Evaluation of Great Toe Extension Strength Using a Novel Portable Device: A pilot cross-sectional study

R. Chandrashekhar[1], J. Zhang[2], H. Wang[1]

[1]University of Florida Department Occupational Therapy, [2]University of Florida Department of Biology

INTRODUCTION

One of the most crucial components of normal walking and balance under-researched is the strength and range of motion of the metatarsophalangeal joint (MTJ) or the great toe. [1–3] Great toe flexion and extension depicted in Fig. 1 represent the two movements involved in generating propulsion forces during walking and maintaining balance/stability of the foot during different phases of gait.[4–6] The great toe is also part of the first ray of the foot (a single functional unit of the foot consisting of the MTJ and cuneiform bones)[7], which is reported to bear 40-60% of an individual's body weight during the mid- and terminal stance phases of gait.[4,8,9] Researchers have reported a large degree of coactivation in the tibialis anterior (TA) with the flexor hallucis longus and brevis muscles, particularly during certain functional tasks related to balance, with.[10] These findings further corroborate studies reporting an association between great toe strength (GTS) and outcomes of functional mobility, balance, and gait.[11–14] Additionally, GTS is a potential clinical biomarker which could be used to evaluate the onset or progression of health conditions such as peripheral neuropathy or radiculopathy. [3,12,14,15] Despite this, GTS, particularly great toe extension strength (GTES), is often overlooked during routine physical checkups or clinical practice.[15]

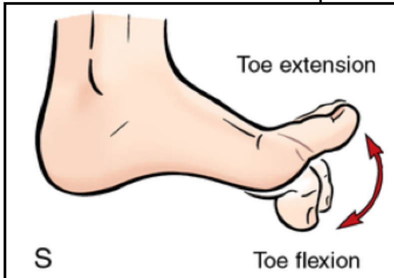


Figure 1. Great Toe Extension and Flexion

While different methods and technologies have been used to measure GTES (Figure 2(a)), such as manual muscle testing (MMT),[16,17] hand-held dynamometry,[18,19] custom devices developed in research labs,[20] and toe grip dynamometry,[13] the most commonly used clinical standard for muscle strength measurement is MMT. MMT involves the evaluator using their own internal "gauge" to monitor and evaluate the forces exerted by the participant/patient. Similarly, hand-held dynamometry is also affected by force exerted by the evaluator. Some studies have also raised concerns regarding the discriminant validity of MMT, particularly in the higher grades (Grades 3 to 5), where the sensitivity of MMT is inadequate to detect smaller changes in muscle strength. A pseudo ceiling effect could potentially limit the detection of smaller changes with clinical or research significance [21]. Although the existing methods have reasonable psychometric properties, multiple research groups have reported potential inaccuracies and errors due to the subjective nature of these methods.[13,18,19,22] To address the limitations of the existing technologies and methodologies, we developed a novel, portable device, ToeScale, to measure GTES and this device is shown in Figure 2(b).[23] The purpose of this study is to establish early validation of the GTES measure by determining the relationship between GTES measured via the ToeScale with grip strength (GS) and their variation with demographic variables such as age, sex, and body mass index (BMI).

Figure 2. (a) Left: Existing methods for measuring GTES (b) Right: ToeScale: A novel, portable device to measure GTS

METHODS

We conducted a pilot cross-sectional feasibility study with a convenience sample of young and older adults. This study was part of a course project, where no identifiable information was collected as per the University of Florida IRB waiver guidelines. The primary outcome measures evaluated in this study were peak GTES and GS. Peak GTES was measured using the ToeScale with the participant seated in a chair with their knee and ankle maintained at right angles as shown in Figure 2(b). GS was measured using the Jamar handgrip dynamometer following clinical standard procedure. The participants were first asked to provide demographic information and the international physical activity questionnaire – short form (IPAQ-SF), then given the handgrip dynamometer for GS, which was followed by the peak GTES measurement. Descriptive statistics, correlation analyses, and independent sample t-tests were applied for data analysis.

