Discriminative Ability of Fall Risk Outcome Measures

THESIS

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By

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Abstract

Falls among the elderly represent a major problem because of the high incident, the involvement of many different risk factors, and the consequential post-fall morbidity and mortality. Many balance scales have been created to help identify the causes and outcomes of elderly falls, and in turn, help health care providers better assess fall risk. The Berg Balance Scale (BBS),^{1,2} Fullerton Advanced Balance (FAB) Scale,³ Timed Upand-Go (TUG),^{4,5} and the Activity- specific Balance Confidence (ABC) Scale⁶ have been developed to measure balance and functional mobility among older people, as well as quantify confidence and fear of falling in different balance conditions. It is important to identify which tests can discriminate fallers from non-fallers, retrospectively,^{3,7–9} and certainly there is more data to be discovered on the prospective abilities of the same tests to predict future falls. Few have considered age as a covariate when evaluating the predictive validity of these tests. Therefore, the purpose of this study was to identify which test(s) best discriminate fallers from non-fallers among 60-79 years and 80-100 years of age.

Forty-six community-dwelling heathy older adults (mean age 79.1 ± 10.2 , range 60-100 years, 14 male, 32 female) were recruited from three senior centers and two independent living facilities. Participants filled out an information log which included

history of falls within the previous six months, prescription medication number, arthritis and joint replacements in either leg, exercise regularity, and assistive device use. Participants completed the ABC scale, and then in random order the TUG, BBS and FAB scale. Logistic regression was used to determine the discriminative power of the ABC, TUG, BBS, and FAB on falls within the six previous months. The models had a binary outcome of self-report history of ≥ 1 falls vs. no falls. Receiver operating characteristics (ROC) curves and subsequently the area under the curve (AUC) were calculated. Specificity and Sensitivity were calculated for each of the tests for all subjects and by age group (60-79 years and 80-100 years). Significance was set a priori at alpha= .05.

Results showed the discriminative abilities for at least one fall versus no falls to be poor. Corresponding area under the curve values were as follows: ABC (0.366), TUG (0.554), BBS (0.426), and FAB (0.437). Although the discriminative abilities were poor, we did see a correlation between all tests and age. As age increased, an appropriate directional change was observed for the ABC (-0.49), TUG (0.41), BBS (-0.58), and FAB (-0.70). Additionally, most models had a greater specificity than sensitivity; they were better at identifying non-fallers than fallers. The present results suggest that the ABC, TUG, BBS, and FAB may be used to assess functional capacity but not necessarily fall risk. They should be used with other fall risk assessment tools such as home safety, polypharmacy risk, vision and hearing, and assistive device evaluations.

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Vita

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Publications

Publications

Hanson NJ, Madaras L, **Dicke, J.**, Buckworth J (2015) "Motivational differences between half, full and ultra marathoners".*Journal of Sport Behavior* – 38(2): pages TBD

Saunders, N. W., Koutakis, P., Kloos, A. D., Kegelmeyer, D. A., **Dicke, J. D.**, & Devor, S. T. (January 05, 2015). Reliability and Validity of a Wireless Accelerometer for the Assessment of Postural Sway. *Journal of Applied Biomechanics*.

Abstracts

Saunders, N. W., Koutakis, P., Kegelmeyer, D. A., Kloos, A. D., **Dicke, J. D.**, LaFountain, R. A., & Devor, S. T. (2013, May). Reliability Study of a Wireless Accelerometer for the Assessment of Postural Control in Older Adults. In MEDICINE AND SCIENCE IN SPORTS AND EXERCISE (Vol. 45, No. 5, pp. 289-289)..

Saunders, N., **Dicke, J**., Koutakis, P., Kegelmeyer, D., Kloos, A., & Devor, S. (2014, May). Dual-Task Interference in Older Adults. In MEDICINE AND SCIENCE IN SPORTS AND EXERCISE (Vol. 46, No. 5, pp. 554-555).

Dicke, J., Saunders, N., Koutakis, P., Kegelmeyer, D. A., Kloos, A. D., & Devor, S. (2014, May). Validity Of A Wireless Accelerometer For The Assessment Of Postural Control In Older Adults. In MEDICINE AND SCIENCE IN SPORTS AND EXERCISE (Vol. 46, No. 5, pp. 699-699).

Dicke, J., Saunders, N., Koutakis, P., Kegelmeyer, D. A., Kloos, A. D., & Devor, S. (2015, May). Fall Characteristics in Community-Living Older Adults: A Prospective Study. In MEDICINE AND SCIENCE IN SPORTS AND EXERCISE (TBD).

Fields of Study

Major Field: Kinesiology

Interdisciplinary Specialization in Aging

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Chapter 1: Introduction

Falls among the elderly represent a major problem because of the high incident, the involvement of many different risk factors, and the consequential post-fall morbidity and mortality. Many balance scales have been created to help identify the causes and outcomes of elderly falls, and in turn, help health care providers better assess fall risk. The Berg Balance Scale (BBS),^{1,2} Fullerton Advanced Balance (FAB) Scale,³ Timed Upand-Go (TUG),^{4,5} and the Activity- specific Balance Confidence (ABC) Scale⁶ have been tested for validity and reliability. These tests were developed to measure balance and functional mobility among older people, as well as, quantify confidence and fear of falling in difference balance task situations.

These tests are used among a variety of older adults with different ages and functional abilities, but it is unclear which test is most appropriate to identify fall risk. It is important to identify which tests can discriminate fallers from non-fallers, retrospectively, and certainly there is more data to be discovered on the prospective abilities to predict future falls. There is also little data that divides these tests by age range. Therefore, the purpose of this study was to identify which test(s) best discriminate fallers from non-fallers among 60-79 years and 80-100 years of age.

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Chapter 2: Literature Review

The Aging of America

Although there is little consensus on when "old age" begins, the elderly population has been divided into three categories: young-old, old, and oldest-old¹⁰. The young-old, ranging from 65-74 years, includes a numerous amount of Baby Boomers (those born during the post- World War II baby boom between the years 1946-1964). The first wave of Baby Boomers reached full retirement age in 2011. In the next 20 years, 74 million Boomers will retire, adding 10,000 new retirees to Social Security and Medicare each day.¹¹ The next subpopulation of "old" adults ranges from 74 to 84 years of age. Total numbers within this population will continue to grow due to increased life expectancy.^{10,11} Disease prevention, water purification, improved nutrition and health care, and advanced treatment of age-related diseases contribute to the increasing lifespan.¹⁰ Future breakthroughs in gene therapy and stem cell research could also greatly extend elders' lives and possibly eliminate some diseases.¹⁰ Lastly, the oldest-old contribute to the fastest growing segment of the population- age 85+ years.^{10,11} Currently, 13% of the country's population, or 38 million Americans, exceed age 65, and by the year 2030, 20%, or 70 million, will exceed age 85.¹⁰ It is not surprising that 2 in 10,000 Americans now live to be 100 years. Estimates show that by the middle of this century there will be 835,000 worldwide centenarians or more.¹⁰

With an increase in lifespan, gerontologists see an increase in research of "healthspan," total number of years a person remains in excellent health.¹⁰ Gerontology now recognizes that successful aging must include maintenance of physical function and physical activity in addition to spiritual, emotional, and social health.¹⁰ Physical inactivity increases with age, and in turn, is followed by an increase in all cause morbidity and mortality.¹⁰ In order to understand physical activity changes with older adults, exercise physiologists must understand the physiological changes the body goes through as a result of aging. Older adults face inevitable changes to the cardiovascular, muscular, and nervous systems.

