THESIS

VALIDATION OF SMART DEVICE-BASED ASSESSMENT OF SIT-TO-STAND

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ABSTRACT

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The sit-to-stand (STS) field test provides a relatively crude (timed or counted) outcome measure when assessing daily functional activity and quality of life. Coupling the current STS test with commercially available mobile smart device applications that can sample, store, and wirelessly transmit data strengthen the test by adding speed, velocity, and potentially power through the built in IMU.

Expensive lab-based biomechanics equipment is required to obtain measures of leg power (LP) for individual repetitions during STS tasks. Modern smart devices are inexpensive, portable, user friendly, and contain sensitive inertial sensors that contain accelerometers and a gyroscope. The purpose of this study was to determine the ability of the smart device equipped IMU through the use of its gyroscope to detect movement across varying speeds, and make comparisons with an electro goniometer (eGONI) and force platform.

Forty-two young adults (22.9 ± 2.9 years) performed three trials of a modified STS, which included five fast STS repetitions followed by fifteen successively deliberate decelerated repetitions to mimic fatigue in the elderly. A 5th generation iPod Touch was firmly attached (Velcro) to a strap around the lower thigh. An eGONI (Biometrics) was placed laterally across the knee joint. The feet were on a force platform (AMTI Accusway) in front of the chair. Concurrently, iPod gyroscope data (rad), knee joint angle (rad), and ground reaction force (GRF, N) were sampled at 100Hz. The peak slope (0.1s time constant) of the iPod pitch signal, eGONI signal, and GRF was calculated for the rising phase of each rep. For each device, the max, min, and max-min across the 20 reps were calculated for the three trials. Correlations and Bland

Altman analyses were computed between the devices for all subjects combined and individually to assess R^2 distributions for all trials.

The iPod Touch versus the two devices aforementioned was highly correlated when comparing peak slopes of the devices output measures (rad/s, N/s). The iPod Touch measured angular speed similarly to the eGONI which is considered a gold standard found in research laboratories looking at the kinematics of joint movements. The force platform, which is a gold standard commonly used to measure muscular power peak slopes aligned with the iPod Touch's providing evidence the iPod Touch's metric of angular speed correlates with power though the devices are measuring different units. As measured with the iPod, min and max rising speeds are easily detected during the 20 STS fast to progressively slowing STS protocol. The iPod based gyroscope is sufficiently sensitive to detect differences in chair rising angular speed at the thigh and can replace an electronic goniometer and force plate for assessing slow and ballistic chair rising speeds.

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CHAPTER I - LITERATURE REVIEW

Introduction

The morbidity, reduced quality of life, and mortality associated with physical dysfunction and falls in older adults is a large and growing public health problem in the United States. In 2012, the CDC reported that over 3.2 million Americans 65+ years of age were treated for non-fatal injuries due to falls [1]. The impaired physical function and reduced mobility that accompanies sarcopenia and dynapenia exerts a large negative impact on quality of life [2-4], and the overall burden will grow with the doubling of the US elderly population by 2050 [5]. Accordingly, improving, or at minimum maintaining, mobility and physical function is key to quality of life for older adults [6,7]. Since 1985, and likely before, the sit-to-stand (aka chair rise) test has been used to measure physical function in the elderly. The test has been used across many different protocols such as the 5x, 10x, and 30 second STS tests. Subjects sit in a standard height chair, arms crossed, feet planted firmly on the floor in front of the chair and stand until knee extension is full, then return seated. This movement is repeated 5x, 10x, or as many times during a 30 second period as possible. Time and count are the current outcome metrics. Overall, the STS is a good test to assess daily function in the elderly due to greater muscle strength required than other daily activities such as walking, or climbing stairs [8].

Researchers have used the STS to measure function across a wide range of patient populations. For example in 2013 Slaughter et al. collected data in dementia patients who completed the sit-to-stand (STS) activity over the course of three months across two nursing homes. Using analysis of covariance and correlations the researchers were able to identify residents who performed the STS activity in their daily routine more versus those that completed it less frequently. The researchers concluded that performing the STS just twice daily can maintain and even improve mobility in the elderly [9]. In 2012, Barbat-Artigas and colleagues developed a new muscle quality index to assess functional status and used the chair stand test to estimate leg muscle power given its high correlation with daily function and independence [10]. In 2010, Morie and colleagues used the short physical performance battery (SPPB) which encompasses the chair rise test to test if performance measures of physical function were related to physical activity and found higher physical activity correlated with better physical function and mobility [11]. In 2010 Paterson and Warburton conducted a systematic review on the use of the STS and its correlation with physical activity and functional limitations in older adults which identified the use of STS in research over the last couple of decades emphasizing its importance in clinical research [12]. Therefore, the findings in this area indicate that high quality measures of leg movement can provide functionally important information for healthy or functionally disabled older adults as well as various clinical populations. Leg strength and increased leg power gives rise to higher quality of life in the elderly, allowing them to maintain their independence in daily functional activities [2-4].

Various STS protocols such as the 5x, 10x, 30-second, and even 1-minute test have been researched vigorously against gold standard devices to assess functional ability. For example, force platforms and the Nottingham power rig have been used to assess strength and power during the STS, while movement sensors and motion capture devices have captured the movement kinematics [13-34]. Timed or counted STS tests have been widely used as a surrogate of lower limb power because administration is simple, rapid, inexpensive, and does not require highly trained personnel [35, 36]. For example, Csuka and McCarty's primary research goal was to create an inexpensive, convenient timed test to assess functional lower limb function in older adults. By using the 10x STS protocol they compared knee extensor and flexor function measures on an isokinetic dynamometer, and found a highly correlated relationship with power data collected versus STS repetitions. From this comparison they derived predictive equations from time versus increasing age data to complete the 10x STS. They concluded the STS test was "simple, inexpensive, rapid and reproducible, lending itself to outpatient practice [37]." These studies led many researchers to conclude the STS could be used as a standard when measuring leg power, however Hardy (2010) et al found that power cannot be accurately calculated based on time and count alone. His team used leg extensor power (LEP) obtained from a Nottingham Power Rig and found though high correlations exist between STS and power calculated there are more variables to consider when measuring chair rise performance. For example, when standing from a chair good balance and coordination are needed for repeated chair stands that contribute to the overall time in count in the current STS methodology [38]. Lord (2002) et al earlier study agreed with Hardy's performance concerns on the STS, stating sensation, speed, balance, and psychological issues in addition to strength contributes to STS performance [39].

In 2010 Smith and research team used more advanced technology such as video kinematics and force plates to develop similar predictive equations to quantify lower extremity power similar to the Csuka's 1985 study [40]. In 1994, Guralnick and colleagues used the STS in addition to other functional tests to determine performance measures in three older communities with the goal of using the performance measures to predict death and nursing home admission. The 5x STS method, balance test, and time to walk eight feet were used to determine lower extremity functionality and was completed on an in home assessment basis with instructions delivered through video. Lower test scores on three tasks related to daily function was associated with higher chances of nursing home admissions and deaths. [41] This study sought to use the

STS in a home setting to collect data quickly, however as with Csuka and McCarty's study, more error may have been introduced by allowing patients to time themselves [42]. In 1999, Jones and team at Cal-State Fullerton used the 30sec STS compared to two leg maximal press test (Keiser Leg Press) and concluded it has good stability and reliability, supporting the use of the STS to measure lower body strength. These researchers went on to emphasize the potential of the 30sec STS for measuring across a wide range of function, from those able to stand only once to others with the strength and power to stand more than 20 times during a 30 second period making it a solid clinical research test of lower extremity power [43].

