# Are Mobile Gait Sensors a Better Tool at Predicting Elder Falls in the Emergency Department Setting Than the Current Screening Questionnaire?

by

**James N. Huber**

BS, Molecular Biology, University of Pittsburgh, 2018

Submitted to the Graduate Faculty of

Health Policy and Management

Graduate School of Public Health in partial fulfillment

of the requirements for the degree of

Master of Public Health

University of Pittsburgh

2021

UNIVERSITY OF PITTSBURGH

GRADUATE SCHOOL OF PUBLIC HEALTH

This thesis was presented

by

**James N. Huber**

It was defended on

April 20, 2021

and approved by

Steven Albert, PhD, MS, FGSA, Professor and Chair; Department of Behavioral and Community Health Sciences, Graduate School of Public Health

Adam Frisch, MD, MA, Assistant Professor; Department of Emergency Medicine

Thesis Advisor: Howard Degenholtz, PhD, Associate Professor; Department of Health Policy and Management, Graduate School of Public Health

**Are Mobile Gait Sensors a Better Tool at Predicting Elder Falls in the Emergency Department Setting Than the Current Screening Questionnaire?**

James N. Huber, MPH

University of Pittsburgh, 2021

## Abstract

Elder falls are becoming an increasing area of concern for rising Medicare expenditures in the United States, especially as Medicare-eligible individuals continue to make up a larger proportion of the total population. One way to reduce these expenditures is to improve our ability to predict future falls in this population, thereby allowing clinicians to provide fall-prevention strategies before an injurious (and costly) fall occurs. While current recommendations for fall prediction strategies in the Emergency Department setting primarily focus on fall risk questionnaires, mobile gait assessments may offer greater predictive potential. This study aimed to compare several different fall assessment strategies to gauge which strategy offers the greatest potential for elder fall risk identification.

## Table of Contents

## List of Tables

## List of Figures

## Preface

Funding for this project was provided by the Shadyside Research Foundation and the University of Pittsburgh Claude D. Pepper Center Pilot Grant through the University of Pittsburgh Department of Emergency Medicine. Special thanks is owed to Adam Frisch, MD, MA; the Principal Investigator of this project. Dr. Frisch oversaw the study design and concept of this project, as well as the acquisition of study funding. He also helped to provide pivotal feedback during data analysis and the interpretation of study results for this thesis paper. Dr. Frisch served as Third Reader for this thesis paper.

It is also important to acknowledge Howard Degenholtz, PhD, the Primary Essay Reader and Thesis Adviser; and Steven Albert, PhD, MS, FGSA, the Second Reader for this paper, for their contributions and feedback throughout the writing and editing process.

## 1.0 Introduction

In the United States, Medicare is a federally funded national health insurance program available to elderly adults and younger individuals with certain disabilities. In 2016, there were approximately 50 million adults aged 65 or older in the country, the minimum age requirement for Medicare enrollment (without certain disabilities). These Medicare-eligible individuals accounted for 15.2% of the total US population.[1] At the same time, there were roughly 200 million Americans between the ages of 18-64, generally considered prime working years. This group comprised nearly 62% of the US population[1] **(Figure 1)**. While Medicare enrollment only included 15% of the national population, its services accounted for over $670 billion in healthcare expenditures; this was more than one-fifth of the national total[2] **(Figure 2)**.

This is to be expected; as a population ages, so too will its prevalence of chronic disease and disability. One CDC study conducted by the National Center for Health Statistics (NCHS) found that, for a selection of nine self-reported chronic conditions; including hypertension, heart disease, diabetes, and stroke, prevalence among Medicare-eligible adults was about double that of the 45-64 age group[3] **(Figure 3)**. And as medical care continues to improve and increase the life expectancy of older adults, these chronic conditions will only become more common. In the United States today, nearly 80% of adults aged 65 and over have been diagnosed with at least one chronic health condition, and nearly half have two chronic conditions or more.[4] Many of these chronic diseases and disabilities will result in increased healthcare expenditures, especially when these elderly individuals continue to account for an increasing proportion of the total population.

Although adults aged 65 and older currently only account for 15% of the total US population, the continued aging of the Baby Boomer generation into Medicare eligibility, coupled with the decreasing fertility rate among working-age adults in the United States today, will continue to drive this elderly proportion higher. According to projections by the United States Census Bureau, by the year 2030 the number of Medicaid-eligible adults will rise to nearly 75 million, or 20.6% of the total population. At the same time, the number of working-age adults will only rise six million, from 200 to 206 million (58.1% of the total population)[1].

As the US population continues to get older and working-age Americans make up a smaller percentage of the total population, entitlement programs such as Medicare will continue to be stretched thinner and thinner. And as time wears on, the projections get worse. By the year 2060, the US Census Bureau projects that the number of Medicare-eligible Americans will balloon to 95 million (23.4% of the US population), while working-age adults will make up less than 57% of the total population[1] **(Figure 4)**.

With the growing proportion of elderly adults, we can expect to see a dramatic rise in national healthcare expenditures, particularly from Medicare enrollees. If current population and healthcare utilization projections hold, then it is estimated by the Centers for Medicare and Medicaid Services (CMS) that the Medicare Hospital Insurance (Part A) trust fund will be depleted by 2026.[5] One possible option for reining in Medicare costs will be to reduce per capita expenditures. While there are a wide range of health issues among the Medicare population that will have to be addressed to reduce growing expenditures, one opportunity at curbing healthcare costs may come in the form of fall prevention strategies.

## 1.1 The Costs of Elder Falls

A serious but often overlooked health concern for elderly adults is the increased risk of falls that are experienced as one ages, and the negative health outcomes and reduced quality of life associated with these falls. One generally accepted clinical definition of a fall is "coming to rest unintentionally on the ground or lower level, not due to an acute event" (e.g., seizure, syncope, or stroke) or an overwhelming external force to which any person would be susceptible."[6]

There are several variables that affect the fall risk of an elderly individual. These risk factors can be defined as either modifiable or non-modifiable, and intrinsic or extrinsic. Intrinsic risk factors are related to the individual and include age, chronic conditions, and lifestyle habits such as physical activity and dietary choices. There are a number of health conditions spanning multiple organ systems that can affect an individual's gait pattern, and therefore impact their risk of falling. Extrinsic factors include environmental conditions that can impact an individual's likelihood of falling, including cluttered living spaces, improper lighting, inadequate use of assistive walking devices, improper footwear, and interactions between medications and drugs and alcohol. A combination of these various factors typically determine which individuals are at an increased risk of falling.[7]

Falls are the leading cause of fatal and non-fatal injuries among older adults in the United States.[8] They are also extremely prevalent in the Medicare population, as fall risk increases with age and reduced physical activity and motor skills. At the same time, injurious falls often result in decreased motor skills and physical activity, making future falls increasingly likely after an initial one has occurred. The National Council on Aging estimates that an older adult is treated in an emergency department for fall-related injuries every 20 seconds; every 20 minutes, a fatal fall occurs.[9] Each year in the United States, about one in every three adults aged 65 and over will experience at least one fall (with varying degrees of injury and disability); this rises to one out of every two adults 80 years or older. At the same time, it is estimated that only one in four community-dwelling older adults will discuss falling and fall risks with their healthcare provider.[10]

While most of these falls will be non-fatal, many will still result in serious injuries and potential long-term disabilities. In 2012 alone, there were roughly 25,000 fatal falls and 3.2 million non-fatal fall-related injuries among US adults aged 65 and over. The direct medical costs associated with these non-fatal falls was just over $30 billion; the direct medical costs associated with fatal falls in the same year was $600 million.[11]

These fall-related costs have risen even higher in recent years. One study found that an estimated $50 billion was spent on direct medical costs related to falls in 2015.[10] To put this in perspective, the total Medicare expenditures in 2015 was just shy of $650 billion; this means that direct medical costs related to falls accounted for nearly 8% of total Medicare expenditures. As greater proportions of Americans gain Medicare eligibility, the costs associated with falls is projected to rise substantially. By the year 2030, the CDC Injury Center estimates that the number of older adult fatal falls will reach 100,000 per year, and the associated costs will reach $100 billion[12] **(Figure 5)**. This does not even begin to account for the reduced quality of life that is often associated with these fall-related injuries.

