.33 ± 8.07 seconds and 4.11 ± 6.05 seconds, respectively [13]. Hurvitz et al noted that UBT in a younger group of nonfallers and fallers was 31.3 ± 16.3 seconds and 9.6 ± 11.6 seconds, respectively [9], and in a group of older men with peripheral neuropathy

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who did, and did not, report a history of multiple falls the values were 3.7 ± 3.3 seconds and 7.8 ± 8.6 seconds [8]. In each of these studies, the SD is a significant percentage of the mean and often exceeds it. This degree of spread around mean values prevents clinicians from clearly categorizing a number of patients and reduces the precision of the measure in scientific pursuits. Therefore, any modification of technique for measuring UBT that would decrease this degree of spread would be welcome for clinicians and scientists alike.

Another concern with measuring clinical UBT is that the technique has not been standardized. To the authors' knowledge, studies have neither precisely defined the initial stance width (ISW) before the measuring UBT nor the effect of varying ISW on UBT. This is the case despite it being intuitively clear that initiating unipedal balance with the feet starting, for example, 36 inches apart is a different task than initiating unipedal balance with the feet starting 6 inches apart. Furthermore, studies do not mention the rate of transfer from 2 feet to 1 foot, and so it is likely that some subjects transfer their weight slowly, whereas others may move from bipedal to unipedal stance quickly. The latter is the more challenging and functionally relevant task, given that most falls occur during ambulation [14], avoidance of falls is often time contingent, and strategies for achieving unipedal stance vary according to speed of weight transfer [15]. This lack of standardization of UBT prevents clear comparisons between studies and may serve to increase within-study group, and even within subject, variability.

Therefore, the primary purpose of this study was to determine whether systematically varying ISW while standardizing rate of transfer to the extent possible would affect clinical UBT. If so, then a source of a portion of the variability in UBT data described previously would be identified, and future work on UBT could be standardized so as to allow more precise comparisons within and between subjects. To explore these questions, 61 subjects were recruited, 31 from an outpatient physical medicine and rehabilitation clinic with disorders expected to influence balance and 30 healthy subjects. The primary hypotheses of this work were as follows: (1) mean UBT would increase with decreasing ISW; (2) within-subject spread of UBT, as determined by analyses of the ranges of within subject measures, would decrease with decreasing ISW. The secondary hypotheses were as follows: (3) healthy subjects would demonstrate greater UBT than the clinic subjects; and (4) the group differences would be more marked with increasing ISW. Finally, which measure of UBT most effectively distinguished between the clinic and healthy subjects was explored.

METHODS

Subject Recruitment

The study was approved by the institutional review board at the University of Michigan, and all subjects signed informed consents before participation. Healthy and clinic subjects were not directly matched, but efforts were made to recruit healthy older subjects so that the groups would not significantly differ by age, given its known effect on UBT [5]. Clinic subjects were obtained from the University of Michigan Department of Physical Medicine and Rehabilitation Outpatient Clinic. Some of the older control subjects were identified with the assistance of the Human Subjects Core within the University of Michigan Claude D. Pepper Older American Independence Center. The remainder of the control subjects were clinic patients with exclusively upper limb concerns (for example, shoulder or wrist pain) or subjects of convenience such as departmental staff.

Inclusion and Exclusion Criteria for Healthy Subjects

Healthy subjects were included if they were age 21 and older, without known neuromuscular or musculoskeletal impairments, and had normal mobility skills and function. History and examination were focused on excluding subjects with significant neuromuscular or musculoskeletal disorders. Therefore, subjects were excluded from this group if they had evidence of any of the following:

a. central neurologic disorders including stroke, major depression, dementia, myelopathy, or Parkinson syndrome;
b. musculoskeletal disorders including severe scoliosis, amputation, lower limb arthritis and/or history of lower limb joint replacement, low back pain and/or radicular symptoms;
c. peripheral neurologic or neuromuscular disorders including peripheral neuropathy, diseases of the neuromuscular junction, myopathies, vestibular dysfunction, and visual impairment despite correction; or
d. an accidental fall in the 6 months before testing.