Cardiovascular System Changes

The cardiovascular system does not escape the diminishments brought on by aging. Cardiovascular structural changes include an increase in left ventricular wall thickness, size of cardiac myocytes, and focal collagen.¹² With large arteries, dilation and a thickened intima, as well as, frayed elastin are viewed.¹² Changes in cardiac myosin, elasticity of arteries, and ventricular function contribute to a decreased max heart rate, stroke volume, cardiac output and oxygen consumption.^{10,12} Increase in cardiovascular disease is also viewed with aging. Over 80 percent of all cardiovascular deaths occur in those aged 65 years and older.¹² It is important to note that lifestyle factors- physical activity or nutrition habits- substantially impact the process of aging and disease incidence.¹²

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Muscular System Changes

During the ages of 20-40, women and men have their highest muscle cross sectional area and muscle strength.¹⁰ Between 40 and 80 years, a loss of 30-50% of skeletal muscle leads to a loss of strength, power, and body mass. Sarcopenia is a progressive loss of muscle mass and strength due to a number of influences including genetic contributions, nutritional changes, lack of physical activity and more.¹³ Motor unit remodeling deterioration in old age leads to an irreversible loss of Type II fibers associated with chronic inflammation and reduction in circulating growth hormone, insulin like growth factor-1, mitochondria number, and endplate structures.^{10,13} Older adults have more than twice the non-contractile content in locomotor muscle as young adults, which can lead to physical disabilities and a lower quality of life.^{10,13}

Nervous System Changes

Older adults also face a diminished movement capacity due to neurological declines associated with aging.¹⁴ Movement and reaction time changes in older adults are a result of a 40% decline in the number of spinal cord axons and a 10% decline in nerve conduction velocity.¹⁰ This decline in neuromuscular function can have harmful effects on a senior's daily life. Studies have shown elderly adults change movement patterns to complete activities of daily living (ADLs) including decreased gait velocity, step length, time of single leg support, hip flexion, and ankle plantar-flexion during walking.^{14,15} *Fall Etiology*

Physiological decrements of the aging body greatly contribute to the risk of elderly falls and a loss of independence. Falls are multifactorial making it difficult to

assign a specific cause. A compilation of 12 studies showed the "most likely" causes of elderly falls.¹⁶ Environmental hazards, such as wet floors, poor lighting, loose rugs, and improperly fitted wheelchairs, contribute to up to 27% of falls.¹⁷ Environmental hazards are often paired with physical insufficiencies.¹⁶ The loss of independence, including difficulty in at least one activity of daily living (ADL) or instrumental activity of daily living (IADL), is a major risk factor for falls.¹⁸ In order to complete most daily activities, physical strength is needed. Leg weakness and gait problems are one of the most potent internal risk factors for falls.¹⁶ Dizziness and vertigo can also increase the risk of falling.¹⁶ This could also be a sign of other problems including cardiovascular disease, hyperventilation, drug side effect, anxiety, or depression.¹⁶ Drop attacks are being reported more frequently by older adults. They are defined as a fall not due to a loss of consciousness or dizziness thought to be cause by a lack of blood flow to certain areas of the brain.¹⁶ Other causes of falls include postural hypotension, visual disorders, arthritis, acute illness, alcohol, epilepsy, or falling from a bed.¹⁶ Physiological insufficiencies compounded with neurological disorders and environmental hazards¹⁷ create a detrimental situation for older adults.

Fall Statistics

One in three adults, age 65 years and older, and one in two, aged 80 years and older, fall each year.^{19,20} Of these falls, 20-30% sustain a moderate to serious injury-contusions, lacerations, hip fractures, head injuries, etc.¹⁹ Hip fractures are among the worst of the injuries causing many to never recover to full functional capacity. One out of five hip fracture patients will die within a year of the injury.²¹ In addition to the physical

injury, falls can lead to a loss of confidence in ability to perform every day activities, leading to social withdrawal, depression, decreased mobility, and increased dependence.²⁰ Falls not only affect the individual, but the society as a whole. Falls create a major burden for the health care system. According to the CDC in 2012, falls among older adults cost \$30 billion in direct medical costs.¹⁹ The direct costs include fees for hospital and nursing home care, doctors, rehabilitation, medical equipment, prescription drugs, and insurance processing costs.¹⁹ They expect by 2020 the annual cost of fall injuries will reach \$67.7 billion.¹⁹ There are other costs, beside medical, that are extended to society. These could include: disability, work loss, emotional distress of family members or co-workers, property damage, and community fear.¹⁹ The multi-dimensional aspects of falls create a dire need for measures to assist in the detection and prevention of falls.

Fall Outcome Measures

Many fall risk assessment tools have been developed to aid in physician care of elderly patients. Current and future research focuses on the ability of these tools to accurately discriminate fallers from non-fallers and to predict fall risk. Reliable, accurate, and predictive tools can then be used to refer patients to fall risk programs.

Berg Balance Scale

The Berg Balance Scale (BBS) was validated by Berg et.al as a tool to measure functional balance.²² The 14-item objective measure assesses static and dynamic balance through activities such as: sitting to standing, standing unsupported, transfers, reaching forward, tandem stance, etc.²³ Item-level scores range from 0-4 with 4 as full ability to

perform the activity. Items are summed to a maximum score of $56.^{23}$ In elderly individuals a cut-off score of less than 45 indicates the individual may be at greater risk of falling.²² Various studies of elderly population have shown high intra (0.99)- and inter (0.98)- rater reliability.^{23,24}

Studies have revealed mixed reviews about the predictive ability of the BBS. Chandler at al. used a fall questionnaire pertaining to 6 months before and after the Berg Balance assessment. The sensitivity of the BBS to the initial fall frequency was 53%, whereas the specificity was 96%.⁷ Specificity and sensitivity remained approximately the same in the 6 month follow-up data. Using a chi-square test, the two groups (scored less than 45 and scored 45 or above on test) showed a difference that would not occur by chance. Chandler claimed that for clinicians, the findings show a person who scores 45 and above will have a high probability of not falling.⁷

A prospective study using the BBS by Muir et al. looked at the predictive validity of this measure for 3 types of outcomes- any fall, multiple falls, and injurious falls. The results showed the BBS had good discriminative ability to predict multiple falls when receiver operating characteristic (ROC) curve analysis was used. However, as a dichotomous scale, with a threshold of less than 45, it proved to be inadequate for identifying the majority of people at risk for falling in the future, with sensitivities of 25% and 45% for any fall and multiple falls, respectively. 58% of people with BBS scores at or below 45 fell, and 39% of people with scores above 45 fell.²⁵

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Fullerton Advanced Balance Scale

The Fullerton Advanced Balance (FAB) Scale is another test of static and dynamic balance under varying sensory conditions.³ It has been validated for use in higher-functioning active older adults.²⁶,²⁷ Rose et al. found high test-retest reliability for the total balance scale score (p=.96), as well as, high interrater reliability (.94-.97) and intrarater reliability (.97-1.00).²⁷ Similar to the BBS, the FAB scale uses a five point ordinal scale (0-4) with a maximum score of 40 points.²⁶ The 10-item test includes the participant standing with feet together and eye closed, reaching forward to retrieve and object, turning in a circle, stepping up and over a bench, tandem walking, standing on one leg, standing on foam with eyes closed, jumping for distance, walking with head turns, and recovering from an unexpected loss of balance.²⁶

A retrospective fall study by Hernandez et al. found the FAB scale score could be used to predict faller status (history of two or more falls in previous 12 months).²⁶ The probability of falling increased by 8% with each 1-point decrease in total score. A cut off score of 25 out of 40 produced the highest sensitivity (74.6%) and specificity (52.6%) in predicting faller status.²⁶ To our knowledge, No prospective studies of community dwelling older adults have been found using the FAB.