Table 1. Participant Demographics

Demographics	Total sample	Older Adults	Younger Adults	p-value
N (Males/Females)	31 (9/22)	17 (4/13)	14 (5/9)	
Weight (lb.)	143.97 (30.12)	149.71 (33.33)	137.00 (25.14)	0.079
Height (in)	65.66 (3.98)	65.79 (4.11)	65.5 (3.96)	0.55
BMI (Kg/m²)	23.34 (3.52)	24.09 (3.51)	22.43 (3.42)	0.194
Vigorous Physical Activity	43.23 (59.56)	21.18 (29.08)	70.00 (75.75)	0.015
Moderate Physical Activity	31.61 (57.45)	40.00 (70.45)	21.43 (36.13)	0.710
Total duration of Walking	48.55 (48.62)	42.65 (33.17)	55.71 (63.24)	0.922
Total duration of Sitting	381.68 (170.34)	397.06 (136.46)	363.00 (208.22)	0.086

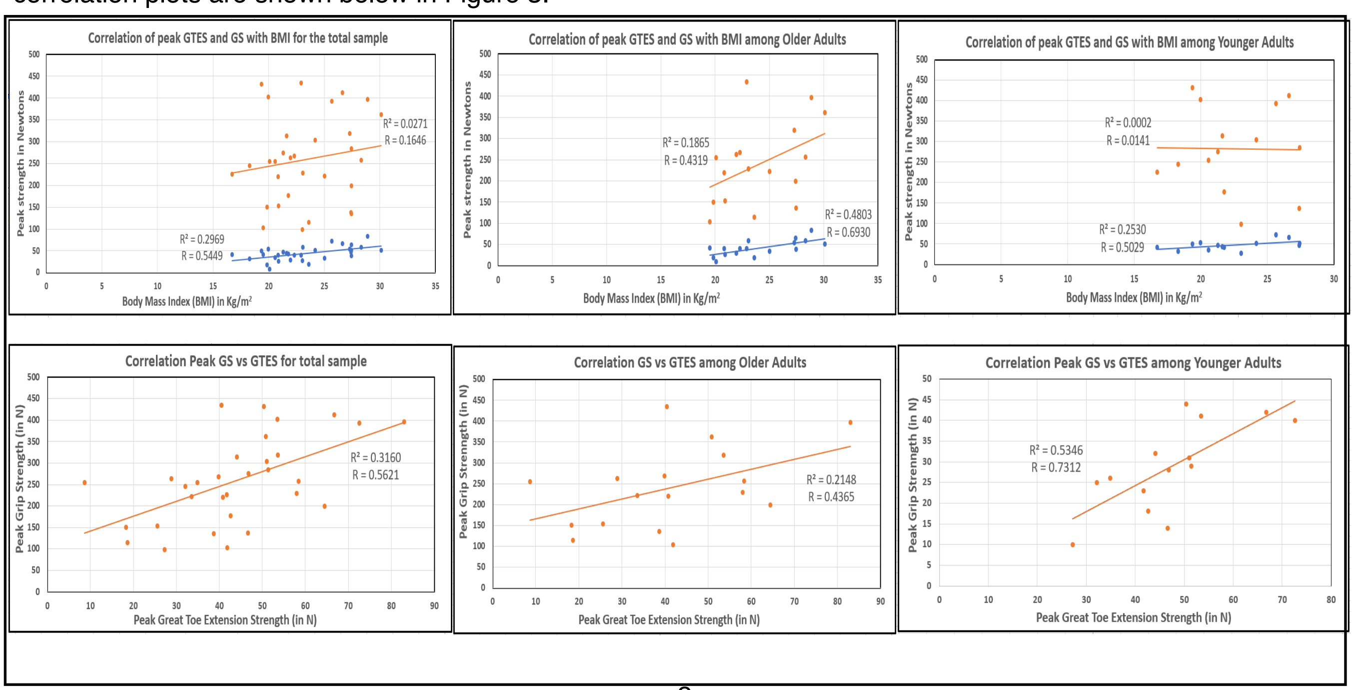
RESULTS

Thirty-one participants volunteered for this study and the demographics are summarized in Table 1 along with the average duration (in minutes) of different types of physical activity in a day during the week prior to the assessment. Large within-group variances were observed in the IPAQ-SF items for different physical activities and only significant difference was in the duration of vigorous physical activity item between the two age groups. The differences in peak GTES and GS by age and sex (Table 2) indicate that males had a statistically significantly higher peak GTES than females among the young (p =0.013) and older (p =0.038) adults. Younger adults had higher mean peak GTES (~5.88N) as well as higher GS (~42.39N) than older adults, neither was statistically significant.

Table 2. Variation of peak GTES and GS scores by age and sex

Outcome Measure/Group	Younger Adults	Older Adults
Peak Great Toe Extension Strength (peak GTES)		
Peak GTES (Total Sample)	47.27 (12.24)	41.38 (18.82)
Peak GTES (Males only)	57.47 (11.81)	58.08 (18.10)
Peak GTES (Females only)	41.60 (8.51)	36.25 (16.39)
Peak Grip Strength (peak GS)		
Peak GS (Total Sample)	282.39 (103.26)	239.99 (96.43)
Peak GS (Males only)	390.44 (45.17)	355.37 (89.58)
Peak GS (Females only)	222.36 (70.40)	204.50 (67.76)

The correlation analyses revealed that peak GTES had significant ($p<0.001$) moderate positive ($r = 0.562$) correlation with the GS for the total sample and significant ($p=0.003$) strong positive correlation ($r = 0.731$) with GS among the younger adults; The comparison between the correlation of GS and peak GTES with BMI showed little to no correlation between GS and BMI, whereas, peak GTES had significant ($p=0.004$) moderate positive correlation ($r = 0.506$) with BMI for the total sample as well as among older adults ($r = 0.598$, $p = 0.011$). The correlation plots are shown below in Figure 3.



DISCUSSION