## 1.2 Elder Falls Prevention Strategies

It is estimated that around 20-30% of falls in older adults result in injury.[13] Because these injurious falls often result in trips to the emergency department and incur high costs, one obvious area for cost reduction potential is elder falls prevention. Fall prevention strategies can be broken into three distinct but interconnected domains, based on current CDC recommendations:[14]

1. Screening of older adult patients for fall-risk
2. Assessing at-risk patients to identify modifiable risk factors
3. Effective intervention strategies to reduce fall-risk

Most fall prevention strategies focus on the third and final step of this process. There are several interventions that have proven successful, to varying degrees, at reducing the risk of serious falls in at-risk individuals. Many of these programs can be single-intervention or multifactorial, and include exercise and educational programs, medication reviews to limit drugs that cause gait impairment, home safety assessments and interventions, Vitamin D supplementation, and interventions to treat vision issues. One systematic review of fall risk interventions that included over 150 randomized trials and 79,000 participants concluded that the risk of falling can be reduced by 20-40% in individuals at elevated risk.[15] While many potential interventions exist, certain types have proven to be more effective at reducing the rate of falls in Medicare populations. Group and home-based exercise programs and home safety interventions (when conducted by an Occupational Therapist) appear to offer the most promise for future fall prevention strategies, as these interventions have been shown to significantly reduce both the rate of falls and the risk of falling in older adult populations.[15]

One cost-benefit analysis conducted by the CDC that focused on three distinct exercise programs at reducing fall risk supports these exercise-based interventions. Based on their findings, the most successful of the programs was *Tai Chi: Moving For Better Balance*. This community-based program is typically conducted during one-hour sessions several times a week, for up to six months. During the classes, instructors take participants through a set of Tai Chi exercises that are focused on increasing postural stability, gait initiation, coordination, and core and lower extremity strength and stability. While the main objectives of this exercise class are improving the mobility and functional balance of participants (and thereby reducing fall risk), secondary gains can include reduced blood pressure, improved sleep quality, and enhanced mental health. [16]

The cost-benefit analysis found that the program had an average cost of $104 per participant and an average expected benefit of $634, or a 509% return on each dollar invested. The other two programs in the cost-benefit analysis also produced positive results, though not as substantial as the *Tai Chi* program. The *Otago Exercise Program* and the *Stepping On* program had return on investments of 127% and 64%, respectively[17] **(Figure 6)**.

While each of these three exercise programs offered cost-effective fall risk interventions for older adults, the high utilization cost per participant could act as a deterrent to increasing access to such programs for Medicare enrollees. The same issue arises for other interventions that require at-home assessments or continued treatment for gait and balance issues, which can prove costly if not tailored to the correct patient population. Although the return on investment for these programs may be promising, the high initial costs incurred by these services limit the potential future cost-savings. However, one (largely) overlooked area of elder falls prevention, the actual methods used to predict at-risk individuals, may help in this regard. More fine-tuned prediction methods would allow healthcare providers to focus fall prevention resources on patients at greatest risk, reducing some of the costs incurred by patients that are at a reduced risk for injurious falls and may not necessarily need these programs.

### 1.3 Predicting Fall Risk in Medicare Populations

Because there are a number of variables that affect the likelihood of a fall, there are a number of ways to attempt to predict the fall risk of an individual. Due to these many factors, there is currently no global assessment tool that is able to appropriately predict fall risk. A multivariate analysis conducted by researchers at the University of California Los Angeles (UCLA) found that the most consistent predictors of future falls include previous falls and gait or balance abnormalities.[18]

There are currently several strategies employed to predict fall-risk among Medicare-eligible adults. As part of the Initial Preventive Physical Examination (IPPE) conducted once within the first twelve months of Medicare enrollment, the healthcare provider must complete a clinical review of the patient's functional ability, including their fall risk. This same assessment is required to be completed at each subsequent Annual Wellness Visit.[8] Based on CDC recommendations, the following questions should be asked during these clinical fall risk assessments:

1. Have you fallen in the past year?
2. Do you feel unsteady when walking or standing?
3. Do you worry about falling?[10]

Because previous falls is a consistent predictor of future falls, this initial set of questions make sense. The CDC also offers a 20-question fall risk questionnaire for patients with indications for elevated fall risk based on the initial three-question triage.[10] Though helpful, this questionnaire is not required.

In addition to these questionnaires, there are also several functional performance assessments that can be used by clinicians to gauge potential fall risk. These functional assessments include the Timed Get-Up-and-Go task, the Sit-to-Stand test, and the Four-Stage Balance test, each of which requires the patient to perform general physical functions while being either observed by a healthcare provider or while data is collected from the patient electronically.[10] Each of these functional exams offers a relatively quick and moderately effective method of gauging fall risk in elderly patients.[19]

While there are numerous methodologies currently used to predict fall risk, one area that shows considerable promise is the use of wearable sensors to evaluate gait patterns that may be predictive of future falls. With the continued evolution of technology, smart phones are now able to collect information on gait and balance through mobile apps that collect accelerometer data with tasks as simple as standing from a chair and walking. A meta-analysis of 13 studies using wearable sensors found that timed Get-Up-and-Go tasks were predictive of future falls. However, these studies were generally performed in controlled research settings, with healthy and non-elderly populations.[20]

Though it is obvious that high fidelity fall risk prediction methods would offer substantial cost-savings potential, these prediction methods currently have limited use in the primary care setting. This is particularly true in emergency departments, where the use of gait-sensors and timed functionality exams are often considered unnecessary and impractical with acutely ill patients and limited time to conduct these assessments. Based on current CDC recommendations for elder fall prediction methods in the Emergency Department setting, gait evaluation is not recommended for elder patients unless they answer yes to one of the three fall survey questions **(Figure 7)**.[21] This is in line with recommendations made by the American Geriatrics Society, who also suggest screening elderly patients with a set of survey questions prior to evaluating for potential gait abnormalities **(Figure 8)**.[22]

However, these acutely ill patients are, in all likelihood, at increased risk of falling compared to their baseline, non-acute levels. Therefore, an emphasis on fall risk should be placed on these patients. The main study question is whether an algorithm that prioritizes gait assessment through a mobile Get-Up-and-Go task instead of survey questions (or a combination of the two assessments) would increase the clinician's ability to predict fall risk in acutely ill elderly patients?

## 2.0 Research Objective

In this project, we aimed to evaluate the ability of mobile gait sensors to predict future falls in an undifferentiated older adult population in the emergency department setting. Specifically, we aimed to compare the predictive ability of future falls between three separate but related diagnostic tools: the currently recommended and standard-of-care fall survey questionnaires, the time to completion of a Get-Up-and-Go task, and a combination of the two metrics.

# 3.0 Research Methods

### *Subject Consent*

We prospectively enrolled a convenience sample of older adults (60 years and older) who presented for care to a local emergency department within the UPMC system. Before approaching potential participants, researchers confirmed with the clinical care team that the patient was both able to consent themselves for the study and would be physically capable of performing the gait assessment task. After initial review by the clinical care team, patients were approached by the researchers and consented.

The consent process included informing the research participants of the activities they would be performing: a short fall assessment questionnaire, a timed Get-Up-and-Go walking task during which the researcher would be recording gait data from a smartphone, and follow-up calls at 30-days and 90-days post enrollment. In addition to these activities, potential research subjects also had to consent to an electronic chart review at 90-days post enrollment. Subjects were given ample time to review the informed consent form and ask any relevant questions during the consent process. IRB approval for this pilot project was provided by the University of Pittsburgh.

After informed consent was completed, research subjects were asked to complete a 25-question survey that included demographic information and fall assessment questions **(Figure 9).** A researcher was present at all times during survey completion to answer any questions that the subject may have. The answers were recorded on paper, and then transcribed to RedCap by a member of the research team.

Subjects were also asked to complete a Contact Form, which included phone and email information to allow researchers to contact the subjects for the follow-up calls. This information was recorded on paper, and then transcribed to a secure excel sheet housed behind UPMC and University of Pittsburgh firewalls. Each participant was given a unique Subject ID, which was used to link their contact information on excel to the demographic and survey question data on Redcap.