Inclusion and Exclusion Criteria for Clinic Subjects

Clinic subjects were included if they were older than the age of 21 and had disorders commonly encountered in the physical medicine and rehabilitation outpatient clinic. These disorders included known central neurologic, neuromuscular, or musculoskeletal disorders that influenced lower extremity function and would be expected to affect gait and balance. Diagnoses in the clinic subjects recruited for this study included lower limb osteoarthritis with and without joint replacement, cerebrovascular accident, multiple sclerosis, peripheral neuropathy, brain tumor, traumatic brain injury, vestibular disorders from stroke and head trauma, spinal stenosis, lower limb radiculopathy, and multiple trauma. Clinic subjects were excluded if they were of low functional level, defined as the inability to walk at least household

distances with or without an assistive device or tolerate standing without assistive device for 2 to 3 minutes.

Experimental Procedure

Two of the authors (C.T. and C.N.) and a physical therapist trained in research techniques recruited subjects and obtained data. Before testing, subjects filled out a brief questionnaire. The information obtained included age, gender, level of education completed, occupation (or former occupation for retired subjects), medical history, and present medications.

UBT testing was then determined under 3 conditions: (1) ISW (as determined by the intermalleolar distance while standing) of 0.3 body height (0.3H); (2) ISW of 0.05H; and (3) ISW of 0H. The last was accomplished by the subject standing on one foot while stabilizing themselves with his or her hands touching a countertop. When the subjects felt well balanced, they were instructed to lift their hands from the stabilizing horizontal surface with the same command used for the 0.05H and 0.3H conditions. Therefore, hand stabilization while on one foot was used only for the 0H condition. This served to eliminate the weight transfer component of the test, as occurs when moving from bipedal to unipedal stance, during the 0H condition.

The order of testing was randomized. Subjects used the foot of choice given previous work by Bohannon et al [5], which found no side to side (left foot versus right foot) difference in UBT. Subjects were given 2 practice trials of 5 to 10 seconds for each ISW before the 3 data collection trials. A total of 1 to 2 minutes of rest was allowed as needed between testing conditions. Although it was not possible without high technology methods to quantitatively monitor the rate of transfer from bipedal to unipedal stance, an effort was made to prevent prolonged transfer times by requiring the achievement of unipedal stance within the cadence of a command. The examiner said, "Ready?" and upon receiving assent from the subject, gave the cadenced command, "One, two, up!" If the subject was unable to raise the nonstance limb, or in the case of the 0H condition the hands from the support surface, at the "Up!" command then the trial was considered a transfer failure and 0 seconds of UBT was recorded.

The inability to maintain unipedal balance for greater than 2 seconds under any condition was also considered a transfer failure, and 0 seconds of UBT was recorded. All subjects were tested in their bare feet in a clinic room that was well lit and had rectangular or square windows or picture frames on the walls for visual reference. Subjects maintained their lifted lower limb with the first metatarsophalangeal joint close to, but not touching, the stance medial malleolus. The posture was chosen because it mimics gait. UBT ended if the lifted foot touched the ground or the stance limb, the stance foot shifted of slid, or the maximum time of 30 seconds elapsed.

Statistical Analysis

The UBT means and ranges were determined for each subject's 3 trials under each ISW. The mean UBT was simply the average of the 3 trials at each ISW, and the UBT range for each subject was the difference between the briefest and longest trials at each ISW. These means and ranges were then compared by the use of a repeated measures analysis of variance procedure to model the within-subject effects of ISW on mean UBT (Hypothesis 1) and UBT range (Hypothesis 2). The model was also used to find significant between subject group (clinic versus healthy) differences in mean UBT (Hypothesis 3), and an ISW*subject group interaction term was used to identify group differences in the effect of ISW on UBT (Hypothesis 4). When significant effects were identified, post-hoc paired *t*-tests were used to compare within subjects variables whereas nonpaired *t*-tests were used to evaluate between group variables.