Timed Up-and-Go

The Timed Up-and-Go (TUG) measures the time is takes a subject to stand up from a chair, walk three meters, turn and walk back toward the chair to sit down.²³ It is a mobility test for frail community-dwelling elderly individuals.²³ The test-retest reliability

for TUG vary from moderate (ICC=.56)²⁸ to high(ICC=.97).²³ It is suggested that elders with longer TUG times are more likely to fall than those with shorter times.²⁹ Shumway-Cook et al. found a cutoff score of greater than 13.5 seconds was indicative of fall risk in community dwelling adults.³⁰

Mixed reviews have been published about the predictive ability of the TUG for elderly falls. Shumway-Cook et al. found the TUG to be sensitive (87%) and specific (87%) to elderly individuals prone to falling.³⁰ Although a small study (N=30), their retrospective study showed positive results, suggesting the TUG is a simple, effective tool to screen for falls among older adults.³⁰ Viccaro et al.³¹ and Sai et al.,³² using prospective studies, also found the TUG to be predictive of falls. On the contrary, Boulgarides et al.³³ and Schoene et al.³⁴ found its predictive ability and diagnostic accuracy to be "poor to moderate." With conflicting conclusions of predictive abilities, the TUG is recommended to be used in collaboration with other fall risk assessments.³⁵ *Activities-Specific Balance Confidence Scale*

A fear of falling can have deleterious effects on the physical function of an older adult, due to the decline in daily activities.³⁶ The Activities-Specific Balance Confidence (ABC) Scale is a questionnaire used to measure fear of falling.³⁷ The subject is asked to rate his/her confidence level when performing 16 different activities, on a scale ranging from 0%-100%.³⁷ Questions are phrased as "How confident are you that you will not lose balance or become unsteady when…"³⁸ The highest score (100%) indicates full confidence and the lowest score (0%) represents no confidence.³⁸ A study of 125 elderly fallers and non-fallers showed a cut-off score of 67% and below indicated an increased risk of falling.³⁶ The scale showed a 84.4% sensitivity to fallers and correct classification of non-fallers with a specificity of 86.7%.³⁶ The ABC scale has shown to have significant correlation with the Berg Balance Scale (r=0.752) and Timed Up-and-Go(r=0.698)³⁹ in community living elderly. The ABC scale has also been found to be more responsive to higher functioning older adults than the Falls Efficacy Scale by Tinetti et al.⁴⁰

Fall Prevention

Falls among older adults have grabbed the attention of many physical therapists, occupational therapists, exercise physiologists and researchers. The amount of fall related injuries and deaths has increased the need for fall prevention programs and activities. Systematic reviews of exercise interventions have shown a reduction in both the risk of falling and rate of falling and a decreased incidence of fall related injuries.^{41,42} Exercise could prove to be advantageous but only less than 20% of older adults are excising,⁴² thus most do not reap these benefits. As the population of older adults continues to grow, an increase in the number of falls will also been seen, reiterating the need for exercise interventions, there is no clear understanding of the optimal program.^{42,43}

A key issue is how to replicate a highly controlled research study to a community program. Studies have shown promising programs to include a multidimensional fall risk assessment with an exercise intervention.⁴⁴ Exercise programs included two to three

sessions per week with a mixture of strength, aerobic, flexibility, and balance exercises.⁴⁴ Robitaille et al. followed this model when he introduced Stand Up!, a multifaceted fallprevention program to community organizations in Montreal, Canada.⁴³ The intervention included biweekly group exercise classes, home-based exercises, and group discussions. Results showed improvement in static balance and mobility.⁴³ Other group based studies have shown similar results in reducing fall rates and improving mobility.^{45,46,47} Important factors of a successful program included: involving various systems of balance.^{45,47} including progression of training, obtaining high attendance/completion rates,^{43,45–47} and adapting to the limitations of the community.⁴³ For widespread use, these programs must be feasible, sustainable, and cost-effective.⁴⁴

Chapter 3: Sensitivity of Fall Risk Outcome Measure by Age

Introduction

Falls among the elderly represent a major problem because of the high incident, the involvement of many different risk factors, and the consequential post-fall morbidity and mortality. Many balance assessments have been created to help identify the causes and outcomes of elderly falls, and in turn, help health care providers better assess fall risk.

The BBS,^{1,2} FAB Scale,³ TUG,^{4,5} and the ABC Scale⁶ have been tested for validity and reliability. These tests were developed to measure balance and functional mobility among older people, as well as, quantify confidence and fear of falling in different balance task situations. Regarding their abilities to successfully discriminate fallers from non-fallers, studies have shown contradictory findings.

The ABC scale is a questionnaire used to measure fear of falling. This fear has been linked to reductions in daily activity and then a loss of independence.³⁶ Both high $(>80.0)^{36}$ and lower $(<61.1)^{48}$ sensitivities have been reported in community dwelling older adults focusing on retrospective falls. It was shown to have a higher correlation to the BBS (r=0.752) in community dwelling older adults,³⁹ but a lower correlation in stroke patients (r=0.36).⁴⁹ Fear of falling has been observed in both fallers and non-fallers, leading to confounding results when using the ABC an independent measure of fall risk.³⁶ The TUG is a short, simple clinical test with high reliability due to its agreement in stop-watch durations versus rating scale. The TUG has been studied in several different populations including healthy older adults,^{30,48} Parkinson's Disease,^{50,51} frail elderly,⁵² stroke patients,^{53,54} and more. Studies have reported different cut-off times to identify risk of falling within certain populations. For example, a cutoff time of >13.5 in community dwelling older adults³⁰ results in increased fall risk, where a cutoff time of >32.6 seconds⁵² in frail elderly is also an indication. The TUG shows that a slower time equates to a lower functional ability,⁵ but studies have shown poor predictive abilities when it comes to falls.^{37,48} The TUG may be more beneficial when examining changes in locomotion function over time.