STS measures have been used in lieu of the strength devices due to high correlations found in studies like Csuka and McCarty's, as previously mentioned. Its use in clinical settings to monitor muscular disease progression and research lower extremity strength and endurance provides easy data collection with count and time, however time and count alone do not quantify lower extremity strength. Pao-Tsai Cheng's 1998 study used the STS and force plates to quantify the rate of rise in force in stroke patients to predict falling. They concluded that a significant lower rate of rise in force and greater postural sway while rising and sitting down could not be accurately quantified without the calculation of power [44]. In 2003, Lindemann compared the Nottingham Power Rig to the 5x STS while standing on force plates. He concluded the STS showed good correlation to isokinetic force measurement, however when correlated with the 5x STS rise time it was extremely poor, indicating not all STS protocols are adequate in measuring lower extremity power [45]. A follow up study in 2007 used the STS and force plates to quantify the strength needed across the phases of the sit-to-stand movement [46]. The quantification of power to differentiate the phases of the STS movement proved more valuable than just time and counting of repetitions [47]. In 1999, Hirschfeld and team used force plates and video technology to quantify the coordinated ground forces needed to identify weight transfer during the STS. The researchers concluded that the weight transfer during the STS is controlled during both seat-off and during deceleration of the center of mass back to the seat [48]. Similar to measuring the phases of power transfer, Papa subsequently investigated the differences in young and elderly subjects' strategies during the STS and identified significant differences in strategies used during rates of rise from the seated position. The elderly adults' altered strategy during the rise phase when fatigued versus the young individuals discredited the time and count metrics currently used during the STS. Findings like these emphasize the need to quantify the power used to stand, as individual variability is present and should be taken into account [49]. Cheng's 2014 study of falls and STS performance also utilized force plates to measure lower limb muscle power and concluded only muscle power and the STS stabilization phase could differentiate between individuals. Cheng provides further evidence that individual subjects' power quantification during the STS is needed to validate its use to predict falls [50]. In 2015 Zanini researched COPD patients' lower extremity muscle strength using the 30s STS and the a 1-minute STS, comparing it to a one-repetition maximum effort on a leg press and found correlations of (R^2 = 0.48) and (R^2 = 0.36) respectively. He went on to further conclude that the timed STS is a valid and reliable tool to assess muscle performance in lower limbs and can be used in COPD pulmonary rehabilitation protocols, but that actual measurement of power would enhance the validity of the STS [51]. However useful in the field setting, the timed/counted STS tests are limited in that they provide a relatively crude reflection of leg power. For example, the rising phase of the STS is the critical limiting phase for older adults, but the simple timed STS includes time devoted to rising, standing, lowering down, and sitting, and also can include an unknown amount of administrator start and stop time variability, an idea reflected by Guralnick and colleagues in 1995 [52]. The notion that rate of force development and rising power are not precisely reflected in the typical timed test was confirmed by Hardy et al who compared the 10x STS time and leg extensor power assessed via the Nottingham power rig [53]. They concluded that the total STS time should not be thought of purely as a proxy measure of leg power. Furthermore, in 2002 Lord et al. corroborated Hardy’s notion that the STS should not be a proxy of lower limb strength due to its performance being influenced by multiple physiological and psychological processes, suggesting it as a transfer skill and not a direct measure of power [54]. With decades of research pertaining to the STS, it is clear that the lower extremity power measures for young, middle aged, and the elderly should be as quantitative as they can be to improve precision and justify its use. The ground reaction forces measured in the STS movement by a force platform reflects lower limb extremity strength and power according to a study by Tsuji et al [55]. Lindemann et al (2003) used the Nottingham power rig to collect one-rep max leg power and compared it to 30 second STS. His team estimated lower extremity power for the STS by using the force applied to the force platform (here the body weight), and the distance between seated and standing position, and the time it took to rise from the chair. They found a high correlation of force production for the force platform to that of the estimated power needed to rise from a chair. The ground reaction force (GRF) therefore could be used as a proxy to estimate power in the STS movement [18]. Cerrito et al (2015) used the same formula [(Power = Force (body weight) * Distance (Seated to Standing) * Time (Time of rise phase)] to validate a smart device to estimate power when placing the device on the sternum and lower back of healthy seniors [30]. By adding power to this functional test, individual lower extremity power provides more meaningful data relevant to the individual allowing for altered treatment to improve daily function and ultimately provide a higher quality of life.

Quantitative measures of lower extremity power usually involve equipment that is research lab-based, expensive, and requires highly trained personnel. These requirements can reduce investigator accessibility, limit widespread application to larger subject populations in the community, and impede the study of many clinical populations. A more portable, economical, and user-friendly tool for STS assessment could provide flexibility of assessment location and increase access to accurate, quantitative outcomes. For example, portable, inexpensive quantitative measurement tools would eliminate the need for subject travel and expand opportunities for field data collection at care facilities, hospitals, medical clinics, and training/rehabilitation facilities. With the advent of measurement technology miniaturization (accelerometers and gyroscopes) and wireless data transmission, researchers have explored their utility in quantifying biomechanical parameters.

Validation of Inertial Units (IU) versus standard laboratory equipment

In 2008 Galli et al. researched the STS movement in healthy control subjects compared to hemiplegic subjects using an 8-camera optoelectronic system for kinematic evaluation, two force platforms for calculation of kinetic outcomes, pressure switches on the seat to assess time of contacts. The more sophisticated measurement was able to detect differences in time across the phases of the STS between groups. Galli's data concluded significant differences in the preparation phase, ascending phase or rising phase, and total time of the STS movement. In addition to the time data, significance differences were identified in the maximal vertical forces (N/kg) across both groups and even in the asymmetry of the hemiplegic subjects' lower appendages [56].

Because abnormal pelvic movement is correlated with a higher prevalence of falls, in 2011 Ishigaki used an IMU to determine pelvic movement during walking. By placing the device on the lumbar region of the back and measuring angle change, angular velocity, and acceleration they were able to detect significant differences in their young and old groups muscular strength, length of body sway, area of body sway and walking time [57].

In 2011, Wagenaar created a functional activity monitor (FAM) to be worn on the sternum and hips, comprised of a tri-axial accelerometer and gyroscope. His algorithms were able to detect walking, lying down, and transfer functions 100% of the time and 98% of the time could detect both sit-to-stand and stand-to-sit movements. He validated his FAM with motion capture technology, suggesting that if the algorithms are sufficient and can detect functional movements it is possible to do so with other accelerometer/gyroscope devices [58].

In 2013, Millor and team used an inertial unit (IU) placed on the lower lumbar (L3) to measure acceleration and orientation during the 30sec STS. An IU was used to quantify the chair stand for detection of frailty in older adults. They concluded that IU's can enhance the information gained from relatively crude functional tests like the STS often used in clinical practice. This generally supported the idea of more precisely quantifying the STS outcome measures using accelerometer and gyroscope devices [59].

Validation of linear encoder based device versus standard laboratory equipment

In 2014, Gray used the 10x STS protocol to compare the Tendo power measurement device with the movement captured by a 2D motion analysis system (COM). Data measured by the Tendo was 5.34 +/ 1.67 watts/kilogram while the COM was 5.39 +/ 1.73 watts/kilogram indicating no differences between devices. Results concluded the Tendo, which attaches to the belt of the participant, was a valid and reliable method for determining muscular power during STS. These findings suggested yet another alternative to assess power during a STS protocol [60].

In 2015 Lindemann continued his research on quantification when he compared results taken from the linear encoder-based device with power measured via the Nottingham Power Rig, concluding a power measurement during the STS could be used in routine clinical practice as well as in large scale studies [61].

In 2014, Regterschot used a Philips hybrid motion sensor that housed a 3D accelerometer to measure accelerations, a 3D gyroscope to measure angular velocities, and a 3D magnetometer to measure orientation in the Earth's magnetic field. The researchers concluded the device was sensitive enough to measure changes in STS speeds during normal and fast STS kinematic movements [62].

Wei Zhang has extensively researched pendant-worn sensor devices measuring chair rise performance. The pendant houses a match-box size hybrid motion sensor with a 3D accelerometer that collects data at 50 Hz that is allowed to float freely on a necklace underneath shirts of subjects. He tested the reliability of the pendant in a lab based study in 2014 and eventually during daily living in 2017 at subjects' residences. First in 2014, he assessed the test-retest reliability and the feasibility of pendant sensor-measured chair rise performance during daily living. The data indicated high levels of agreement between repeated measurements. Three years later his team published his findings on pendant sensors in an assisted living population, finding that peak chair rise power during daily living was better correlated with clinical outcomes than the previously used standardized tests [62-64].

Validation of smartphone sensor versus standard laboratory equipment

It is evident that sophisticated measurement devices such as accelerometers, gyroscopes, and inertial sensors that house both types of sensors are adequate for measuring power, but cheaper more accessible alternatives are important to increase the ability to accurately measure power in the field. Therefore, the present study and a few previous studies have focused on utilizing the gyroscopes present in smart devices to increase a widespread power testing in real life settings.

In 2014 Patterson et al compared the iPod with a Biodex Balance System SD during a static single leg balance test. He concluded there were no significant differences between the balance scores produced by the balance platform (1.41 +/- 0.9) and the iPod's tri-axial accelerometer (1.38 +/- 0.72). He went on to state that the iPod could be used in lieu of the research grade device, making these devices a cost effective, user friendly alternative [65].

Expanding beyond static balance to mobility, Galan-Mercant et. al. (2014) used an iPhone 4 to measure the kinematic patterns in a "timed up and go" test (TUG). Breaking the TUG into phases, the researchers ran correlations on the different phases. The sit-to-stand sub-phase, the portion related to the rate of force development or power, was of primary interest and was correlated between the iPhone 4 and Inertialcube3 with R^2 values between 0.84 to 0.99. The researchers stated that the inertial sensor mounted in the iPhone 4 is sufficiently reliable and accurate to evaluate the TUG test, however the analysis and interpretation of the kinematics of the TUG was dauntingly complex [66].