*Walking Trial*

For the walking trial, we collected accelerometer data from the free smartphone app Phyphox (www.phyphox.org). Prior to beginning the Get-Up-and-Go task, a study smartphone was placed on the lower back of the subject using an elastic belt. Subjects were then instructed to complete the following tasks in succession, at whatever their typical pace is **(Figure 10)**.[23]

1. Stand up from chair
2. Walk 10 steps in a forward line
3. Turn around in place
4. Walk 10 steps in a forward line back to original position
5. Sit down in the chair

Just before subjects began the Get-Up-and-Go task, researchers would turn on the accelerometer app so that it began recording data. After task completion, researchers would stop data collection from the accelerometer app, remove the smartphone and elastic belt from the subject, and download the accelerometer data to a secure file. These files were also stored behind UPMC and University of Pittsburgh firewalls.

*Participant Follow Up*

Research participants were contacted by phone for follow-up interviews at approximately 30-days and 90-days post-emergency department visit, using the contact information provided during the enrollment process. Participants were asked about any subsequent falls, or near falls, in the time since study enrollment. If a fall had occurred, subjects were also asked whether the fall resulted in any serious injury, or if hospital evaluation was required, along with several additional questions **(Figure 11)**. These answers were recorded on RedCap. After the 90-day follow-up phone interview was completed, chart reviews were also conducted by members of the research team to verify subject responses.

*Gait Feature Extraction*

The Phyphox accelerometer app captured linear accelerations (in units of $ms^2$) at a frequency of 90-Hz from the x, y, and z directions which correspond to the mediolateral (ML), vertical (V), and anteroposterior (AP) directions. We first labeled accelerometer time-series data into the segments described above (numbered 1-5 under *Walking Trials* section). Accelerometry data for each segment was further segmented into 1-second windows with a 50% overlap consistent with prior machine learning studies.[24]

The chosen feature for this analysis was time to completion of the walking task. Time to completion for the walking task was calculated by taking the difference in time from the start of segment 1 until the end of segment 5. The participants' time to completion was then organized by quartiles. Since it is estimated that roughly one-third of elder adults will fall each year, the $75^{th}$ quartile was chosen as the timepoint cut-off for fall risk (corresponding to the $25^{\%}$ of participants that took the longest to complete the walking task). While there are additional gait parameters that could be included in an analysis of future falls prediction, this paper focused primarily on the time component.

### *Combining Assessments*

The third diagnostic tool to be assessed used a combination of the survey questions and timed Get-up-and-Go task to predict future fall risk. In this scenario, only the individuals who answered ‘Yes’ to any of the three CDC fall-survey questions were considered for gait assessment. These individuals were then separated into ‘fall risk’ and ‘no fall risk’ based on their time to completion for the gait task (again, the $75^{th}$ quartile was used as the cut-off point). Individuals that did not answer ‘Yes’ to any of the three fall-survey questions were also placed into the ‘No Risk’ category.

## 4.0 Results

From May to October 2019, a total of 135 emergency department patients were enrolled into this research study. The mean age of the participants was 69 years old, with ages ranging from 60 to 94 years. Most study participants were male (60%) and white (68%). Most participants were single (47%) and lived alone (39%).

Of the 135 participants who completed the Fall Assessment Questionnaire, 60 (44.4%) indicated that they had fallen in the previous year, 52 (38.5%) indicated that they felt unsteady when walking, and 40 (29.6%) indicated that they worried about falling. There were 88 participants who answered yes to any of the three primary fall assessment questions (65.2%); indicating that these individuals are at an increased risk of future falls based on current recommendations. See **Table 1** for a breakdown of participant demographics and fall assessment survey responses.

There were 28 participants who did not complete either the 30-day or 90-day assessments, which accounted for 20.7% of participants. The follow-up surveys, collected at 30-days and 90-days post-enrollment and conducted by phone interview, had the following response rates:

- 30-Day Response Rate: 92/135 = 68.1%
- 90-Day Response Rate: 76/135 = 56.3%

**Table 2** and **Table 3** contain data obtained from follow-up calls with subjects, in which they indicated whether they had a fall within 30 days or 90 days post-enrollment. These tables are broken down by subject fall risk (Y/N) based on the currently recommended three-question survey.

**Table 4** contains the breakdown of participants' time to completion for the walking task, organized by quartiles. Because the 75$^{th}$ quartile corresponded to a completion time of 26.7 seconds, this time was chosen as the cut-off for fall risk prediction. This corresponded to 34 participants being labeled as 'fall-risk' for this prediction method. **Table 5** contains the outcome measure (Fall → Yes/No) at 30-days, and **Table 6** contains the outcome measure (Fall → Yes/No) at 90-days.

For the third predictive method, a combination of the survey questions and timed gait assessment were used to predict future falls. In this scenario, only individuals who answered 'Yes' to any of the three survey questions were included in the timed gait analysis, which again used the 75$^{th}$ quartile of time-to-completion for its cut-off. This corresponded to 88 individuals with a time-to-completion cut-off of 28.1 seconds. **Table 7** and **Table 8** contain the outcome measurement of (Fall → Yes/No) at 30-days and 90-days respectively for this combo group.

Here is a breakdown of the accuracy of each predictive method:

- CDC Survey (30-days): 29/92 = 31.5%
- CDC Survey (90-days): 32/76 = 42.1%
- Gait Task (30-days): 72/92 = 78.3%
- Gait Task (90-days): 52/76 = 68.4%
- Combo (30-days): 76/92 = 82.6%
- Combo (90-days): 59/76 = 77.6%

Important measurements to consider in a predictive tool include the Positive Predictive Value (PPV) and Negative Predictive Value (NPV), which measure the ability of a tool to accurately predict true positive and true negative results, respectively. **Table 9** contains the positive and negative predictive values (PPV and NPV) of the three diagnostic tests at 30-days and 90-days.

# 5.0 Discussion

The higher the concordance, PPV, and NPV of a diagnostic tool, the better it will be at predicting whether an individual will or will not be a future fall risk. So, comparing these values across the three diagnostic tools should offer insight into which tool offers the most promise.

Based on the concordance, it appears that the Combo Test offers the most predictive value for future fallers (Y/N) across the three diagnostic tools. But because the purpose of a fall-risk assessment tool is to help prevent future falls (and thereby reduce fall expenditures), emphasis should be added to the PPV, and tools with higher PPVs should be prioritized over those with lower PPVs. Both the Fall Assessment Questionnaire and the Gait Task correctly predicted three future falls and missed two future falls at 30-days post-enrollment, whereas the Combo Tool was only able to accurately predict one fall (and missed four). However, the Gait Task was also able to accurately predict more non-fallers than the Questionnaire, indicating that gait assessments may offer the greatest predictive power for fall risk within 30-days among ED patients.

However, as we move farther away from the ED visit, the predictive ability of the Gait Task appears to diminish, as the 90-day assessment data paints a different picture. Even though the Gait Task had a higher overall proportion of correct predictions than the Fall Assessment Questionnaire ($68^{\%}$ to $42^{\%}$, respectively), the Gait Task missed six of the eight participants who indicated a fall between 30-days and 90-days post-enrollment (the Combo Group had even worse results, missing seven out of the eight fallers). At the same time, the Fall Assessment Questionnaire only missed one of these eight participants, indicating that as more time elapses from the index ED visit, fall assessment surveys become more predictive of future falls than mobile gait assessments.

Based on these results, it appears that the most predictive tool for fall-risk among ED patients is a timed Get-up-and-Go task. However, as individuals move farther away from their index ED visit, mobile gait assessments begin to lose their predictive value, and the survey questions become the most predictive tool. Based on these findings, mobile gait assessments should be used to predict falls within 30-days of ED visits, whereas fall-survey questionnaires should be used for longer term prediction methods, and when individuals are not in an acutely ill state.

# 6.0 Limitations

This study had several limitations. The largest limitation was the fact that a considerable portion of study participants did not complete the follow-up survey calls, leading to incomplete and missing outcome data. Only 68.1% of participants completed the 30-day follow-up; this proportion dropped to 56.3% for the 90-day follow-up. **Table 10** offers insight into what the results would have looked like if each of the 'No Response' participants had not fallen at 30-days or 90-days post-enrollment. **Table 11** shows what the results would be if each of the 'No Response' participants had fallen at 30-days and 90-days post-enrollment. Future studies should include alternate contact information for study participants, as well as research payments for the follow-up calls. These strategies should lead to increased follow-up completion rates, which will give a better indication of which diagnostic tool more accurately predicts future falls.