The BBS is a highly used functional assessment of balance, consisting of 14 static and dynamic tests.²² Studies of elderly population have shown high intra (0.99)- and inter (0.98)- rater reliability^{23,24} but report mixed reviews about the predictive ability of the BBS. Sensitivity ranges from 38.9⁴⁸ to above 80.0 in community dwelling older adults.³⁶ The ability of the BBS to identify non-fallers is as been as high as 96.0.⁷ In elderly individuals a cut-off score of less than 45 indicates the individual may be at greater risk of falling.²² One study of independent living older adults showed a ceiling effect.⁷ Seventy-three percent of the subjects scored above the cutoff score of 45, and 11% of the subjects achieved a perfect score of 56. This test may not be appropriate among persons with very high levels of balance ability.⁷

When compared to the BBS with 14 test items, the FAB is more time efficient due to the 10 test items.²⁷ It requires more equipment, but challenges the individual in

multiple dimensions of balance.²⁷ Few studies have reported on the predictive abilities of the FAB. One retrospective fall study by Hernandez et al. found the FAB scale score could be used to predict faller status (history of two or more falls in previous 12 months).²⁶ The probability of falling increased by 8% with each 1-point decrease in total score. A cut off score of 25 out of 40 produced the highest sensitivity (74.6%) and specificity (52.6%) in predicting faller status.²⁶ This study claimed that in 7 out of 10 cases an individual who scores 25 or lower is at a high risk for falls.²⁶

These tests are used among a variety of older adults with different ages and functional abilities, but it is unclear which test is most appropriate to identify fall risk. It is important to identify which tests can discriminate fallers from non-fallers, retrospectively, and certainly there is more data to be discovered on the prospective abilities of these tests to predict future falls. Few have considered age as a covariate when evaluating the predictive validity of these tests. Therefore, the purpose of this study was to identify which test(s) best discriminate fallers from non-fallers among 60-79 years and 80-100 years of age. We hypothesized that compared to the ABC, TUG, and the BBS, the FAB would best retrospectively discriminate fallers from non-fallers. Additionally, we predicted that discriminative abilities would increase with age.

Methods

Subjects

Forty-six community-dwelling heathy older adults (mean age 79.1 ± 10.2 , range 60-100 years, 14 male, 32 female) were recruited from three senior centers and two independent living facilities. Participants were included if they were 60 years of age or older and independently living. Participants were excluded if they had any diagnosed balance disorder or neurological conditions that would negatively impact balance such as a cerebrovascular accident, Parkinson's disease, multiple sclerosis, neuropathy, or vestibular disorders.

Outcome Measures

Four outcome measures were utilized in this study including one cognitive assessment and three physical function assessments. The cognitive task included the Activities-Specific Balance Confidence (ABC) Scale, which is a questionnaire used to measure fear of falling.³⁷ The subject is asked to rate his/her confidence level, on a scale ranging from 0%-100%, when performing 16 different activities.³⁷ Questions are phrased as "How confident are you that you will not lose balance or become unsteady when..."³⁸ The highest score (100%) indicates full confidence and the lowest score (0%) represents no confidence.³⁸ The functional tests included the Timed Up-and-Go (TUG), Berg Balance Scale (BBS), and the Fullerton Advanced Balance Scale (FAB). The TUG measures the time is takes a subject to stand up from a chair, walk three meters, turn and walk back toward the chair to sit down.²³ It has been used as a mobility test for many populations of elderly.²³ The Berg Balance Scale (BBS) is a 14-item objective measure

that assesses static and dynamic balance through activities such as: sitting to standing, standing unsupported, transfers, reaching forward, tandem stance, etc.²³ Item-level scores range from 0-4 with 4 as full ability to perform the activity. Items are summed to a maximum score of 56.²³ In elderly individuals, a cut-off score of less than 45 indicates the individual may be at greater risk of falling.²² The Fullerton Advanced Balance (FAB) Scale is another test of static and dynamic balance under varying sensory conditions.³ It has been validated for use in higher-functioning active older adults.^{26,27} Similar to the BBS, the FAB scale uses a five point ordinal scale (0-4) with a maximum score of 40 points.²⁶ The 10-item test includes the participant standing with feet together and eye closed, reaching forward to retrieve and object, turning in a circle, stepping up and over a bench, tandem walking, standing on one leg, standing on foam with eyes closed, jumping for distance, walking with head turns, and recovering from an unexpected loss of balance.²⁶

Study Design

Ethical approval was obtained from the Ohio State University Biomedical Sciences Institutional Review Board and written consent was obtained from all participants. Following the informed consent process, the participant filled out an information log which included history of falls within the previous six months, prescription medication number, arthritis or joint replacements in either leg, exercise regularity, and assistive device use. A fall was defined as a sudden unintentional change in position causing one to land on a lower level.^{48,55} The first test administered to subjects was the ABC scale. Mastery experiences have shown to effect self-efficacy, positively and negatively, depending on the experience outcome.⁵⁶ In order to reduce this effect, and for consistency, cognitive tasks were performed before the functional tests. Participants then completed in random order the TUG, BBS and FAB scale. Rest periods were given between tasks if needed. Researchers were present throughout all testing to ensure safety. Lastly, participants were give a fall diary to record any prospective falls and corresponding dates. Participants will be called once a month for 6 months after initial assessment to record any falls. The prospective aspect of this study will be analyzed for future research.

Statistical Analyses

Statistical Analyses were performed using the Statistical Package for Social Sciences (SPSS) version 22.0. Logistic regression was used to determine the discriminative power of the ABC, TUG, BBS, and FAB on falls within the six previous months. The models had a binary outcome of self-reported history of ≥1 falls vs. no falls. Receiver operating characteristics (ROC) curves and subsequently the area under the curve (AUC) were calculated. Specificity and Sensitivity were calculated for each of the tests for all subjects and by age group (60-79 years and 80-100 years). Significance was set a priori at alpha= .05.

Results

Subject Characteristics

Of the 46 participants, 32 were women and 14 men. 22 participants were 60-79 years of age and 24 participants were 80-100 years of age. Twenty (43.5%) of the

participants reported a fall in the previous six months. Thirteen of the women (40.6%) and seven (50%) of the men fell. Table 1 shows subject demographics and average scores for the ABC, TUG, BBS, and FAB between fallers and non-fallers and by age range. Fallers were defined as a self-reported history of at least one fall in the previous six months. Non-fallers were defined as a self-reported history of no falls in the previous six months. The fallers group had slightly lower ABC, BBS, and FAB scores, and slightly slower TUG times, though comparisons were not statistically significant. It is also worthy to note that the mean age for fallers was greater than non-fallers in both age ranges.

_	Non-fallers		Fal	lers
	60-79 years	80-100 years	60-79 years	80-100 years
_	N=10	N=16	N=12	N=8
Characteristic	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD
Age (years)	68.20 ± 6.14	85.25 ± 4.89	72.42 ± 6.45	90.38 ± 5.18
Height (in)	65.00 ± 4.00	64.44 ± 3.63	66.08 ± 4.64	62.38 ± 2.39
Weight (lbs)	161.00 ± 30.75	159.94 ± 36.60	178.00 ± 29.55	127.25 ± 28.11
ABC (out of 100)	92.91 ± 8.38	72.80 ± 27.66	79.17 ± 16.08	66.41 ± 23.14
TUG (sec)	6.72 ± 2.14	11.50 ± 5.86	10.53 ± 9.15	12.79 ± 5.31
BBS (out of 56)	54.70 ± 1.77	47.31 ± 5.84	49.92 ± 6.53	46.38 ± 8.18
FAB (out of 40)	34.40 ± 4.88	20.81 ± 9.83	26.42 ± 9.33	19.00 ± 10.77

Table 1: Descriptive Statistics of Fallers and Non-fallers

Note : No significant difference between age groups and outcome measure scores of fallers and non-fallers

Table 2 shows differences between fallers (n=20) and non-fallers (n=26) with respect to self-reported characteristics. Again, there were no significant differences between groups in regards to prescription medications, presence of arthritis, lower limb replacement, and exercise. It is interesting to note the use of assistive devices is greater among fallers (30.0%) than non-fallers (19.2%). But whether these devices were used prior to a fall or prescribed due to a fall is unknown.