Chi-square analysis was used to analyze UBT as a dichotomous variable, defined as the ability to achieve 10 seconds in any trial in each ISW condition and group. Logistic regression was used to determine which of the different ISW UBT's most effectively distinguished between clinic and healthy subjects.

Power Considerations

In previous work, a 5-second difference in UBT distinguished between clinically important groups, such as older persons at increased and decreased fall risk without and with neuropathy [7,8]. Therefore assuming a 5-second difference in means from different ISWs, a standard deviation of 10 (obtained from previous work), and an alpha of 0.05, 33 subjects were needed to detect within subject differences in ISW with a power of 0.80.

RESULTS

Sixty-one subjects (31 clinic and 30 healthy) were recruited. Between-group demographic characteristics were not significantly different (Table 1). Consistent with Hypothesis 1, mean UBT significantly increased with decreasing ISW ($F = 13.3$; $P < .001$) (Table 2), and post-hoc analysis showed that the mean UBT differences were significant for all compari-

Table 1. *Subject demographic characteristics*

	All Subjects, n = 61	Clinic Subjects, n = 31	Healthy Subjects, n = 30	*P* Value
Gender, (%)				
Women	38 (63)	18 (58)	20 (67)	
Men	23 (37)	13 (42)	10 (33)	.488
Age, years	55.6 ± 16.1	58.5 ± 15.2	52.8 ± 16.9	.181
BMI, kg/m^2	27.9 ± 6.9	27.9 ± 6.6	27.8 ± 7.2	.965

BMI = body mass index.

Table 2. *Mean UBT for all, clinic, and control subjects for each ISW*

	Mean UBT (s) for Each ISW		
Subject Group	**0.3H ISW**	**0.05H ISW**	**0.0H ISW**
All (n = 61)*	14.7 ± 12.0	18.1 ± 11.1	19.6 ± 10.6
Clinic (n = 31)	9.0 ± 11.1	12.5 ± 9.7	14.8 ± 10.6
Control (n = 30)	20.7 ± 10.0	23.8 ± 9.4	24.4 ± 8.1

ISW = initial bipedal stance width; UBT = unipedal balance time.
*Post-hoc ISW comparison *P* values for all subjects: 0.3/0.05, $P = .003$; 0.3/0.0; $P = <.001$; 0.05/0.00, $P = .033$.

sons. In contrast, the data did not support Hypothesis 2 in that mean ranges of UBT did not decrease with decreasing ISW ($F = 1.46$; $P = .237$; Table 3). However, a significant interaction between subject group and mean UBT range was identified ($F = 4.85$; $P = .011$). Post-hoc analyses showed that the healthy subjects demonstrated a significantly decreased mean UBT range at the 0H ISW as compared with the 0.3H ISW ($P = .011$), and a trend toward a decrease at the 0.05H ISW as compared with the 0.3 H ISW ($P = .067$).

Hypothesis 3 was supported by the data as significant group differences in UBT were demonstrated at each ISW ($F = 22.5$; $P < .001$; Table 2). However, Hypothesis 4 was not confirmed because there was no significant interaction between subject group and UBT at different ISWs ($F = 0.69$; $P = .502$; Table 2).

The ability to maintain unipedal stance for at least 10 seconds in any trial under each of the 3 ISW conditions was evaluated, and there were significant differences in this ability between clinic and healthy subjects, particularly in the 0H and 0.3H ISWs. The latter was the best discriminator between clinic and healthy subjects, with 12 (38.7%) of 31 clinic subjects able to achieve 10 seconds of UBT at 0.3H ISW, and 28 of 30 (93.3%) healthy subjects able to do so ($P < .001$). When logistic regression was used to evaluate this measure in the presence of other variables, the ability to achieve 10 seconds of UBT at 0.3 ISW remained a significant predictor in the presence of mean UBT at all ISWs, whereas none of the mean UBT measures were significant in the presence of UBT of 10 seconds at the 0.3H ISW.