Another limitation of the study had to do with the process by which the mobile gait data was collected. Due to budgetary restraints, researchers were forced to use a single smartphone to collect the gait data. Placing the smartphone in a tight pouch by the small of the patient's back allowed for data collection uniformity and limited erroneous smartphone movement during the walking task, but this location may not be the best placement for accurately recording gait measurements.

Additionally, participants were instructed to complete the walking task at their usual walking pace. Future studies should consider having subjects complete the task as quickly as possible, which may lead to increased variation in the task completion times, thereby increasing the sensitivity of the predictive tool. Future studies should also consider increasing the scope of which mobile gait sensor data to incorporate into their predictive tool. A system that incorporates accelerometer data in the x, y, and z directions, in addition to time parameters, may lead to a more predictive diagnostic method.

## Appendix A – Figures

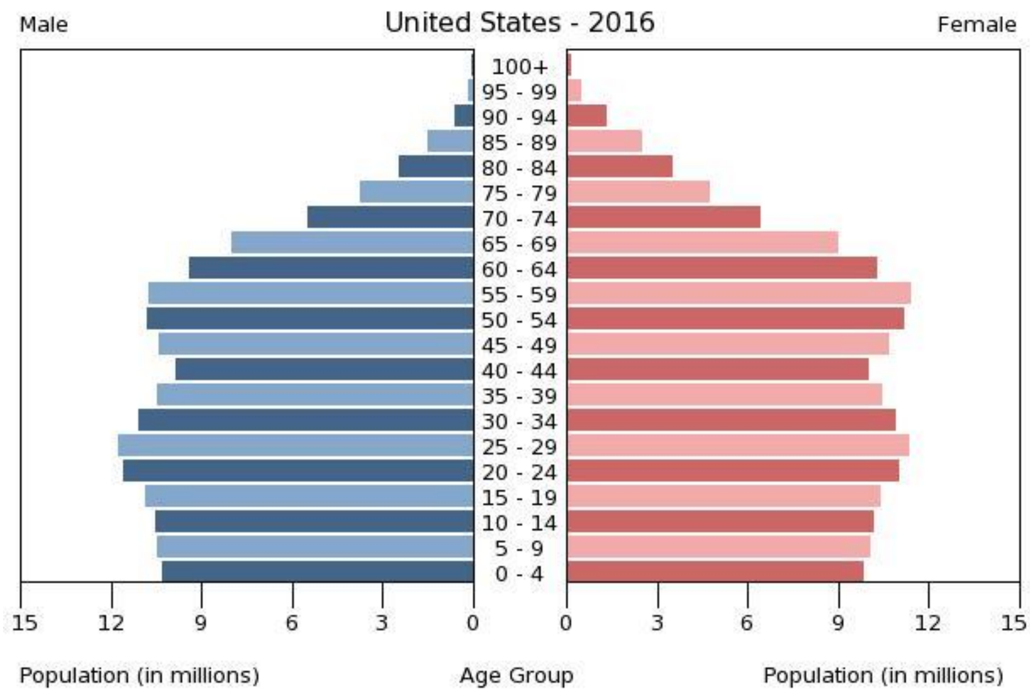


**Figure 1.** US Population Pyramid (2016)

SOURCE: United States Census Bureau, 2016 population.

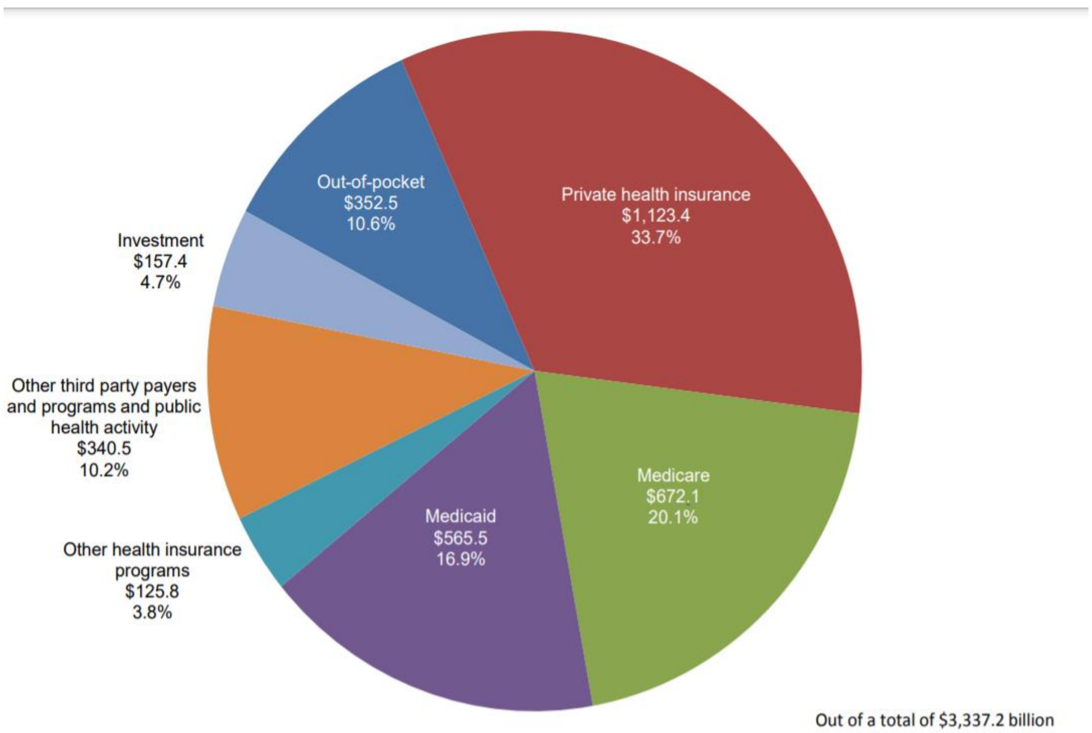


**Figure 2.** 2016 US Healthcare Expenditures by Payer Type.

SOURCE: Rama, Apoorva. "National Health Expenditures, 2016: Annual Spending Growth on the Downswing." Policy Research Perspectives, American Medical Association, Apr. 2018.

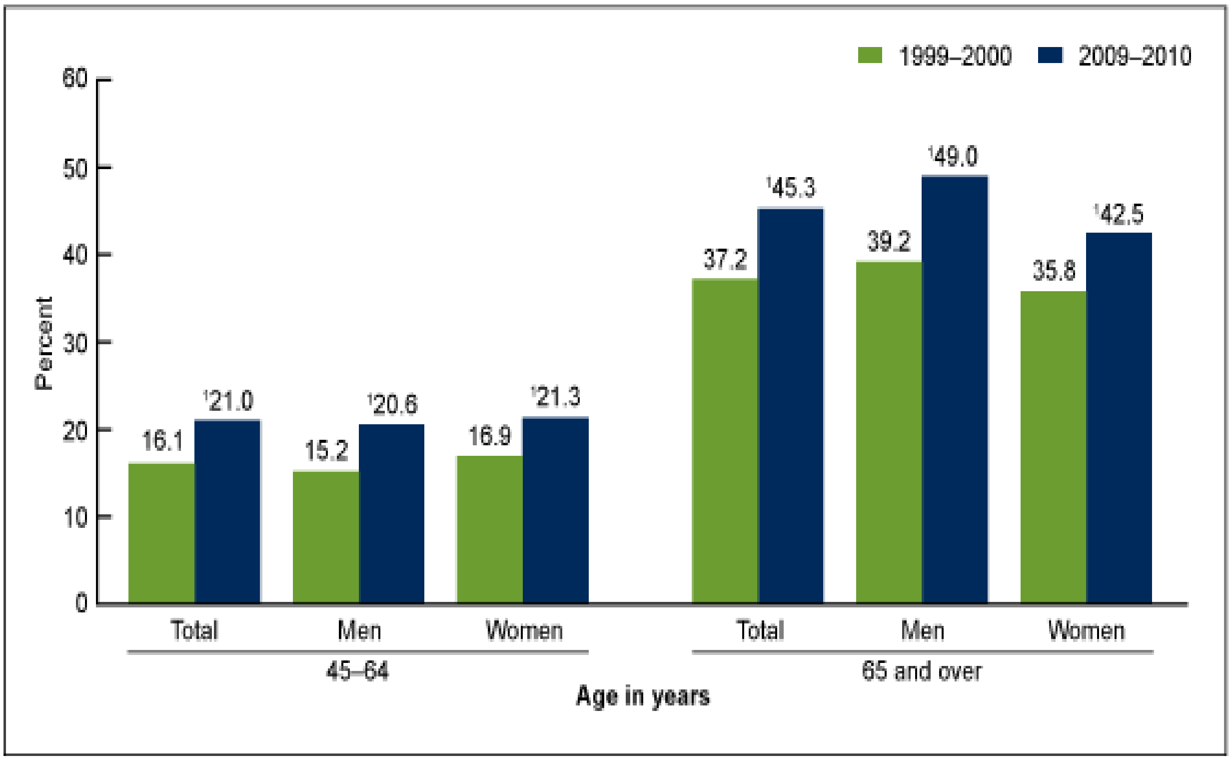


**Figure 3**. Prevalence of two or more of nine selected chronic conditions among adults aged 45 and over, by age and sex: United States, 1999–2000 and 2009–2010

SOURCE: CDC/NCHS, National Health Interview Survey.