	Incidence among non-fallers	Incidence among fallers
Characteristic	N=26	N=20
Prescription Medication Use	46.2%	55.0%
Arthritis in Lower Body	42.3%	45.0%
Lower Body Joint Replaced	15.4%	20.0%
Assistive Device Use	19.2%	30.0%
Exercise \geq 4 days/week	46.2%	50.0%

Table 2: Differences in characteristics among fallers and non-fallers

Note : Prescription medication use included ≥ 4 self-reported medications No significant difference among fallers and non-fallers at $\alpha < 0.05$

Discriminative Ability

Logistic regression was used to determine the discriminative ability of each

outcome measure. Table 3 shows the area under the curve (AUC) for each fall risk tool.

None of the models were able to significantly discriminate fallers from non-fallers. AUC

values were as follows: ABC= 0.366, TUG= 0.554, BBS= 0.426, and FAB= 0.437

≥ One Fall vs. No Falls					
Model	AUC	Std. Error	P-value		
ABC	0.366	0.083	0.124		
TUG	0.554	0.087	0.535		
BBS	0.426	0.086	0.394		
FAB	0.437	0.087	0.465		

 Table 3: Area under the curve

Note : No values were significant at $\alpha < 0.05$

Sensitivity and Specificity

Table 4 shows the sensitivity and specificity of each fall risk tool as a whole group and divided into two age categories (60-79 years and 80-100 years). Sensitivity is the proportion of individuals who were correctly identified as fallers. Specificity is the proportion of individuals who were correctly identified as non-fallers. For all participants with at least one fall vs. no falls, the sensitivity was 30.0% for the ABC, TUG, and BBS and 55.0% for the FAB. The specificity for all participants was between 69.2% and 80.8%. The sensitivity for 60-79 years was 25.0% and for 80-100 years was 37.7% for all outcome measures. The specificity was 100.0% for all outcome measures in the 60-79 years category, but was ≤ 68.8 for the 80-100 years category. In general, most models were better at identifying non-fallers versus fallers.

		8						
		Age 60-	79 years	Age 80-1	00 years	All Part	icipants	
		10 non	-fallers	16 non	-fallers	26 non	-fallers	
		12 fallers		8 fa	8 fallers		20 fallers	
Outcome	Cutoff	Sonaitivity	Spacificity	Songitivity	Spacificity	Sonsitivity	Spacificity	
Measure	Cuton	Sensuivity	specificity	Selisitivity	specificity	Sensuivity	specificity	
ABC	Score<67	25.0	100.0	37.5	68.8	30.0	80.8	
TUG	Time>13.5s	25.0	100.0	37.5	68.8	30.0	80.8	
BBS	Score<45	25.0	100.0	37.5	62.5	30.0	76.9	
FAB	Score<25	25.0	100.0	37.5	50.0	55.0	69.2	

Table 4. Sensitivity and Specificity > One Fall vs. No Falls

Concurrent Validity

Fall risk outcome measures were evaluated against each other for concurrent validity. Additionally, the outcome measures were tested for association with age. All correlations between outcome measures were significant at the 0.05 level, and there was a significant association between age and the tests. As age increased, an appropriate directional change was viewed for the ABC (-0.49), TUG (0.41), BBS (-0.58), and FAB (-0.70). Table 5 shows the correlation between age and clinical tests.

	0			
	Age	ABC	TUG	BBS
ABC	-0.49			
TUG	0.41	-0.64		
BBS	-0.58	0.79	-0.79	
FAB	-0.70	0.80	-0.76	0.92

 Table 5: Correlation table for the association

 between age and clinical tests

Note: All Pearson correlation coefficients were significant at alpha = .05

Discussion

In summary, results showed no statistical difference among fallers and nonfallers. The discriminative abilities of the four outcome measures for at least one fall versus no falls were poor. Corresponding area under the curve values showed no predictive abilities; ABC (0.366), TUG (0.554), BBS (0.426), and FAB (0.437). Although the discriminative abilities were poor, we did see a correlation between all tests and age. As age increased, an appropriate directional change was observed for the ABC (-0.49), TUG (0.41), BBS (-0.58), and FAB (-0.70). Additionally, most models had a greater specificity than sensitivity; they were better at identifying non-fallers than fallers.

Briefly comparing fallers and non-fallers, there were no significant differences between groups in regards to age, gender, scores on the ABC, TUG, BBS, and FAB, prescription medications, lower body joint replacements, presence of arthritis, and assistive device use. None were predictors of falls. Arthritis,⁵⁷ use of four or more prescription medications,⁵⁸ and the use of improper assistive devices⁵⁹ has been shown to increase the risk of falls. While assistive devices have been shown to be a source of confidence in functional abilities,⁶⁰ improper fitting can be a hazard for older adults.⁵⁹ Sainsbury reported 18 of 24 elderly patients who had fallen were using incorrect lengths of canes.⁵⁹ but they did not report the length of canes for non-fallers. It has also been reported that compared to female non-fallers, female fallers were significantly more likely to use an assistive device and take more than four medications.³² These studies may have shown different results due to their inclusion of institutionalized older adults. In our study, 50% of the fallers and 46.2% of the non-fallers exercised at least four days per week. Exercise has been shown to reduce falls,^{20,44} through improved balance, flexibility, reflexes, strength, and coordination.²⁰ Physical activity has also shown paradoxical indications of increased fall risk.²⁰ Increased engagement in physical activities increased the opportunity to fall.²⁰ The role of physical activity is complex, which leads us to believe some of the falls could have been attributed to increased physical activity and in turn more exposure to falls. It could also suggest external factors such as poor lighting, loose rugs, improper footwear and clothing, and inappropriate assistive devices were at play.

The fallers group had slightly lower ABC, BBS, and FAB scores, and slightly slower TUG times, though comparisons were not statistically significant. It is also worthy to note that the mean age for fallers was greater than non-fallers in both age ranges, but also not significant. Given a larger sample size or a different elderly population, age may have played a more prominent role in predicting fall status.

The discriminative abilities of the ABC, TUG, BBS, and FAB were poor (AUC=0.366, 0.554, 0.426, and 0.437) for at least one fall vs. no falls. This did not

support our hypothesis that the FAB would have the highest predictive ability. None of the outcome measures were able to predict falls. Area under the curve values were similar to the findings of Saunders et al. for the ABC (0.548), TUG (0.553), and BBS (0.594) for at least one fall in the previous six month.⁴⁸ Their population was a larger sample size (n=95) of healthy, independent older adults.⁴⁸ A different prospective study, found a higher AUC for the TUG (0.71).³² They studied a larger sample of community dwelling individuals (N=137) but included elderly in assisted living and the AUC was based on recurrent falls. Our study only included independent living older adults and did not analyze multiple falls. Another study of community-dwelling older adults found the of the BBS to be 0.59 for any fall.²⁵ Their cutoff score was 54 while ours was 45. Although another study has reported retrospective discriminative abilities of the FAB, they did not report an AUC value,²⁶ leading us to believe we are the first to report an AUC value for the FAB. It is prudent to conduct additional studies including prospective discriminative abilities of single and multiple fallers to add to the predictive abilities of this test.

Although the discriminative abilities were poor, we did see an apposite correlation between each of the fall risk tests and age, significant at the 0.05 level. As age increased, an appropriate directional change was viewed for the ABC (-0.49), TUG (0.41), BBS (-0.58), and FAB (-0.70). We know that balance is an issue faced by aging individuals¹⁶ so we would assume as age increases we see a drop in balance scores and slower times. This is confirmed with our significant findings, but due to the fair to moderate correlations, we cannot assume that age is the only factor affecting balance scores.