In 2015, Kosse et al. published a validation and reliability study proving the use of an iPod Touch's accelerometer versus a stand-alone accelerometer for use in assessing gait and postural control. The researchers concluded the pattern of time series of the anterior-posterior and medio-lateral accelerations of the two devices had high cross correlations ($R^2 > 0.90$) of the two signals. This was verified further with the use of Bland Altman plots, which showed very low measurement error and small limits of agreement, proving the use of the iPod sensors for gait and postural measurement [67].

The same year Cerrito used an Android-based smartphone on the lower back and sternum with the feet on two force plates to validate the use of the device to measure power. Vertical ground reaction forces (VGRF) and vertical acceleration (VAcc) were recorded simultaneously. The researchers concluded the sternal placement had high correlations ($R^2 = 0.86+$) to total time and max force, providing evidence that the concept of using built in accelerometers can be used to quantify parameters of the sit-to-stand movement [68].

In 2016, Lee et al. validated the use of a smartphone application in an iPod Touch designed to quantify the MDS-UPDRS motor assessment two-target tapping test in Parkinson’s patients. Moderate to strong correlations ($R^2 = 0.34$ to 0.73) were found with the two-target tapping test, concluding the application demonstrated satisfactory repeatability and validity when quantifying hand dexterity [69].

Summary

In summary, it appears that the research community has recognized the potential value of the smartphone as a movement sensing platform, and the data thus far suggest that physical function can be measured using such devices. Compared with some of the previously mentioned mobile measurement technologies, the smartphone could be advantageous in terms of cost, ease of use by non-experts, and data transmission.

The modern smartphone and data collection applications (apps) provide a method for quantitative measurement that is easy to implement, inexpensive, and does not require highly trained research personnel. For example, the iPod Touch contains sensitive tri-axial accelerometer and gyroscopic sensors that can measure linear movement of body segments or rotation of limb segments. Properly applied, the smartphone gyroscope can measure speed of angular movement directly and more precisely than simple timed tests of physical function. The tests could be performed relatively easily, quickly, and in the field. The data can be collected remotely and transmitted wirelessly to lab-based computers for subsequent analysis.

The overall purpose of this study was to assess the ability of the iPod Touch to measure lower extremity movement during the STS task performed across a large range of speeds, compared with an electronic goniometer and force platform. The general expectation was that the speed of thigh tilt measured by the iPod Touch would be correlated with the knee rotation measured by the goniometer and the vertical ground reaction forces from the force platform.

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CHAPTER II – MANUSCRIPT

Introduction

The morbidity, reduced quality of life, and mortality associated with physical dysfunction and falls in older adults is a large and growing public health problem in the United States. In 2012, the CDC reported that over 3.2 million Americans 65+ years of age were treated for non-fatal injuries due to falls [1] The impaired physical function and reduced mobility that accompanies sarcopenia and dynapenia exerts a large negative impact on quality of life [2], and the overall burden will most likely grow with the doubling of the US elderly population by 2050 [3,4,5]. Accordingly, improving, or at minimum maintaining, mobility and physical function is key to quality of life for older adults [6,7]. Researchers such as Bassey (1992), Skelton (1994), and Jones (1998) all found positive correlations between lower extremity strength or power and related functional ability via tests such as the chair rise or sit-to-stand test (STS) [8,9,10]. Therefore, high quality, quantitative movement measures that can be incorporated into calculation of leg power can provide functionally important information for healthy or functionally disabled older adults as well as various clinical populations.

Various STS protocols such as the 5x, 10x, 30-second, and even 1-minute test have been researched vigorously against gold standard devices to assess functional ability. For example, force platforms and the Nottingham power rig have been used to assess strength and power during the STS, while movement sensors and motion capture devices have researched the kinematics [11-32]. Studies that involve STS could benefit from more quantitative outcome measures compared with the relatively crude timed or counted outcomes. Timed STS tests have been widely used as a surrogate of lower limb strength and power measures because administration is simple, rapid, inexpensive, and does not require highly trained personnel. However useful in the field setting, these tests are limited in that they provide a relatively crude reflection of leg power. For example, the rising phase of the STS is the critical limiting phase for older adults, but the simple timed STS includes time devoted to rising, standing, lowering down, and sitting, and also includes an unknown amount of administrator start and stop time variability. The notion that rate of force development and rising power are not precisely reflected in the typical timed test was confirmed by Hardy et al who compared the 10x STS time and leg extensor power assessed via the Nottingham power rig. They concluded that the total STS time should not be thought of purely as a proxy measure of leg power [33].

Quantitative measures of lower extremity leg speed and power usually involves equipment that is university research lab-based, expensive, and requires highly trained personnel. These requirements reduce investigator accessibility, limit widespread application to larger subject populations, and can impede the study of many clinical populations. A more portable, economical tool for STS assessment could provide flexibility of assessment location and increase access too accurate, quantitative outcomes. Portable, inexpensive quantitative measurement tools would eliminate the need for subject travel and expand the opportunities for field data collection at care facilities, hospitals, medical clinics, and training facilities.

The miniaturization of sensors has led to their use for research in many different laboratories assessing human movement. For example, Cutti (2008) used inertial and magnetic measurement systems (IMMS), specifically the MT9B by Xsens to measure shoulder and elbow kinematics and concluded high r-squared values validating the systems use for human movement assessment [34]. Two years later Saber-Sheikh et al conducted a feasibility to assess inertial sensors (Xsens products) versus an electromagnetic motion tracking system and concluded the

Xsens products were in good agreement with current research devices and could be used for human research [35]. In 2011, Chung et al validated the Vicon Motion Analysis system versus the Xsens sensors when analyzing upper limb kinematics [36]. The Xsens products have become a gold standard in measuring human movement. Given the price of sensors have dropped significantly the devices have found their way into smart devices such as iPhones, iPods, and other Android related products. Given the same type of sensors are in these mobile devices Mourcou et al (2015) used a robotic arm to assess the Xsens against sensors found in an iPhone 4, 5s, and Samsung Galaxy Nexus and concluded the IMU's found in such devices worthy of human movement research when compared against the industries gold standard Xsens products [37].

The modern smart device and data collection applications (apps) provide a method for quantitative measurement that is easy to implement, inexpensive, and does not require highly trained research personnel. For example, the iPod Touch contains sensitive IMUs that can measure movement of limb segments. Properly applied, the smart device gyroscope can measure speed of movement directly and more precisely than the simple timed test, in the field, with minimal difficulty and time burden. Data can be collected remotely and transmitted wirelessly for subsequent analysis.

The purpose of this study was to assess the ability of the iPod Touch to measure lower extremity movement during the STS task performed across a large range of speeds, against an electronic goniometer and force platform. The expectation was that the speed of thigh tilt measured by the iPod Touch would be highly correlated with the knee rotation measured by the goniometer and the vertical ground reaction forces from the force platform.

Methods and Procedures

Participants

A convenience sample of young, healthy adults (N=42, 22.9 ± 2.9 years, 21 male, 21 female) were recruited via word of mouth. They reported moderate to high physical activity levels and did not report health problems or medications that could affect the measures. They were oriented to the study and provided written informed consent. The procedures were approved by the Colorado State University Human Subjects Committee.

Experimental Design

The goal of the investigation was to compare values obtained from the different devices. The goal of the protocol was to obtain a large number of STS movements across a wide range of speeds, in order to 1) simulate the effects of fatigue or aging on chair rise speed, and 2) capture the performance of the devices across a large range of human performance. During the single experimental visit, three trials of 20 sit-to-stand movements were performed with 2-3 minutes rest between trials. Careful attention was paid to standardized form: 1) arms folded across the chest, 2) feet at a comfortable self-chosen width that remained constant for the duration of the protocol, 3) no part of the foot visibly left the ground even for the fast movements, 4) return to full seated position in the chair after each repetition. Subjects were instructed to begin with five repetitions at their maximal speed, and then to incrementally and progressively reduce their STS speed over the remaining 15 repetitions such that by the 20th repetition they were moving "very slowly". The speeds and change in speeds were therefore unique to each participant. The result for a particular trial from an individual was a wide range of self-selected speeds rather than specifically dictated speeds or a prescribed range of speeds (Figure 1A).

Equipment

A rigid chair with a 42cm seat height was used. The starting knee angle was measured by manual goniometer and was adjusted to 90±3 degrees by placing hard rubber mats under the chair (for taller people) or under the force platform (for shorter people). Data was recorded simultaneously from an iPod Touch, electronic goniometer, and force platform during all tasks.