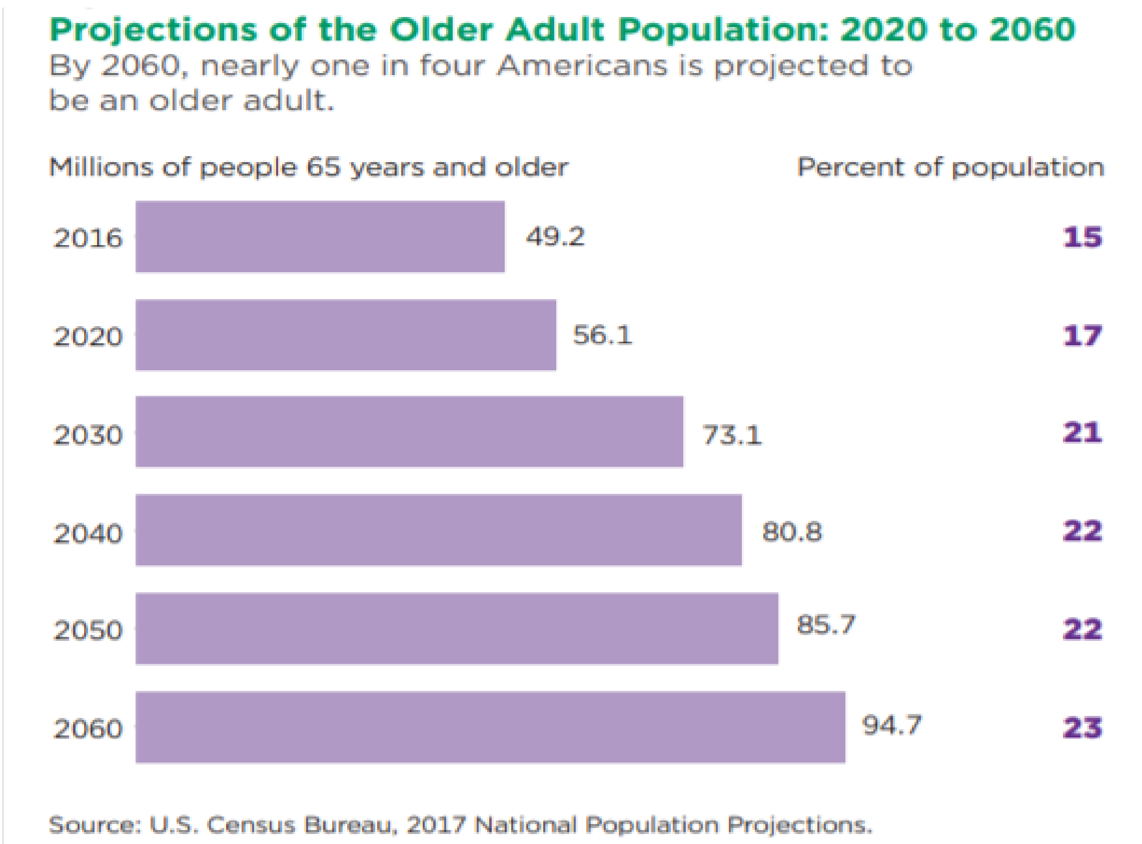


**Figure 4.** US Population Projections 2016-2060.

SOURCE: United States Census Bureau, 2017 National Population Projections

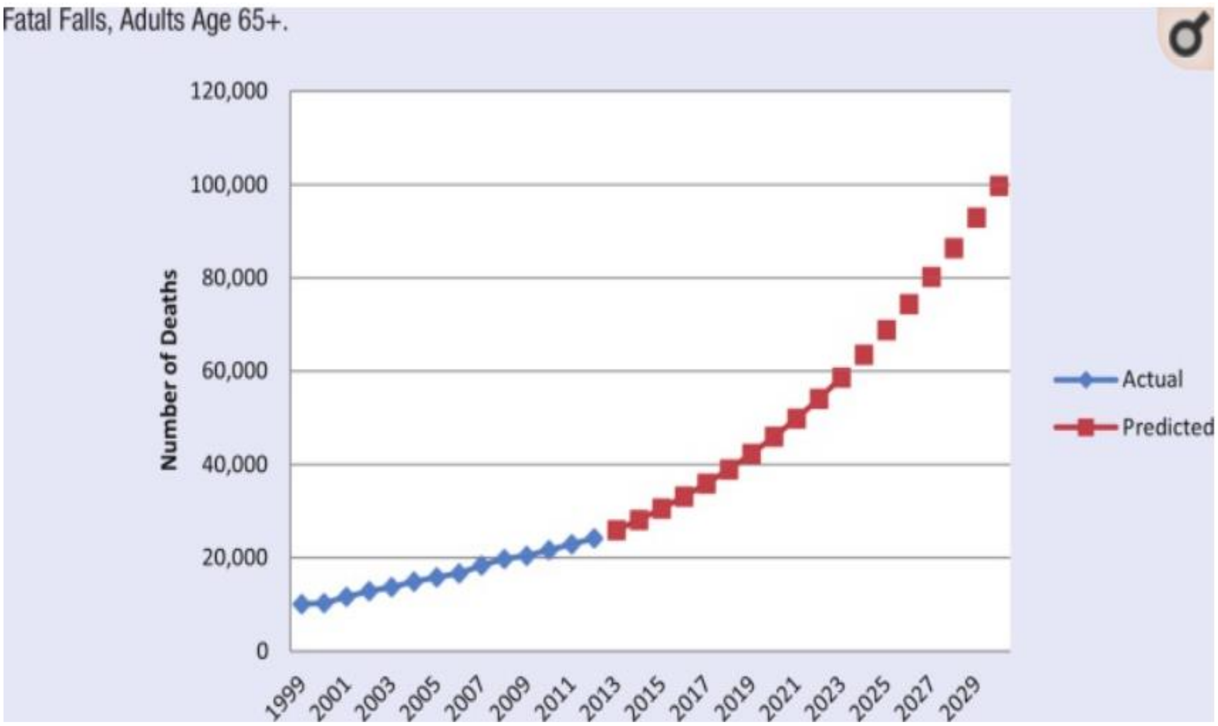


**Figure 5.** Actual and predicted fatal falls in older adults, 1999-2029.

SOURCE: CDC estimates based on WISQARS fatal injury database and US Census Bureau population projections.