We also viewed appropriate positive and negative correlations between the four outcome measures. As ABC scores increased we also saw an increase in BBS(r = 0.79) and FAB (r = 0.80) scores, as well as a decrease in TUG (r = -0.64). A study of community dwelling older adults, with a slighter higher mean age (81.7±6.7 years) found similar values.³⁹ ABC was correlated with BBS(0.75) and TUG (-0.698) and the BBS was associated with the TUG (-0.81).³⁹ This was similar to our findings between BBS and TUG with a correlation of (-0.79). The positive correlation between the FAB and BBS for our study was 0.92. Lower but significant results of FAB correlation with BBS (0.75) were seen in a different study of community dwelling older adults.²⁷ This study represented a Spearman rank correlation versus a Pearson correlation in our study. The variance in the correlations between studies suggests the scales may be testing different aspects of balance, or the population used in our study was higher functioning producing higher scores on the FAB and BBS. To our knowledge, we are the first to report an association between the FAB and the TUG and ABC. These results suggest that a person who is less confidence in their balance may actually have a functional issue, instead of having low confidence due to past experiences or other health concerns. It also suggests that if an individual is having difficulty in one test they may want to have their functional abilities assessed with another. For example, if a participant scores poorly on the TUG, which assesses balance during locomotion, they may also want to perform the FAB for further assessment of functional movements during sitting, standing, and stepping.

Although the ABC, TUG, BBS, and FAB were significantly associated with each other, their abilities to discriminate fallers from non-fallers were poor. The AUC values

were as follows: ABC (0.366), TUG (0.554), BBS (0.426), and FAB (0.437). Poor results should not rule out these assessment tools for clinical settings. Rather, they should be looked at in a different light. In addition to fall risk, it is important to assess the functional capacity of older adults, specifically those movements involved in everyday activities. Clinical assessments should move toward physical tests that incorporate these movements, as well as different physiological systems and components. The BBS was designed to test functional abilities, but lacks effectiveness when used with active, highly functional older adults.²⁷ The FAB includes actions that test the sensory systems (vision, vestibular, proprioception) - standing on foam, eyes closed or open, standing on one leg, etc.²⁷ The adaptive and anticipatory mechanisms are challenged by the reactive postural control and the walking with head turns test items.²⁷ Lastly, the FAB incorporates the musculoskeletal system through almost all test items, but specifically the two-footed jump, tandem walk, and the step up and over.²⁷ Although not predictive of falls, the multidimensional aspects of the FAB have an advantage over the BBS or TUG. The FAB could be used for further assessment of specific balance impairments including muscle weakness, slowed reaction time, or visual impairments.

As for sensitivity and specificity, most models were better at identifying nonfallers versus fallers. Looking at each measure individually, studies have mixed results on the sensitivity and specificity of these fall risk tools. In our study, the ABC sensitivity for at least one fall versus no falls was 30.0, but the specificity was 80.8 for all participants. Contradictory to our results, Lajoie et al. found the ABC scale to have 84.4% sensitivity to fallers and correct classification of non-fallers with a specificity of 86.7%.²⁶ These results were similar in specificity in our findings, but much higher with sensitivity. Lajoie included residents from nursing homes and defined a fall similar to ours but did not include falls "as a consequence of a violent blow, loss of consciousness, or sudden onset of paralysis."³⁶

Mixed reviews have been published about the predictive ability of the TUG for elderly falls. Our results showed a sensitivity of 30.0% and a specificity of 80.8%. Saunders found a higher sensitivity (44.4%) and lower specificity (68.4) in his study with a great sample size (N=95) of community dwelling older adults.⁴⁸ In a recent study, Bhatt found the TUG to be sensitive (56.0%) and specific (60.0%) to falls.⁶¹ The sensitivity may have been higher because the predictive ability was based on the reproduction of an actual fall. Older adults experienced a forward slip of the right foot through an unannounced release of a floor plate. They received no warning or prior practice. Although this study simulated a slip, it does not take into account the predictive abilities of the TUG with a trip or a backward fall.⁶¹

In our study the BBS had a sensitivity of 30.0% and a specificity of 76.9% for at least one fall. Similar in findings and a community-dwelling population, Muir et al. found a low sensitivity of 25.0% with the BBS for any fall.¹⁵ Although Muir's study was prospective, unlike ours, he found 58% of people with BBS scores at or below 45 fell, and 39% of people with scores above 45 fell.¹⁵ Lajoie also investigated the BBS and found a higher sensitivity (82.5%) and specificity (93.0%), but had a cutoff score of 46 instead of 45 in our study.³⁶ Again Lajoie included nursing home residents, which may account for the higher sensitivities and specificities. Saunders showed the ABC, TUG,

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and BBS scales combined the sensitivity was low (22.2%) and specificity was high (91.2%). His results also showed no significance when the tests were evaluated individually.⁴⁸ Shumway-Cook et al. found the BBS to be sensitive (77%) and specific (86%) to community-dwelling elderly individuals prone to falling.³⁰ Their findings were higher than ours because their cut-off value was 49 while ours was 45. Increasing the cut-off value could label more individuals at risk and would therefore increase the sensitivity.

Lastly, few studies have been done on the FAB, but Hernandez et al. found with a cutoff score of 25 the sensitivity to be 74.6% and specificity to be 52.6%.²⁶ Our study found a lower sensitivity for the FAB to be 55.0% and a higher specificity to be 69.2% They had a much larger sample size (N=192) but a similar mean age $(77 \pm 6.5 \text{ years})$.²⁶ Hernandez may have found higher sensitivity because they only included older adults with two or more falls within the past year. This eliminates older adults with a single fall that may not necessarily represent the true status of a "faller."

Our results showed an increased sensitivity (from 25.0% to 37.5%) between 60-70 years and 80-100 years. Specificity decreased from 100.0% to a range from 50.0% to 68.8% between the two age groups. This supports our hypothesis that sensitivity would increase with age, although the sensitivities are low for both groups. The increased ability to identify fallers with age is crucial. Take for example the 25.0% sensitivity for the younger group (60-79 years) with 12 fallers. All outcome measures were only able to identify three of the fallers in this group. In a clinical setting, 9 of those patients would not have been identified and would not be referred to a falls prevention program. The consequence of not treating someone could result in another fall which could lead to an injury, lack of independence, and even death. Looking at the ability to identify nonfallers, with age the tests were more likely to misidentify non-fallers as fallers. For example, the FAB had a specificity of 50.0% for the older group (80-100 years) with 16 non-fallers. It correctly identified 8 as non-fallers, but identified the other 8 as fallers when they were not. It would not be harmful to send these 8 patients to a falls prevention program. These older adults would participate in strength, flexibility, and balance training that they should already be doing anyways.