Using a heavy duty elastic strap around the distal thigh, a 5th generation iPod Touch (Apple, Inc.) was firmly attached with Velcro to the lateral side of the left thigh, 2/3 of the distance between the greater trochanter and the center of knee rotation. A data collection App was used (Sensor Data, Wavefront Labs) to record the pitch, roll, yaw, and XYZ acceleration values from the onboard sensors at 100 samples/s. The pitch signal represented the change in thigh tilt during the STS movement and was the measurement used. The device was used while in airplane mode to avoid outside wireless communication and dedicate the processor to data collection. The data was saved on the device as a text file and transferred wirelessly to computer for analysis.

An electronic goniometer (eGONI) was attached on the lateral side of the knee joint according to the manufacturer's instructions (Model Type R3000, Biometrics). The knee angle data was digitized at 100 samples/s and recorded on computer (1401 A/D device, Spike 2 ver. 7 software, Cambridge Electronic Design, UK).

A force platform (Accusway, AMTI), placed in front of the chair, was used to acquire the ground reaction forces (GRF) from the feet. Data was recorded at 100 samples/s and stored on computer. The vertical GRF was used in this analysis.

The signals from the three separate devices were time-aligned using a sharp tap that was applied to the iPod and force platform at the same moment as the keystroke that initiated data acquisition for the goniometer. This mechanical event occurred 2-3s before the task began. The mechanical artifact was used to import all three signals, time-aligned, into the same data file in Spike 2 software (Figure 1A).

Measurements

The pitch signal from the iPod represents the angular rotation of the thigh in the sagittal plane. The slope of the iPod pitch signal, the eGONI signal, and the vertical GRF signal was calculated over a 0.1s time period, data point by data point, using the slope calculation in the Channel Process function in the Spike 2 software (Figure 1A, B). The processing produced a new slope channel for each device in Spike 2 from the processing. The rising phase of the STS was readily manually identified from the pitch signal and the peak value of the slope signal was calculated from the three processed slope channels for the rising phase of each individual STS repetition. Further justification for using the peak slopes of GRF and movement to validate the devices comes from Lindemann's (2003) analysis in which they evaluated the slope of the rate of force development between 20% and 90% of body weight during the preparatory/rising phase [46].

For all of the peak slope values from each repetition, the maximum (MAX), minimum (MIN), and difference in peak slope between the fastest and slowest repetition (MAX-MIN) was calculated from each trial of 20 repetitions. All data was analyzed using manual interaction with the Spike 2 software.

Statistical Analysis

The overall analytic goal was to assess the degree to which the STS speed outcomes measured from each device agreed with each other. By design, each trial of 20 repetitions from each subject produced a unique range of speeds from maximal speed to very slow (Figure 2A). Furthermore, the changes in speed between each adjoining pair of repetitions were unique to that subject.

Thus, we first assessed the extent to which the values were correlated between devices, across the range of speeds produced within trials for individual subjects. Prior to analysis, the peak slope values for each of the 20 repetitions in a trial were converted into Z-scores around the mean peak slope value for that trial. The rationale for this strategy is threefold: 1) different units of measurement were produced from the iPod (thigh tilt in rad), eGONI (knee angle in rad), and force platform (vertical GRF in N), 2) each subject produced a different range of speed values from the fastest to the slowest repetition for a particular trial of 20 repetitions, and 3) each subject produced their own unique decrements in speed between subsequent repetitions. The Z-score strategy removed the units of measure and converted the value to a standardized value around the mean for that trial, which allowed a simple and more robust comparison between devices.

First, simple regressions were calculated for each trial of 20 repetitions to obtain an R^2 value for the relation between the peak slope values for the iPod vs. eGONI and iPod vs. Force platform comparisons, across the range of speeds produced for that 20 repetition trial (Figure 3). The peak slope values were then pooled across trials and subjects and the relation between the devices (iPod vs. eGONI, iPod vs. Force platform) was calculated on the pooled data. Histograms were constructed to examine the distribution of trial-specific R^2 values calculated for both iPod vs. eGONI and iPod vs. Force platform regressions (Figure 4). The purpose was to examine the number of R^2 values that were 0.7, 0.8, or 0.9 and above, so as quantify the prevalence of medium or strong correlations between devices at the level of the individual participant's trial.

In order to assess the relation between the devices with particular regard to the absolute agreement of the values, concordance correlation coefficients [38,39] were calculated between the iPod and eGONI and between the iPod and Force platform.

Agreement between devices was also assessed using Bland Altman plots and limits of agreement calculations [40-42]. Plots were constructed of the between-device differences vs. mean of the devices and calculations performed for iPod vs. eGONI and for iPod vs. Force platform.

Results

Qualitative comparisons of original data between devices

An examination of the original data traces (Figure 1A) from the iPod and eGONI reveals clear qualitative similarity between the knee angle changes from the eGONI compared with the gyroscope data from the iPod. The original data traces appear to be tracking knee angle (eGONI) and thigh tilt (iPod) in real time though measuring from slightly different anatomical positions. This similarity is also evident for the rotation rate traces obtained from the eGONI compared with the iPod. For example, the decline in the peak rising phase rotation rate from the individual repetitions across the 20 descending-speed repetitions is clear and very similar for both devices (Figure 1A). This natural qualitative comparison is not possible for the GRF data from the force platform because of the different profile of the raw data. Nonetheless, the visually observed similarity in time of occurrence for the 0.1s-calculated peak slope value from the iPod, goniometer, and GRF suggests the devices are producing similar outcomes despite the differences in signals.

Correlations (association) between devices for individual participants

For the iPod vs. eGONI, simple between-device correlations of peak rotation rate, across the range of speeds, for individual subjects, revealed consistently high coefficients of determination (R^2 values) (Figures 3A,B, 4A). This set of R^2 values came from 126 correlations, one per trial of 20 repetitions (42 subjects x three trials). One trial of 20 reps was removed due to technical problems and four trials of (iPod vs. eGONI) and six trials of (iPod vs. Force Platform) with R^2 values greater than three standard deviations from the mean were also removed, leaving 121 (iPod vs. eGONI) and 119 (iPod vs. Force Platform) of trials of 20 repetitions in the analysis. The mean R^2 value was 0.95 ± 0.057 for iPod vs. eGONI. Although the range of R^2 values was 0.65 to 0.99, the distribution of values was strongly positively distributed toward the high end, with 98.4% over 0.7, 96.8% over 0.8, and 88.7% over 0.9 (Figure 4A). The mean R^2 values for iPod vs. Force Platform was 0.88 ± 0.079, with R^2 values that ranged from 0.54 to 0.98. Similarly, the R^2 values for the iPod vs. Force Platform correlations were still strongly positively distributed above the > 0.7 range, although not as strongly, with 96% above 0.7, 85.7% above 0.8, and 47.6% above 0.9 (Figure 4B).

Correlations (associations) between devices for the pooled values

When the Z-score values across 42 subjects, three trials, and 20 repetitions were pooled (N=2,520 repetitions), the R^2 value was 0.98 for the iPod vs. eGONI (Figure 5A), and 0.94 for the iPod vs. Force Platform (Figure 5B). The standard error of the estimate (SEE) for the prediction provided by the iPod vs. eGONI was 0.207 Z-scores. The SEE for the iPod vs. Force Platform prediction was 0.343 Z-scores.

Correlations (associations) between devices for max speed, min speed, and change in speed

To determine the ability of the iPod to detect specific outcome parameters, the minimum, maximum, and maximum-minimum rotation rate was extracted from each trial of 20 repetitions. Correlations and SEE values between the iPod and eGONI were $R^2 = 0.83$ and SEE = 0.149 for the minimum value (Figure 6A), $R^2 = 0.78$ and SEE = 0.239 for the maximum value (Figure 7A), and $R^2 = 0.78$ and SEE = 0.344 for the max-min value (Figure 8A). The correlations and SEE values between the iPod and Force Platform were $R^2 = 0.46$ and SEE = 700 for the minimum value (Figure 6B), $R^2 = 0.33$ and SEE = 1223 for the maximum value (Figure 7B), and $R^2 = 0.51$ and SEE = 1113 for the max-min value (Figure 8B).

Agreement between devices

Simple bivariate correlation or regression can provide a measure of association but not of numerical agreement between sets of values. To quantify agreement of the Z-scores between devices, the concordance correlation coefficient (CCC) [38] was calculated on the pooled values from all of the repetitions. The value of the CCC describes the extent to which the relation deviates away from a 1:1 slope (perfect agreement). For the pooled set of values, the CCC suggested strong agreement; 0.98 for the peak rotation rate values for the iPod vs. eGONI and 0.94 for the peak rotation rate values from the iPod vs. the peak GRF slope from the force platform.