The findings of this study indicate that peak GTES might vary based on gender and age and correlate with BMI more strongly than grip strength. Additionally, the correlation analyses of both primary outcomes with BMI revealed a stronger correlation of peak GTES with BMI than GS indicates that GTES could be a better predictor for functional mobility. The larger GTES variations among older adults were due to the different health conditions among the older adults. However, the ToeScale demonstrated good specificity to capture those differences. These findings are intriguing because, to the best of our knowledge, there are no known studies that have previously focused strictly on the relationship between GTES with BMI or GS. Muscle strength is a strong predictor of mobility limitation and GS is a well-established measure of overall muscle strength status that is widely used in clinical practice and it has also been used as an indicator of mobility limitation. [24,25] BMI and GS have both been associated with functional mobility, balance, and gait outcomes, where they have been used individually or in combination (using BMI to identify cut-off values/scores for GS), to determine mobility limitations, particularly among older adults.[26–28]

Although lower extremity muscle strength (LEMS) would potentially be more useful in predicting or identifying mobility limitations, GS is used because of its ease of use as existing methods for LEMS assessments are either time consuming, cumbersome, or require user effort. [29] The protocol presented in our study demonstrates the potential feasibility of LEMS assessment, particularly, the toe strength (flexion and extension). While GS is being used along with BMI as indicators of mobility limitations, there is ample evidence supporting the use of only BMI as a predictor of mobility limitation and other health conditions [30]; However, the findings from this study indicating a stronger correlation of BMI with GTES over GS indicates that GTES could potentially be a better indicator/predictor of mobility limitations and overall health, which can help in disease prevention.[6,9] While the results presented in this paper seem promising, future studies with larger samples and more methodological rigor are warranted. Furthermore, like BMI and GS, toe strength seems to decline with age and future research examining the relationship between toe strength and fall risks may contribute to new fall predictors. As the device is portable and convenient, it could be used for toe strength routine examination, which may help with early detection of aging-associated health conditions such as peripheral neuropathy. Additionally, identifying cut-off scores or normative values for GTES can be used to disease prevention.

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