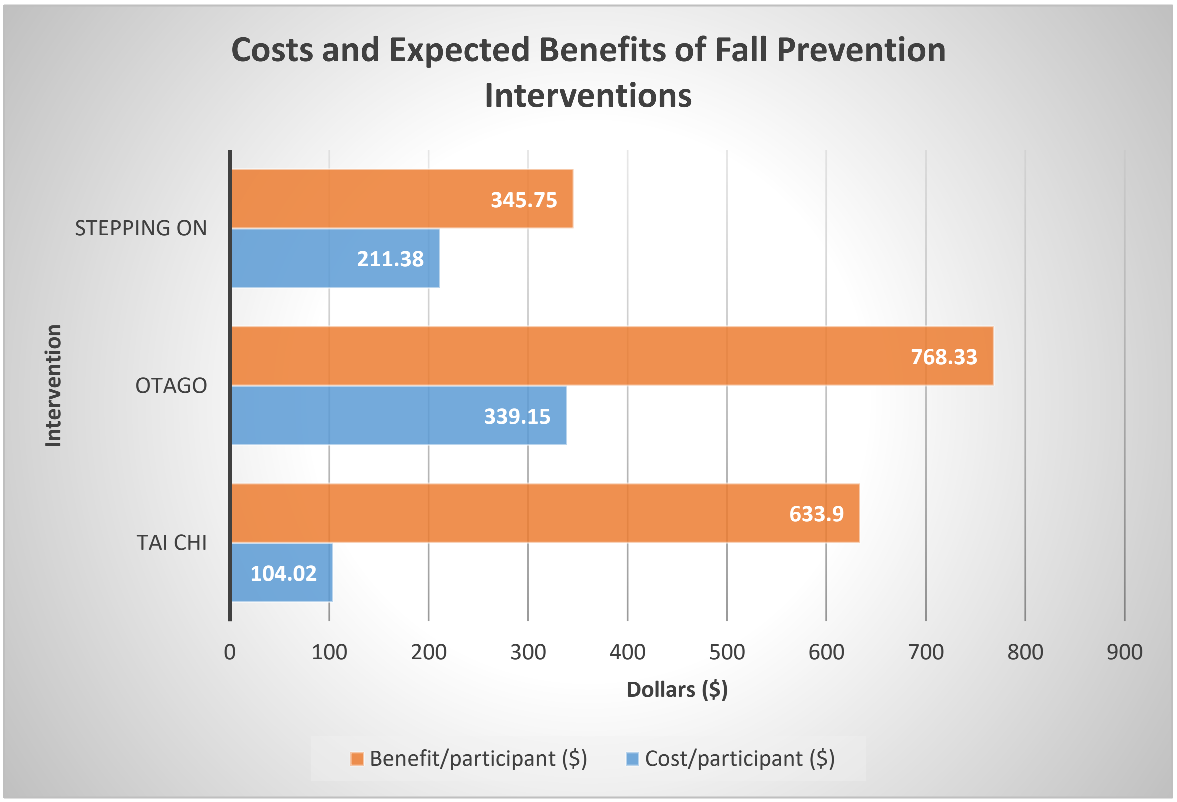


**Figure 6.** Costs and expected benefits of fall prevention interventions.

SOURCE: Data taken from CDC Special Report; February 2015.


**Figure 7**. Current CDC clinical fall assessment algorithm.

SOURCE: US Centers for Disease Control and Prevention, 2019.

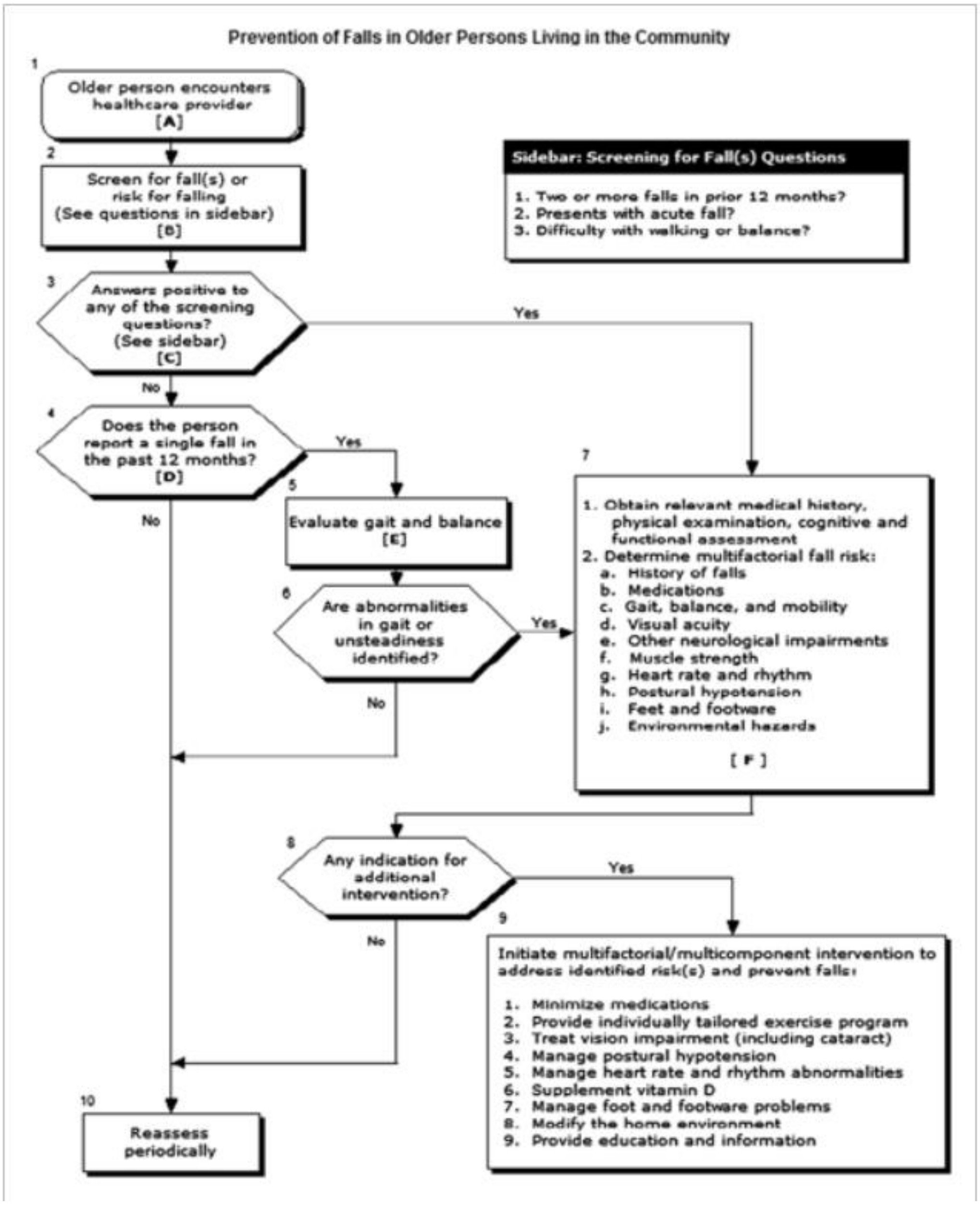


**Figure 8.** Current American Geriatric Society clinical fall assessment algorithm.

SOURCE: American Geriatrics Society, 2011.

| | |
|---|---|
| Record ID | ______________ |
| How old is the patient? | ______________ |
| Are they a man or a woman? | ○ man<br>○ woman |
| How would you best describe your race? | ○ Black<br>○ White<br>○ Other |
| How would you best describe your ethnicity? | ○ Hispanic or Latino<br>○ Not Hispanic or Latino |
| How would you describe your current relationship status? | ○ Married<br>○ Single<br>○ Separated<br>○ Widowed |
| How would you describe your current living arrangement? | ○ Live by self<br>○ Live with another, age >=65 years<br>○ Live with another, age < 65 years<br>○ Live with multiple family members |
| How would you best describe your mobility today? | ○ I have no problems walking<br>○ I have slight problems walking<br>○ I have moderate problems walking<br>○ I have severe problems walking<br>○ I am unable to walk |
| How about your mobility prior to the illness or injury which brought you in today? | ○ I had no problems walking<br>○ I had slight problems walking<br>○ I had moderate problems walking<br>○ I had severe problems walking<br>○ I am unable to walk |
| How would you best describe your ability for self-care? | ○ I have no problems washing or dressing myself<br>○ I have slight problems washing or dressing myself<br>○ I have moderate problems washing or dressing myself<br>○ I have severe problems washing or dressing myself<br>○ I am unable to wash or dress myself |
| How would you best describe your ability to conduct routine activities? | ○ I have no problems doing my usual activities<br>○ I have slight problems doing my usual activities<br>○ I have moderate problems doing my usual activities<br>○ I have severe problems doing my usual activities<br>○ I am unable to do my usual activities |
| How much pain or discomfort do you have when you walk? | ○ I have no pain or discomfort<br>○ I have slight pain or discomfort<br>○ I have moderate pain or discomfort<br>○ I have severe pain or discomfort<br>○ I have extreme pain or discomfort |