Limits of agreement analysis

The Bland-Altman limits of agreement analysis, performed on the pooled set of Z-score values across trials and repetitions, yielded values that also suggest good agreement between the different devices (Figure 9A,B). For the peak rotation rate from the iPod vs. eGONI, the bias, or mean difference between the Z-scores from the different devices, was -0.0027 Z-score units. The

95% confidence intervals (limits of agreement) around the mean difference were ± 0.406. For the peak rotation rate from the iPod vs. the peak slope of the GRF values from the force platform, the bias was 0.0001 Z-score units and the limits of agreement were ± 0.684 Z-score units around the mean difference.

Discussion

The overall purpose of this study was to compare measures of movement speed and rate of force development during the rising phase of the sit-to-stand movement between a smart device, electronic goniometer, and force platform. Movements were deliberately performed across a large range of speeds, from maximal to very slow. The main qualitative observation was the remarkable similarity in the original data traces between the iPod Touch and the goniometer (Figure 1A/B). The major quantitative findings were 1) the measure of peak knee rotation rate was highly correlated between the iPod Touch and an electronic goniometer (Figure 5A), 2) the measure of peak knee rotation rate from the iPod Touch was strongly correlated with the peak slope of the vertical ground reaction force (GRF) (Figure 5B), 3) for single repetitions, specific performance parameters such as the maximum speed, minimum speed, and the max-min (the change in speed from the fastest to slowest repetition) was strongly correlated between the iPod Touch and goniometer, and moderately correlated between the iPod Touch and the peak slope of the vertical GRF of the force platform (Figures 6,7,8).

The observation of similarity of the data traces from the iPod Touch gyroscope and the electronic goniometer across subjects suggests congruency in mechanical output between the two devices (Figure 1A). From a biomechanical perspective, the iPod gyroscope measures thigh tilt and the goniometer measures knee joint angle. With the foot planted during the rising phase, thigh tilt changes directly with knee angle. Slight non-linearities in this relation would be introduced by sagittal plane ankle rotation and slight fore-aft shifts in the position of the knee joint during the rise phase [43-45]. Regardless of the small biomechanical difference between the two signals, the thigh tilt mirrors the knee angle. For the force platform, the profile of the vertical GRF slope vs. iPod Touch and goniometer slope are naturally different because the force platform measures rate of vertical force application (N/s) instead of limb movement (radians/second) (Figure 1A). Nonetheless, the rising phase peaks in the vertical GRF slope traces can still be readily observed to decline across the range of speeds with a similar pattern of decline across the force platform, goniometer, and iPod Touch (Figures 1A, 2A,B).

The limitations of timed STS tests

The ease, speed, and low cost of the traditional timed methods of STS assessment makes them useful for field-based or large scale studies – many tests can be performed in a short time in non-laboratory settings. The tests are understandably useful for investigators who lack access to lab-based equipment. However, the weaknesses of crude timed or counted assessments is readily apparent.

One of the major weaknesses is a reduced ability to measure specific, key features of a functionally important movement. For example, we performed an ancillary analysis of 5x STS data from ten young healthy subjects in our lab. From knee rotation data from a thigh-placed iPod, we measured the total time for the five repetition task (as is commonly performed). Also, the times of just the rising phases were measured and summed. For these young subjects, an average of only 41% (range 35-45%) of the total task time was spent in the rising phase of the STS movement, which agrees with Lindemann's 2003 finding that 38% of the total task time was spent in rising [46]. This leaves ~55-65% of the total 5x task time spent in sitting, standing, and lowering. A large proportion of the total time of a typical STS assessment is therefore devoted to phases unimportant to the most important functional goal of the STS, successful rising, which requires power over a certain threshold. This notion underscores the importance of obtaining actual measures of STS speed when possible. Other sources of error, such as timing variability between technicians or counting errors, can also contribute to lack of precision for these traditional tests.

Potential utility of the smart device compared with previously used technologies

The use of smart device technology could provide a truly quantitative, inexpensive, portable, and user friendly means to assess precise features of the STS performance by measuring the speed of each STS movement. This strategy could also eliminate timing and counting variability and provide a more standardized protocol and outcome. This would enhance the quality of the outcome, improve diagnostic utility, and improve the ability of the task to identify and track functional status, daily functional activity, and risk factors related to quality of life. Investigators have used force platforms, linear encoders, goniometers, motion capture technologies, inertial measurement units (IMU), and even smart devices housed with accelerometers and gyroscopes to quantify the speed used to stand from a chair [7-28]. However, these devices and associated analysis systems can be expensive and require trained personnel, thus limiting access to quantitative assessment.

Other groups have used portable technology to measure the STS movement

Williamson et al. (2001) and Boonstra et al (2006) both employed gyroscopic and accelerometer measures to assess the kinetics of the STS and concluded that the gyroscope, not the accelerometer, was more accurate in quantifying the movement [47, 48]. Also, and more specifically comparable to our findings, the utility of the smart device as a movement sensor in the STS task has been examined previously. Cerrito et al. compared smartphone-based accelerometry from the sternum and lower back with a force platform to validate peak vertical acceleration, peak force, and rate of force development. They performed ten single maximal STS repetitions and reported strong correlations across devices ($R^2 = 0.86$-0.93) [27].

In a similar vein, Galan-Merchant et al. assessed the reliability and validity of an iPhone 4 during the timed-up and go (TUG) test, a functional test with an STS component. Their study compared an Inertiacube3 (2 two-axes accelerometer, 3 single-axis gyroscope, and a three-axis magnetometer) to the onboard accelerometer sensor of an iPhone 4 and found sub-phase sit-to-stand correlations ($R^2 = 0.84$-0.99) and the stand-to-sit correlations range between ($R^2 = 0.88$ to 0.99). The iPhone 4 accelerometer produced similar correlations to the gyroscope in our study [49].

Other portable devices have examined the STS movement across a range of speeds

To our knowledge the current study is the first time a smart device's gyroscope has been compared with a goniometer and force platform to quantify STS power across a large range of sit-to-stand speeds. Jannsen et al (2005) used self-selected slow and fast movements to validate an accelerometer, concluding the accelerometer signals could identify the STS movement compared with motion capture technology, further proving its ability to quantify STS kinetics [50]. Given our robust data set we also wanted to go beyond the across-speed examination and analyze measures extracted from single repetitions to determine the ability of the devices to track the fastest and slowest repetitions.

The novelty of this protocol provides new, potentially clinically impactful information

Our novel protocol was designed so that the subjects produced small changes in speed, across a large number of STS movements, across a large overall range of speeds. The results thus expand on the previous data from other types of portable movement sensors, and provide new information on the utility and sensitivity of the common smart device itself as a movement sensor. The protocol used here allowed us to examine between-device correlations for very fast STS, very slow STS, and declines in speed across the progressively slowing repetitions. We found excellent correlations between devices for the maximal speed repetitions and for the difference in speed between the fastest and slowest repetitions, and good correlations for the slowest repetitions. The practicality of the findings are underscored by two observations, 1) the ability of the smart device to measure maximal efforts and 2) the ability to detect fatigue-related slowing of STS during a functional test.

The finding that the iPod Touch ($200) can provide a quantitative and accurate measure of STS angular velocity across a wide range of speeds indicates that such devices can be used as a replacement for expensive existing technologies. This opens up the possibility of highly accessible STS assessment in locations such as neurology clinics, geriatric institutions, rehabilitation clinics, community/senior centers, exercise facilities, and the home. The true novelty of these findings is that the iPod Touch was accurate and agreed with the goniometer across a wide range of speeds. To our knowledge, this is the first data to test the device across the range of speeds that might be expected from young healthy adults to elderly, frail, or clinical populations.

Placement on the thigh simplifies the movement being measured

Zijlstra's team (2010) used a similar design to Jannsen's to quantify vertical power by placing motion sensors on the upper and lower trunk. They reported fair to excellent linear relationships. However, they suggest the best estimate of peak power was a combination of data from the different trunk locations. Although the use of sensors on two anatomical locations may be appropriate for the research setting, such a strategy does not move toward the simplest possible, practical, user friendly strategy for truly quantitative assessment of STS function. We chose the thigh versus the sternum or lower back due to the different movement strategies individuals use to complete a STS movement. Depending on the strategy, the sternum and lumbar locations can introduce more movement and fluctuation into the data, creating the need for a more robust algorithm to identify the movement phases and extract the speed outcome. In Jannsen's research mentioned above, they reported a larger inertia in the trunk acceleration signal than in the thigh, which potentially corroborates the notion of a more complicated signal that necessitates a very robust algorithm [51]. Though the fore-aft movement of the knee produces a slight kinetic confounder when compared across subjects, the signal from the smart device during the knee extension phase is very clean and appears to represent the movement upward very well. By limiting the movement in the device primarily to the knee joint when measuring angular velocity we address Pao-Tsai Cheng's [52] concerns of the biomechanical alterations across individual movements due to age, variation in rising speed, initial body position, and trunk flexion.