Study Limitations

The study was limited by several factors. First, the population consisted of healthy, independent living older adults. The findings and conclusions may have been different in a population with greater frailty, comorbidities, or balance disorders. Secondly, although the sample size was small, another study with a similar population and larger sample size⁴⁸, showed congruent results. It would have been beneficial to have a larger sample size to divide into four age categories instead of two: 60-69, 70- 79, 80-89, 90-100 years old. Lastly, the discriminative abilities of the tests were based on previous six month history of falls. Results may have been different had it been a

Chapter 4: Conclusion

In this study, there were no significant differences between fallers and non-fallers in regards to age, gender, scores on the ABC, TUG, BBS, and FAB, prescription medications, lower body joint replacements, presence of arthritis, and assistive device use. None were significant predictors of falls. Although the ABC, TUG, BBS, and FAB were significantly associated with each other, their abilities to discriminate fallers from non-fallers were poor. In general the tests were better able to classify non-fallers than fallers, indicated by a larger specificity than sensitivity. Sensitivity increased and specificity decreased with age (60-79 years to 80-100 years), but values were low. We suggest these tools be used to assess functional capabilities and paired with other measures for a total fall risk assessment. Evaluations of home modifications, prescription medications, assistive device use, and vision and hearing would harmonize well with these physical function tests.

References:

- 1. Ko B, Sl W-D, Ji W, B M. Measuring balance in the elderly: validation of an instrument. *Can J Public Health Rev Can Sante Publique*. 1991;83 Suppl 2:S7-S11.
- 2. Qutubuddin AA, Pegg PO, Cifu DX, Brown R, McNamee S, Carne W. Validating the Berg Balance Scale for patients with Parkinson's disease: a key to rehabilitation evaluation. *Arch Phys Med Rehabil*. 2005;86(4):789-792. doi:10.1016/j.apmr.2004.11.005.
- 3. Klein P J, Fiedler R C, Rose D J. Rasch analysis of the Fullerton Advanced Balance (FAB) Scale. *Physiother Can.* 2011;63(1):115-125. doi:10.3138/ptc.2009-51.
- 4. Bischoff HA, Stähelin HB, Monsch AU, et al. Identifying a cut-off point for normal mobility: a comparison of the timed "up and go" test in community-dwelling and institutionalised elderly women. *Age Ageing*. 2003;32(3):315-320. doi:10.1093/ageing/32.3.315.
- 5. D P, S R. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc.* 1991;39(2):142-148.
- Powell LE, Myers AM. The Activities-specific Balance Confidence (ABC) Scale. J Gerontol A Biol Sci Med Sci. 1995;50A(1):M28-M34. doi:10.1093/gerona/50A.1.M28.
- 7. Chandler J, Newton RA, Thorbahn LDB. Use of the Berg balance test to predict falls in elderly persons. *Phys Ther*. 1996;76(6):576+.
- Muir SW, Speechley M. Establishing Predictive Validity of the Fullerton Advanced Balance Scale. *Arch Phys Med Rehabil.* 2010;91(7):1147. doi:10.1016/j.apmr.2010.03.003.
- 9. Beauchet O, Fantino B, Allali G, Muir SW, Montero-Odasso M, Annweiler C. Timed Up and Go test and risk of falls in older adults: a systematic review. *J Nutr Health Aging*. 2011;15(10):933-938.
- 10. *Exercise Physiology: Nutrition, Energy, and Human Performance.* http://www.alibris.com/Exercise-Physiology-Nutrition-Energy-and-Human-

Performance-William-D-McArdle-PhD/book/11811952. Accessed February 1, 2015.

- CDC State of Aging and Health in America (SAHA) Aging Healthy Aging for Older Adults. http://www.cdc.gov/aging/help/dph-aging/state-aging-health.html. Accessed February 1, 2015.
- 12. Lakatta EG. Age-associated Cardiovascular Changes in Health: Impact on Cardiovascular Disease in Older Persons. *Heart Fail Rev.* 2002;7(1):29-49. doi:10.1023/A:1013797722156.
- 13. Bolam K. *Nutrition and Performance in Masters Athletes*.; 2015. http://alltitles.ebrary.com/Doc?id=10949638. Accessed February 2, 2015.
- 14. Vandervoort AA. Aging of the human neuromuscular system. *Muscle Nerve*. 2002;25(1):17-25.
- 15. Winter DA, Patla AE, Frank JS, Walt SE. Biomechanical Walking Pattern Changes in the Fit and Healthy Elderly. *Phys Ther*. 1990;70(6):340-347.
- 16. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. *Age Ageing*. 2006;35:37.
- CDC Older Adult Falls Falls in Nursing Homes Home and Recreational Safety - Injury Center. http://www.cdc.gov/HomeandRecreationalSafety/Falls/nursing.html. Accessed February 4, 2015.
- Bloch F, Thibaud M, Dugue B, Breque C, Rigaud A, Kemoun G. Episodes of falling among elderly people: a systematic review and meta-analysis of social and demographic pre-disposing characteristics. *Clinics*. 2010;65(9):895-903. doi:10.1590/S1807-59322010000900013.
- CDC Older Adult Falls Costs of Falls Among Older Adults Home and Recreational Safety - Injury Center. http://www.cdc.gov/homeandrecreationalsafety/falls/fallcost.html. Accessed September 6, 2014.
- O'Loughlin, JL; YR; Boivin JF, Suissa S. Incidence of and Risk Factors for Falls and Injurious Falls among the Community-dwelling Elderly. *Am J Epidemiol*. 1993;137(3).
- 21. Farahmand BY, Michaëlsson K, Ahlbom A, Ljunghall S, Baron JA. Survival after hip fracture. Osteoporos Int J Establ Result Coop Eur Found Osteoporos Natl Osteoporos Found USA. 2005;16(12):1583-1590.

- 22. Berg KO, Wood-Dauphinee SL, Williams JI, Maki B. Measuring Balance in the Elderly: Validation of an Instrument. *Can J Public Health Rev Can Santee Publique*. 1992;83:S7-S11.
- 23. Steffen TM, Hacker TA, Mollinger L. Age- and Gender-Related Test Performance in Community-Dwelling Elderly People: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and Gait Speeds. *Phys Ther*. 2002;82(2):128-137.
- 24. Berg K. Measuring balance in the elderly: preliminary development of an instrument. *Physiother Can.* 1989;41(6):304-311. doi:10.3138/ptc.41.6.304.
- 25. Muir S, Berg K, Chesworth B, Speechley M. Use of the Berg Balance Scale for predicting multiple falls in community-dwelling elderly people: a prospective study. *Phys Ther*. 2008;88(4):449-459. doi:10.2522/ptj.20070251.
- Hernandez D, Rose DJ. Predicting which older adults will or will not fall using the Fullerton Advanced Balance scale. *Arch Phys Med Rehabil*. 2008;89(12):2309-2315. doi:10.1016/j.apmr.2008.05.020.
- Rose DJ, Lucchese N, Wiersma LD. Development of a Multidimensional Balance Scale for Use With Functionally Independent Older Adults. *Arch Phys Med Rehabil*. 2006;87(11):1478-1485. doi:10.1016/j.apmr.2006.07.263.
- 28. Feasibility and measurement properties of the functional reach and thetimed up and go tests in the Canadian study of health and aging. *J Gerontol A Biol Sci Med Sci*. 2000;55(2):M70-M73. doi:10.1093/gerona/55.2.M70.
- 29. Greene BR, Donovan AO, Romero-Ortuno R, Cogan L, Scanaill CN, Kenny RA. Quantitative Falls Risk Assessment Using the Timed Up and Go Test. *IEEE Trans Biomed Eng.* 2010;57(12):2918-2926. doi:10.1109/TBME.2010.2083659.
- Shumway-Cook A, Brauer S, Woollacott M. Predicting the Probability for Falls in Community-Dwelling Older Adults Using the Timed Up & Go Test. *Phys Ther*. 2000;80(9):896-903.
- Viccaro L J, Perera S, Studenski S A. Is Timed Up and Go Better Than Gait Speed in Predicting Health, Function, and Falls in Older Adults? *J Am Geriatr Soc.* 2011;59(5):887-892. doi:10.1111/j.1532-5415.2011.03336.x.
- 32. Sai AJ, Gallagher JC, Smith LM, Logsdon S. Fall predictors in the community dwelling elderly: a cross sectional and prospective cohort study. *J Musculoskelet Neuronal Interact*. 2010;10(2):142-150.