10/22/2018 12:10pm projectredcap.org REDCap

| | |
|---|---|
| Have you fallen in the last year? | ○ Yes<br>○ No<br>○ I don't remember |
| About how often did you fall? | ○ Once<br>○ A few times<br>○ Monthly<br>○ Weekly<br>○ Daily |
| Were you injured in any of these falls? | ○ Yes<br>○ No |
| Have you been advised to use a cane or walker to get around safely? | ○ Yes<br>○ No |
| Do you sometimes feel unsteady when walking? | ○ Yes<br>○ No |
| Do you ever steady yourself by holding on to furniture when walking at home? | ○ Yes<br>○ No |
| Do you ever worry about falling? | ○ Yes<br>○ No |
| Do you need to push with your hands to stand up from a chair? | ○ Yes<br>○ No |
| Do you ever have trouble stepping up onto a curb? | ○ Yes<br>○ No |
| Do you ever feel rushed to the toilet? | ○ Yes<br>○ No |
| Have you lost any feeling in your feet? | ○ Yes<br>○ No |
| Do you take medicine that sometimes makes you feel light-headed or more tired than usual? | ○ Yes<br>○ No |
| Do you take medicine to help you sleep or improve your mood? | ○ Yes<br>○ No |
| Do you ever drink more than a couple of alcoholic drinks in one day? | ○ Yes<br>○ No |

**Figure 9.** Demographic and Fall Assessment Questionnaire.

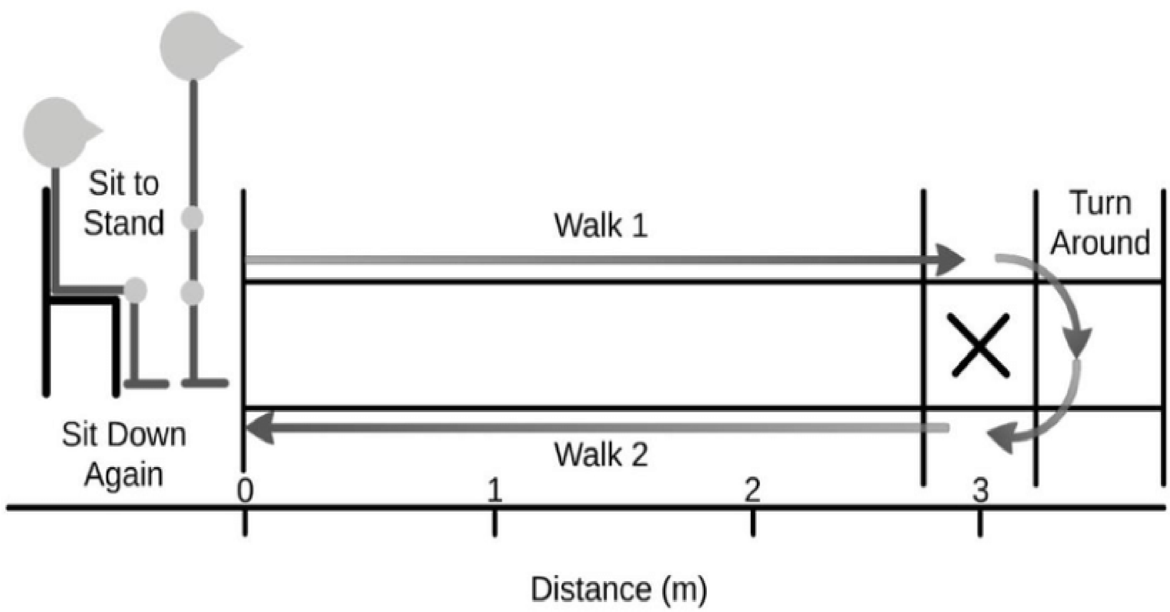


**Figure 10.** Timed Get-Up-and-Go diagram.

SOURCE: Vicent Benavent-Caballer, July 2016.

| | |
|---|---|
| Record ID | ____________________ |
| Baseline RedCap ID | ____________________ |
| Is this the 30 day or 90 day follow up call? | ○ 30 Day<br>○ 90 Day |
| Have you fallen since we last spoke with you? | ○ 0 times<br>○ 1 time<br>○ 2 times<br>○ 3+ times |
| Did you require any medical care from these falls? | ○ No<br>○ Yes - 1 time<br>○ Yes - multiple times |
| Do you worry about falling? | ○ Yes<br>○ No |
| Do you feel unsteady when walking or standing? | ○ Yes<br>○ No |
| Do you feel like you might fall in the next two months? | ○ Yes<br>○ No |

**Figure 11.** Follow Up Questionnaire.

## Appendix B - Tables

**Table 1.** Demographic and fall assessment data for 135 enrolled participants.

| | |
|---|---|
| Age (mean) | 69 |
| Age (range) | 60,94 |
| Male | 60% (81) |
| Female | 40% (54) |
| *Race* | |
| Black | 29.6% (40) |
| White | 68.9% (93) |
| Other | 1.5% (2) |
| *Relationship Status* | |
| Married | 35.6% (48) |
| Single | 46.7% (63) |
| Separated | 0.7% (1) |
| Widowed | 17.0% (23) |
| *Living Situation* | |
| By self | 38.5% (52) |
| With other >/= 65 | 18.5% (25) |
| With other < 65 | 27.4% (37) |
| Multiple family | 15.6% (21) |
| *Fall Assessment* | |
| Fall in last year (Y) | 44.4% (60) |
| Unsteady (Y) | 38.5% (52) |
| Fall Worry (Y) | 29.6% (40) |
| Yes to any | 65.2% (88) |

**Table 2**. Subject responses to 30-day follow-up call, broken down by Fall Risk/No Fall Risk based on CDC-questionnaire.

| | Fall (Y) | Fall (N) | No Response |
|---|---|---|---|
| Fall Risk (Y) | 3 | 61 | 25 |
| Fall Risk (N) | 2 | 26 | 18 |

**Table 3**. Subject responses to 90-day follow-up call, broken down by Fall Risk/No Fall Risk based on CDC-questionnaire.

| | Fall (Y) | Fall (N) | No Response |
|---|---|---|---|
| Fall Risk (Y) | 7 | 43 | 39 |
| Fall Risk (N) | 1 | 25 | 20 |

**Table 4.** Participants' time to complete walking task, broken down by quartiles. Quartile 3 (26.7 seconds) was chosen as the predictive cut-off for fall risk.