There is a need for development of an app designed to analyze the STS movement

In the current study, we collected the iPod data with a purely data collection app, transferred the data to computer, and performed the analysis offline with a sophisticated program. Considering the ubiquity of the common smart device among lay people, clinicians, and researchers alike, an application with a robust algorithm to quantify STS movements across diverse clinical populations would be useful. Lummel et al. (2013) conducted a feasibility study with the use of a gyroscope during the 5x STS to assess if an automated algorithm could detect transitional phases of the STS. The gyroscope was placed on the sternum to measure the STS in an attempt to identify a device that could be worn daily to measure physical function in elderly adults. Lummel concluded that the automated detection of angular velocity during a STS is feasible and that their parameters were of clinical utility [53]. Recently, Wei Zhang and colleagues (2015) published a study validating the use of a pendant accelerometer worn in normal living conditions and concluded the STS peak powers in daily life had stronger associations with clinical measurements than traditional timed tests [54-56]. The overall result of these studies suggests there are algorithms capable of reducing the STS data measured by expensive sensors. However, downloading the data and analysis by trained personnel is still required. Similar to the work from Lummel (2013) and Zhang (2015), using the iPod Touch for data collection and analysis of the STS requires sophisticated analytics, expensive software, and trained personnel. The remaining limitation for using the iPod Touch is the lack of a combined data collection/analysis application for complete ease of use by minimally trained personnel. Researchers have implemented such algorithms in combination with other portable devices, such as the Inertiacube3, DynaPort Hybrid, or Pendant Sensor, which suggests the same could be done with common smart devices such as the iPod Touch.

A practical next step would be to combine a data collection and analytical capability in a simple interface that allows the user to quantify power based on collected data and inputted subject information. The iPod is small and light enough to allow flexible placement on many different limb segments for use in clinical, exercise, and research settings. Many proprietary devices exist in the marketplace, however nothing as inexpensive and user friendly as a smart device with its on-board movement sensors. The approach that our data suggests is feasible, inexpensive, user-friendly, sensitive, and accurate. The added metric of individualized repetition-by-repetition power should minimize the weaknesses of the traditional field tests of STS function and thus be useful to clinicians, researchers, and their patients and clients.

Limitations

The data from the smart device in this study came from the thigh segment only. Therefore, the movements of the trunk, which would change considerably with different STS speeds or in different populations such as frail older adults, were not included in this analysis.

The smart device data was compared with an expensive electronic goniometer across the knee and a force platform underneath the feet. Therefore, the smart device was compared with another accepted method but not necessarily validated directly against the gold standard of high speed motion capture and sophisticated kinematic analysis.

Summary

This study has shown that a smart device (iPod Touch) can measure the speed of leg movement across a wide and realistic range of sit-to-stand speeds, thus providing a quantitative and accurate field test of lower limb function suitable for use in remote settings by minimally trained personnel.

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APPENDIX A – FIGURES

Figure 1

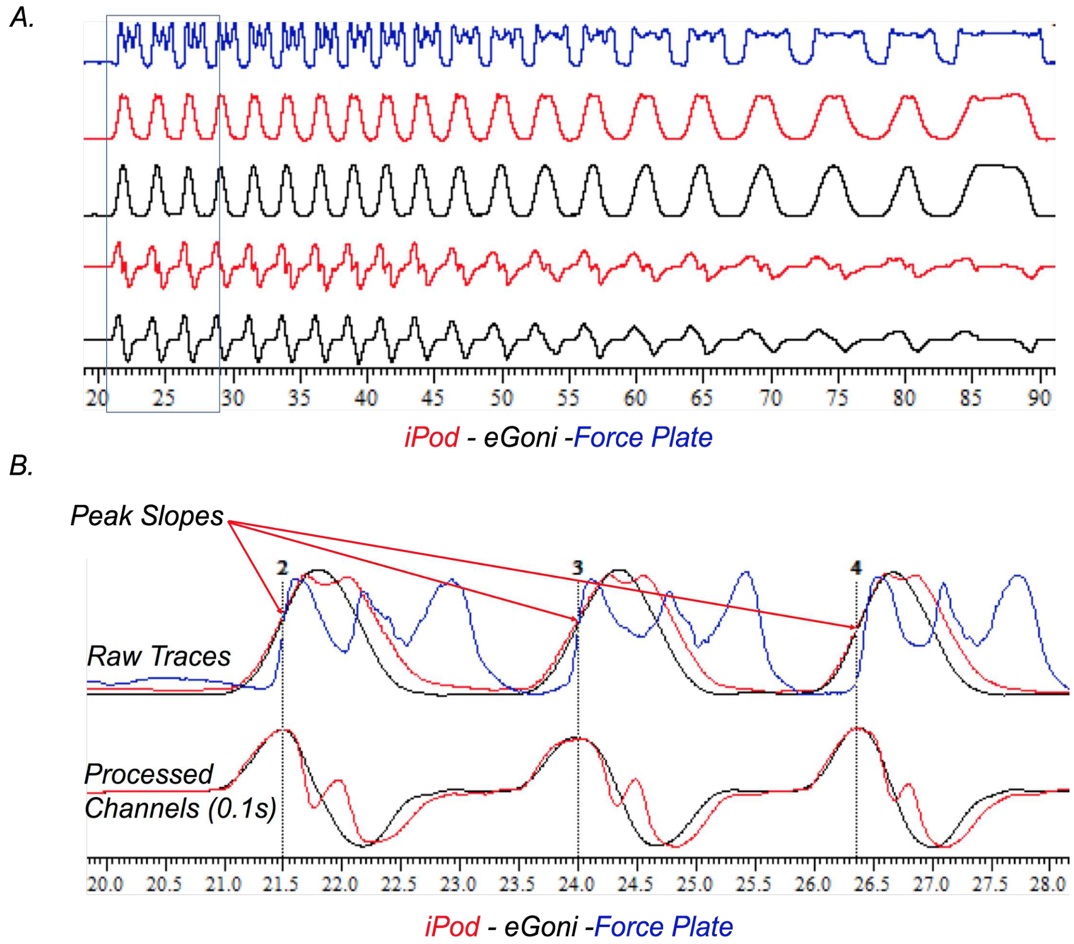

Figure 1. A) Experimental data traces from twenty chair rises from one subject. Subjects performed five maximal speed repetitions followed by incrementally slower repetitions. Top three traces from top to bottom: vertical ground reaction force (GRF), iPod thigh rotation, knee angle from electronic goniometer (eGONI). Bottom two traces are the slope calculated from the iPod and eGONI data above. Slope was calculated over 0.1 s epochs . B) First three repetitions from Fig. 1A. Top data is the three raw data traces overlaid. Bottom data is the two slope channels (slope calculated). The peak slopes in the bottom data align with the rising phase of the STS movement.

Figure *2*

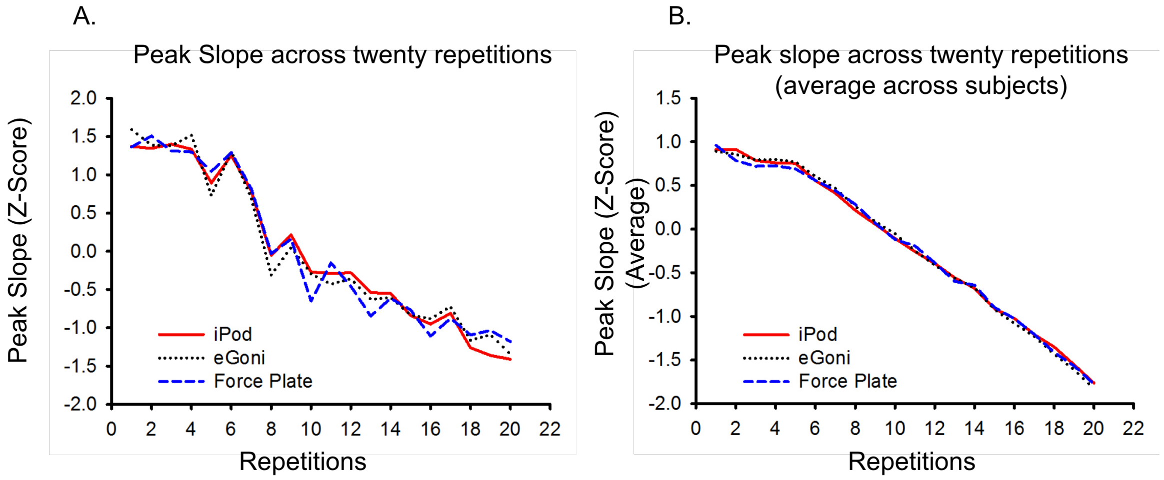

Figure 2. A) Peak slope data (Z-score) from the iPod, eGONI, and force platform for a single trial of 20 repetitions from an example subject. Values from twenty progressively slowing repetitions display the similarity in speed measurement between devices. B) Peak slope data (Z-score) from the iPod, eGONI, and force platform, averaged across trials and within repetitions for each subject, then averaged across subjects for each repetition. Values from the twenty progressively slowing repetitions are shown.