DISCUSSION

This study's main finding is that systematically increasing ISW significantly decreased UBT. This influence of ISW on UBT suggests that clinical unipedal balance testing should be considered 2 discrete tasks: (1) transfer of the center of mass from an inter-malleolar location during bipedal stance to a position over the stance foot; and (2) maintenance of the center of mass over the stance foot. Jonsson et al [16] performed a biomechanical analysis of older and younger persons who performed the unipedal stance and noted that the initial "postural adjusting component," which represents the transitional phase, should be separated from the maintenance phase, which the authors referred to as the "muscle component."

Recent doctoral work [17] has confirmed this impression and, further, clarified and extended the understanding of unipedal stance. The biomechanical analyses show that if the transfer of the center of mass over the stance limb is not performed within narrow bounds of velocity and location, then it will fail. The second task, maintenance of unipedal stance, appears to require precise distal somatosensory information [18,19] and rapidly available ankle strength [20], as well as more proximal strength at the hip and thigh [21,22]. It should be noted, however, that although UBT appears closely related to lower limb strength, strength is not consistently related to broader measures of balance which correlate more strongly with velocity, or power, of lower limb movement [23].

The within-subject range of UBT decreased in the healthy subjects as ISW decreased; however, this was not true for the clinic subjects or the group as a whole. This finding suggests that when comparing healthy subjects with a clinically impaired group, the use of a narrow ISW will likely reduce the spread of data within the former, which may sharpen group comparisons. However, the data also suggest that regardless of the technique used for determining UBT, the within-subject variability remains large for the clinic group. This feature renders clinical opinions obtained on the basis of UBT less than certain.

The findings also suggest that investigators and clinicians should standardize and report the ISW used when UBT results are reported. Such standardization may allow more consistent conclusions in the clinic and during research. For example, as pointed out by Jonsson et al [16], the highest score possible on the Berg Balance Scale [24] occurs with a UBT of 10 seconds, whereas Bohannon and Leary used 30 seconds [25], and Tinetti [26] and Vellas et al [7] used 5 seconds. Much of this variance is likely attributable to the different populations tested and the varied hypotheses investigators examined; however, it is likely that some portion of the variance was due to absence of between study standardization of ISW and/or rate of transfer from bipedal to unipedal stance.

Although this research does not definitively answer the question as to which ISW UBT is the most effective measure of functional balance, examination of the data suggests that

Table 3. *Means of subject ranges (seconds) of UBT for each ISW*

	Range of UBT for Each ISW		
Subject Group	**0.3H ISW**	**0.05H ISW**	**0.0H ISW**
All subjects (n = 61)	9.6 ± 12.1	8.4 ± 10.8	7.3 ± 9.1
Clinic (n = 31)	8.4 ± 11.7	10.9 ± 10.6	9.7 ± 9.3
Control (n = 30)	10.9 ± 12.5	5.7 ± 10.4	4.9 ± 8.5

ISW = initial bipedal stance width; UBT = unipedal balance time.

the answer may depend on the population being tested. For example, the best screening test for healthy patients appears to be testing the ability to maintain unipedal balance for >10 seconds from the 0.3H ISW. However this will be challenging for older and frailer patients, not all of whom fall or have significant disease. In such cases it is possible that UPBT measured from 0H ISW will allow discrimination between patients within such a group who have functionally relevant balance dysfunction and those who do not.

The strength of the conclusions obtained from this work must take into account its limitations. The numbers of subjects were adequate, as determined by the power analysis; however, the numbers were still relatively modest and so sampling error is clearly possible. The data were obtained by 2 of the investigators and by a physical therapist trained in research techniques, and the interrater reliability of these examiners was unknown. In addition, the examiners were not blinded to the hypotheses being tested and so the introduction of bias is possible. Finally, the subjects were tested without shoes and so it is possible that different results would be obtained if subjects wore their own shoes or if they all wore standardized shoes supplied by the research team.

Despite the study's limitations, it offers evidence that UBT is influenced by ISW. Therefore, clinicians and investigators should consider standardizing ISW, and making an effort to minimize between and within subject differences in rate of transfer from bipedal to unipedal stance. The data also suggest that varying UBT measurement technique based on the patient population and clinical concern may allow the test to be of greater utility. These last points are potential areas for continued research.

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