- 33. Boulgarides LK, McGinty SM, Willett JA, Barnes CW. Use of Clinical and Impairment-Based Tests to Predict Falls by Community-Dwelling Older Adults. *Phys Ther*. 2003;83(4):328-339.
- Schoene D, Wu SM-S, Mikolaizak AS, et al. Discriminative ability and predictive validity of the timed up and go test in identifying older people who fall: systematic review and meta-analysis. *J Am Geriatr Soc.* 2013;61(2):202-208. doi:10.1111/jgs.12106.
- 35. Barry E, Galvin R, Keogh C, Horgan F, Fahey T. Is the Timed Up and Go test a useful predictor of risk of falls in community dwelling older adults: a systematic review and meta- analysis. *BMC Geriatr*. 2014;14(1):14. doi:10.1186/1471-2318-14-14.
- Lajoie Y, Gallagher SP. Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers. *Arch Gerontol Geriatr*. 2004;38(1):11-26. doi:10.1016/S0167-4943(03)00082-7.
- 37. Herman T, Inbar-Borovsky N, Brozgol M, Giladi N, Hausdorff JM. The Dynamic Gait Index in Healthy Older Adults: The Role of Stair Climbing, Fear of Falling and Gender. *Gait Posture*. 2009;29(2):237-241. doi:10.1016/j.gaitpost.2008.08.013.
- Rehab Measures Activities-Specific Balance Confidence Scale... Rehabil Meas Database. http://www.rehabmeasures.org/Lists/RehabMeasures/DispForm.aspx?ID=949. Accessed January 12, 2015.
- 39. Hatch J, Gill-Body KM, Portney LG. Determinants of Balance Confidence in Community-Dwelling Elderly People. *Phys Ther*. 2003;83(12):1072-1079.
- 40. Legters K. Fear of Falling. *Phys Ther*. 2002;82(3):264-272.
- 41. Chang JT, Morton SC, Rubenstein LZ, et al. Interventions for the prevention of falls in older adults: systematic review and meta-analysis of randomised clinical trials. *BMJ*. 2004;328(7441):680. doi:10.1136/bmj.328.7441.680.
- 42. Grabiner MD, Crenshaw JR, Hurt CP, Rosenblatt NJ, Troy KL. Exercise-based fall prevention: can you be a bit more specific? *Exerc Sport Sci Rev.* 2014;42(4):161-168.
- 43. Robitaille Y, Laforest S, Fournier M, et al. Moving Forward in Fall Prevention: An Intervention to Improve Balance Among Older Adults in Real-World Settings. *Am J Public Health*. 2005;95(11):2049-2056.

- 44. Rubenstein LZ, Josephson KR. Falls and their prevention in elderly people: what does the evidence show? *Med Clin North Am.* 2006;90(5):807-824. doi:10.1016/j.mcna.2006.05.013.
- 45. Barnett A, Smith B, Lord SR, Williams M, Baumand A. Community-based group exercise improves balance and reduces falls in at-risk older people: a randomised controlled trial. *Age Ageing*. 2003;32(4):407-414. doi:10.1093/ageing/32.4.407.
- 46. Day L, Fildes B, Gordon I, Fitzharris M, Flamer H, Lord S. Randomised factorial trial of falls prevention among older people living in their own homes. *BMJ*. 2002;325(7356):128.
- 47. Suzuki T, Kim H, Yoshida H, Ishizaki T. Randomized controlled trial of exercise intervention for the prevention of falls in community-dwelling elderly Japanese women. *J Bone Miner Metab.* 2004;22(6):602-611. doi:10.1007/s00774-004-0530-2.
- Saunders N. Reliability and Validity of an Accelerometer-based Balance Assessment for Fall Risk Screening. 2013. https://etd.ohiolink.edu/ap/10?0::NO:10:P10_ACCESSION_NUM:osu1372337896. Accessed June 13, 2015.
- 49. Botner EM, Miller WC, Eng JJ. Measurement properties of the Activities-specific Balance Confidence Scale among individuals with stroke. *Disabil Rehabil*. 2005;27(4):156-163.
- 50. Morris S, Morris ME, Iansek R. Reliability of measurements obtained with the Timed "Up & Go" test in people with Parkinson disease. *Phys Ther*. 2001;81(2):810-818.
- 51. Brusse KJ, Zimdars S, Zalewski KR, Steffen TM. Testing functional performance in people with Parkinson disease. *Phys Ther*. 2005;85(2):134-141.
- 52. Thomas JI, Lane JV. A Pilot Study to Explore the Predictive Validity of 4 Measures of Falls Risk in Frail Elderly Patients. *YAPMR Arch Phys Med Rehabil*. 2005;86(8):1636-1640.
- Andersson Å, Kamwendo K, Seiger Å, Appelros P. HOW TO IDENTIFY POTENTIAL FALLERS IN A STROKE UNIT: VALIDITY INDEXES OF 4 TEST METHODS. J Rehabil Med Taylor Francis Ltd. 2006;38(3).
- 54. Flansbjer U-B, Holmbäck AM, Downham D, Patten C, Lexell J. RELIABILITY OF GAIT PERFORMANCE TESTS IN MEN AND WOMEN WITH HEMIPARESIS AFTER STROKE. *J Rehabil Med Taylor Francis Ltd.* 2005;37(2).

- 55. Currie L. Fall and Injury Prevention. In: Hughes RG, ed. Patient Safety and Quality: An Evidence-Based Handbook for Nurses. Vol Advances in Patient Safety. Rockville (MD): Agency for Healthcare Research and Quality (US); 2008. http://www.ncbi.nlm.nih.gov/books/NBK2653/. Accessed June 29, 2015.
- 56. Bandura A. Self-Efficacy: The Exercise of Control. Macmillan; 1997.
- 57. Barbour KE, Stevens JA, Helmick CG, et al. Falls and fall injuries among adults with arthritis--United States, 2012. *MMWR Morb Mortal Wkly Rep.* 2014;63(17):379-383.
- Robbins AS, Rubenstein LZ, Josephson KR, Schulman BL, Osterweil D, Fine G. Predictors of falls among elderly people: Results of two population-based studies. *Arch Intern Med.* 1989;149(7):1628-1633. doi:10.1001/archinte.1989.00390070138022.
- 59. Sainsbury R, Mulley GP. Walking sticks used by the elderly. *Br Med J Clin Res Ed.* 1982;284(6331):1751-1751. doi:10.1136/bmj.284.6331.1751.
- 60. Dean E, Paoni L, Ross J, Yack HJ. Relationships among cane fitting, function, and falls. *Phys Ther.* 1993;73(8):494+.
- 61. Bhatt T, Espy D, Yang F, Pai Y. Dynamic Gait Stability, Clinical Correlates, and Prognosis of Falls Among Community-Dwelling Older Adults. *Arch Phys Med Rehabil*. 2011;92(5):799-805.