Figure 3

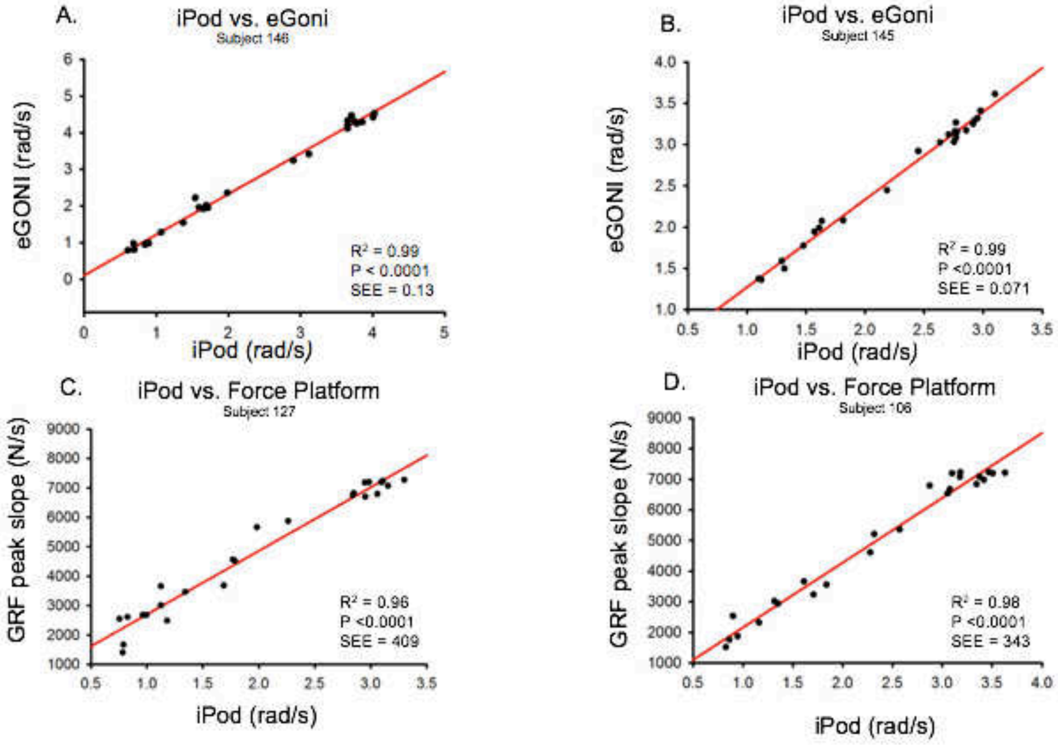

Figure 3. Examples of between-device peak slope correlations for one trial of 20 repetitions from four different participants. A) iPod peak slope vs. eGONI peak slope ($R^2 = 0.99$). B) iPod peak slope vs. eGONI peak slope ($R^2 = 0.99$). C) iPod peak slope vs. GRF peak slope ($R^2 = 0.96$). D) iPod peak slope vs. GRF peak slope ($R^2 = 0.98$).

Figure 4

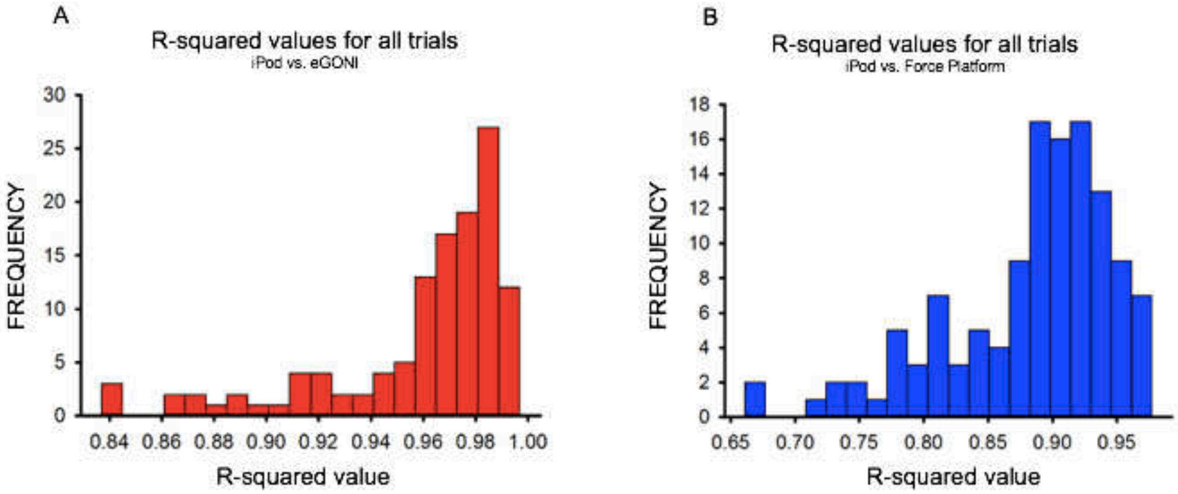

Figure 4. Distribution of the R^2 values from all 126 individual participant trials for A) the correlation between iPod peak slope vs. eGONI peak slope (Z-score), and B) the correlation between iPod peak slope vs. GRF peak slope (Z-score).

Figure 5

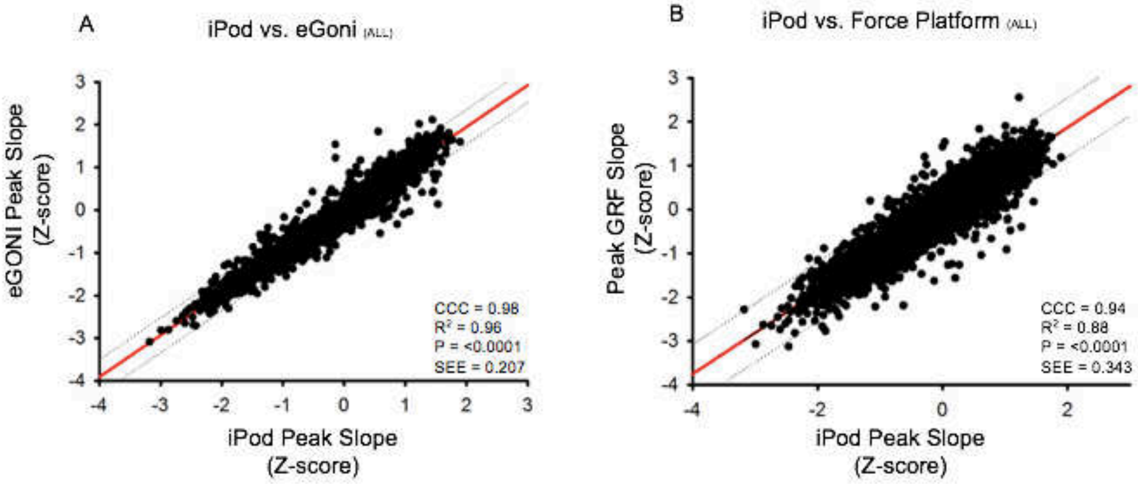

Figure 5. A) The iPod peak slope Z-score values for 42 subjects across three trials x 20 repetitions plotted against the values for eGONI peak slope Z-scores ($R^2 = 0.96$), with 95% confidence intervals. The Concordance Correlation Coefficient (CCC = 0.98) indicated excellent between-device agreement. B) The iPod peak slope Z-score values for all of the repetitions plotted against the values for GRF peak slope Z-scores ($R^2 = 0.88$), with 95% confidence intervals. The Concordance Correlation Coefficient (CCC = 0.94) indicated excellent between-device agreement.

Figure 6

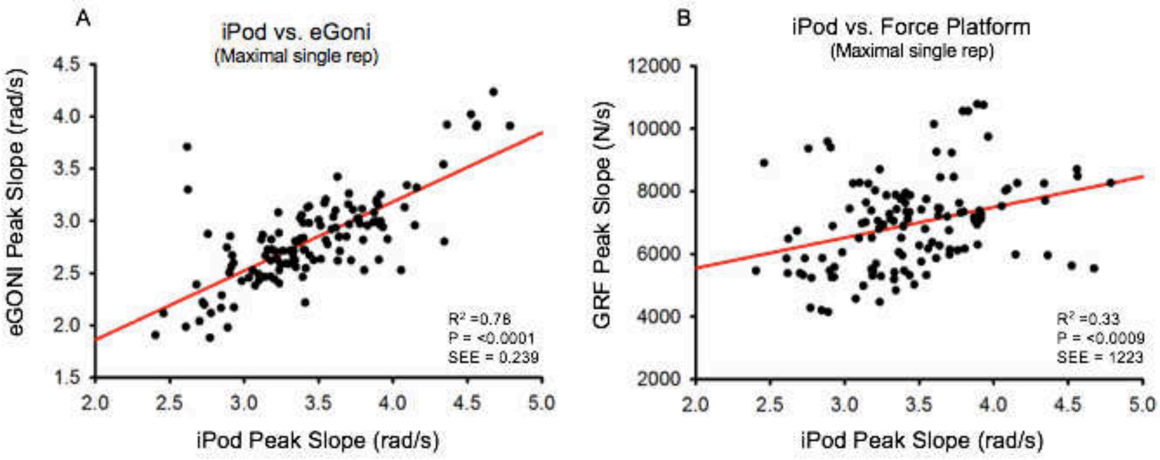

Figure 6. Between-device correlations for the maximal peak slope from the fastest single repetition from each trial of 20 repetitions. A) The maximal iPod peak slope was positively correlated with the maximal eGONI peak slope ($R^2 = 0.78$), and B) less strongly correlated with maximal GRF peak slope ($R^2 = 0.33$).

Figure 7

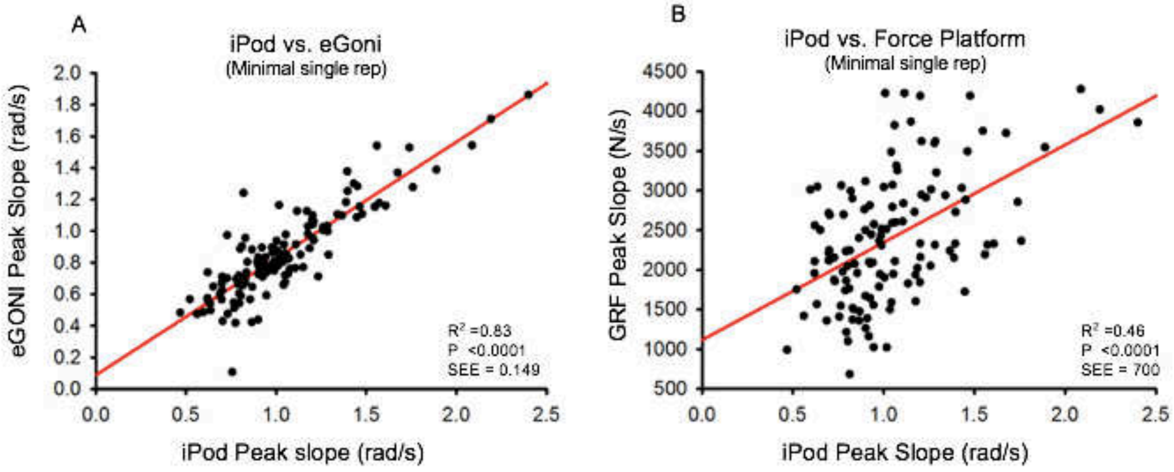

Figure 7. A) Between-device correlations for the minimal peak slope from the slowest single repetition from each trial of 20 repetitions. A) The minimal iPod peak slope was positively correlated with the minimal eGONI peak slope ($R^2 = 0.83$), and B) less strongly correlated with minimal GRF peak slope ($R^2 = 0.46$).

Figure 8

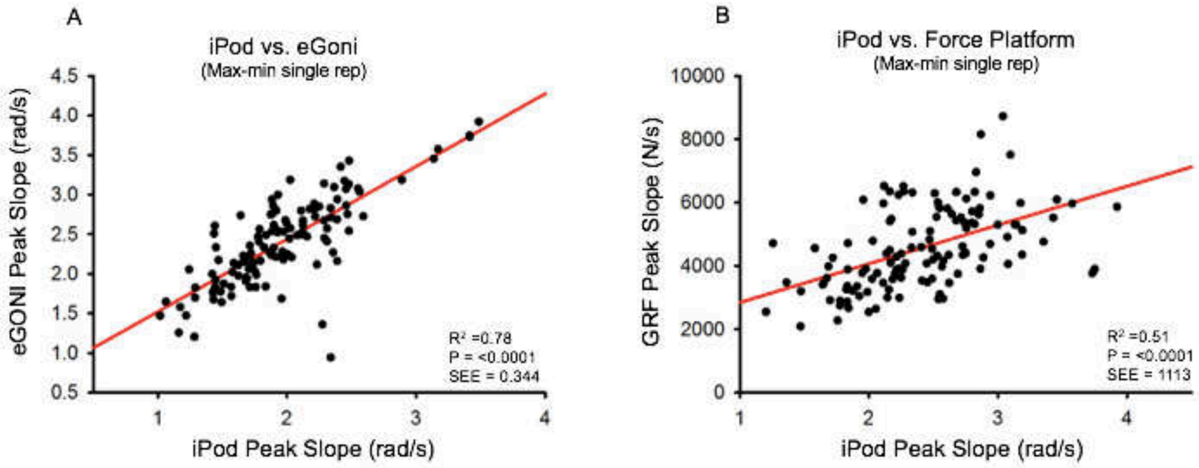

Figure 8. Between-device correlations for the difference in peak slope between the fastest single repetition and the slowest single repetition in a trial of 20 repetitions. A) The iPod peak slope difference (Max-Min) was positively correlated with the eGONI peak slope difference (Max-Min) (R^2 = 0.78) B) The iPod peak slope difference (Max-Min) was moderately correlated with the GRF peak slope difference (Max-Min) (R^2 = 0.51).

Figure 9

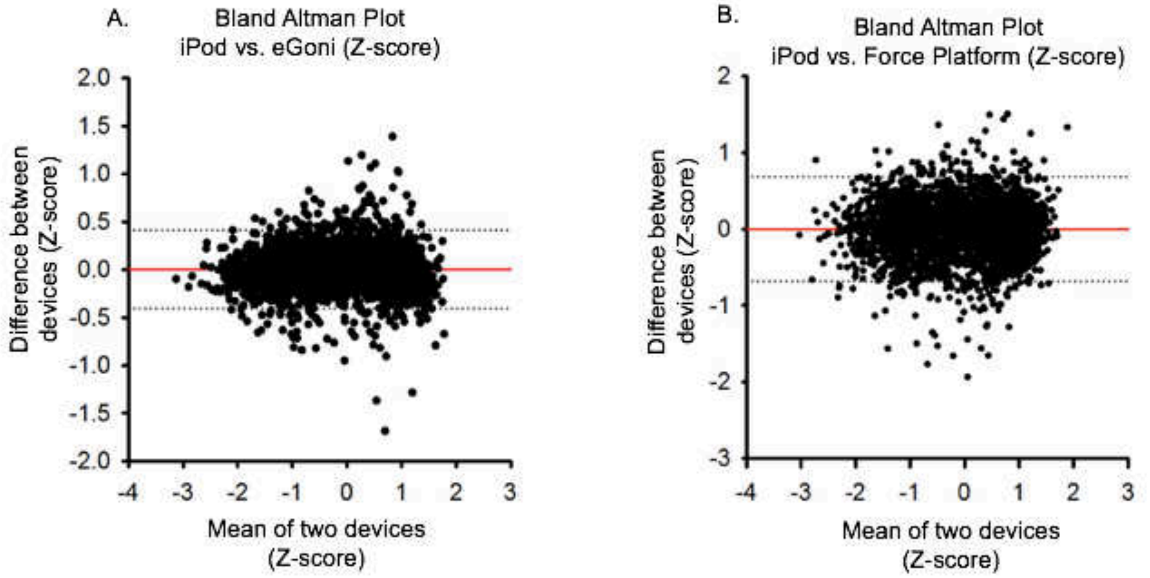

Figure 9. Bland-Altman limits-of-agreement plots between devices. A) The difference between the iPod peak slope and eGONI peak slope Z-score values plotted across mean Z-scores of the two devices. Average difference (Bias) = -0.0027 Z-score units, SD = 0.209. The 95% (+/- 1.96 SD) limits of agreement were -0.406 to 0.412 Z-score units. For 95% of sit-to-stand repetitions, the difference between iPod and eGONI was no greater than approximately 0.41 Z-score units away from a difference of zero. B) The difference between the iPod peak slope and GRF peak slope Z-score values plotted across values of the mean Z-score for the two devices. Average difference (Bias) = 0.0001 Z-score units, SD = 0.349. The 95% (+/- 1.96 SD) limits of agreement were -0.684 to 0.684 Z-score units. For 95% of sit-to-stand repetitions, the difference between iPod and Force Platform GRF was no greater than approximately 0.69 Z-score units away from a difference of zero.