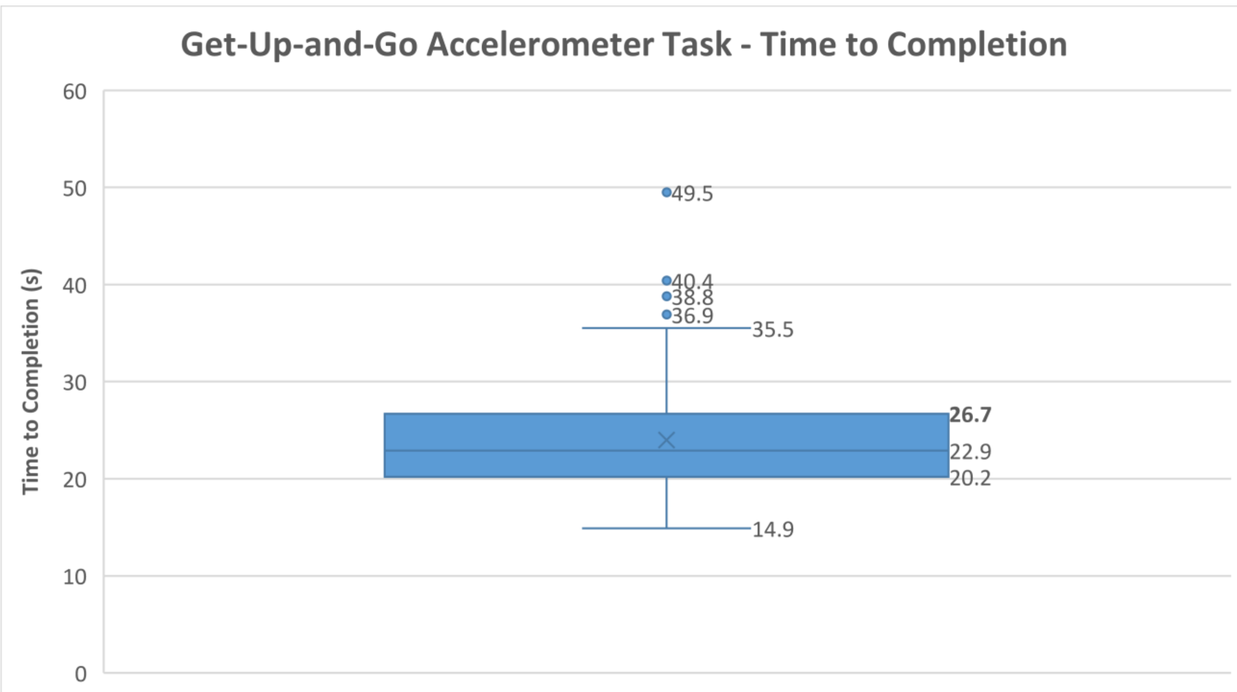

**Table 5**. Subject responses to 30-day follow-up call, broken down by Fall Risk/No Fall Risk based on timed Get-Up-and-Go task.

| | Fall (Y) | Fall (N) | No Response |
|---|---|---|---|
| Fall Risk (Y) | 3 | 18 | 13 |
| Fall Risk (N) | 2 | 69 | 30 |

**Table 6**. Subject responses to 90-day follow-up call, broken down by Fall Risk/No Fall Risk based on timed Get-Up-and-Go task.

| | Fall (Y) | Fall (N) | No Response |
|---|---|---|---|
| Fall Risk (Y) | 2 | 18 | 14 |
| Fall Risk (N) | 6 | 50 | 45 |

**Table 7**. Subject responses to 30-day follow-up call, broken down by Fall Risk/No Fall Risk based on a combination of the CDC-questionnaire and the timed Get-up-and-Go task.

| | Fall (Y) | Fall (N) | No Response |
|---|---|---|---|
| Fall Risk (Y) | 1 | 12 | 10 |
| Fall Risk (N) | 4 | 75 | 33 |

**Table 8**. Subject responses to 90-day follow-up call, broken down by Fall Risk/No Fall Risk based on a combination of the CDC-questionnaire and the timed Get-up-and-Go task.

| | Fall (Y) | Fall (N) | No Response |
|---|---|---|---|
| Fall Risk (Y) | 1 | 10 | 10 |
| Fall Risk (N) | 7 | 58 | 49 |

**Table 9**. The Concordance, PPV, and NPV of the three diagnostic tools used to predict fall-risk at 30-days and 90-days.

| **30-days** | **Concordance (%)** | **PPV (%)** | **NPV (%)** |
|---|---|---|---|
| *Questionnaire* | 31.5 | 4.7 | 92.9 |
| *Gait Task* | 78.3 | 14.3 | 97.2 |
| *Combo* | 82.6 | 7.7 | 94.9 |
| **90-days** | | | |
| *Questionnaire* | 42.1 | 14 | 96.2 |
| *Gait Task* | 68.4 | 10 | 89.3 |
| *Combo* | 77.6 | 9.1 | 89.2 |

**Table 10.** The Concordance, PPV, and NPV of the three diagnostic tools used to predict fall-risk at 30-days and 90-days (assuming no-response participants had no falls).

| **30-days** | **Concordance (%)** | **PPV (%)** | **NPV (%)** |
|---|---|---|---|
| *Questionnaire* | 34.8 | 3.4 | 95.7 |
| *Gait Task* | 75.6 | 8.8 | 98 |
| *Combo* | 80.8 | 4.3 | 96.4 |
| **90-days** | | | |
| *Questionnaire* | 38.5 | 7.9 | 97.8 |
| *Gait Task* | 71.9 | 5.9 | 94.1 |
| *Combo* | 80 | 4.8 | 93.9 |

**Table 11.** The Concordance, PPV, and NPV of the three diagnostic tools used to predict fall-risk at 30-days and 90-days (assuming no-response participants did have falls).

| **30-days** | **Concordance (%)** | **PPV (%)** | **NPV (%)** |
|---|---|---|---|
| *Questionnaire* | 40 | 31.5 | 56.5 |
| *Gait Task* | 63 | 47.1 | 68.3 |
| *Combo* | 63.7 | 47.8 | 67 |
| **90-days** | | | |
| *Questionnaire* | 52.6 | 51.7 | 54.3 |
| *Gait Task* | 48.9 | 47.1 | 49.5 |
| *Combo* | 51.1 | 52.4 | 50.9 |

## Bibliography


1. "Projected Age Groups and Sex Composition of the Population: Projections for the United States 2017-2060." *2017 National Population Projections Tables*, United States Census Bureau, 20 Feb. 2020.
2. Rama, Apoorva. "National Health Expenditures, 2016: Annual Spending Growth on the Downswing." Policy Research Perspectives, American Medical Association, Apr. 2018.
3. Freid VM, Bernstein AB, Bush MA. Multiple chronic conditions among adults aged 45 and over: Trends over the past 10 years. NCHS data brief, no 100. Hyattsville, MD: National Center for Health Statistics. 2012.
4. Prasad S, Sung B, Aggarwal BB. Age-associated chronic diseases require age-old medicine: role of chronic inflammation. Prev Med. 2012;54 Suppl(Suppl):S29-S37. doi:10.1016/j.ypmed.2011.11.011
5. Cubanski, Juliette, et al. "The Facts on Medicare Spending and Financing." *Medicare*, Kaiser Family Foundation, 20 Aug. 2019.
6. The prevention of falls in later life. A report of the Kellogg International Work Group on the Prevention of Falls by the Elderly. **Dan Med Bull**. 1987;34 Suppl 4:1-24. [PMID: 3595217]
7. Tinetti ME , Speechley M , and Ginter SF . Risk factors for falls among elderly persons living in the community. **N Engl J Med**. 1988;319:1701-7. [PMID: 3205267]
8. "Issue Brief: Funding for Elder Falls Prevention." *National Council on Aging*, Falls Free Coalition, Aug. 2018.
9. Bergen G, Stevens MR, Burns ER. Falls and Fall Injuries Among Adults Aged ≥65 Years United States, 2014. MMWR Morb Mortal Wkly Rep 2016;65:993–998. DOI: http://dx.doi.org/10.15585/mmwr.mm6537a2external icon.
10. Phelan EA, Ritchey K. Fall Prevention in Community-Dwelling Older Adults. Ann Intern Med. 2018 Dec 4;169(11):ITC81-ITC96. doi: 10.7326/AITC201812040. PMID: 30508457.

11. Burns ER, Stevens JA, Lee R. The direct costs of fatal and non-fatal falls among older adults - United States. J Safety Res. 2016;58:99-103. doi:10.1016/j.jsr.2016.05.001
12. Houry D, Florence C, Baldwin G, Stevens J, McClure R. The CDC Injury Center's response to the growing public health problem of falls among older adults. Am J Lifestyle Med. 2016 Jan-Feb;10(1):74–7. doi: 10.1177/1559827615600137. PMID: 26688674; PMCID: PMC4681302.
13. Carande-Kulis V, Stevens JA, Florence CS, Beattie BL, Arias I. A cost-benefit analysis a of three older adult fall prevention interventions. J Safety Res. 2015 Feb;52:65-70. doi: 10.1016/j.jsr.2014.12.007. Epub 2015 Jan 6. PMID: 25662884; PMCID: PMC6604798.
14. Florence CS, Bergen G, Atherly A, Burns E, Stevens J, Drake C. Medical Costs of Fatal and Nonfatal Falls in Older Adults. J Am Geriatr Soc. 2018;66(4):693-698. doi:10.1111/jgs.15304
15. Gillespie LD, Robertson MC, Gillespie WJ, Sherrington C, Gates S, Clemson LM, Lamb SE. Interventions for preventing falls in older people living in the community. Cochrane Database Syst Rev. 2012 Sep 12;(9):CD007146. doi: 10.1002/14651858.CD007146.pub3. PMID: 22972103.
16. "Tai Chi: Moving For Better Balance." *Administration for Community Living*, United States Department of Health and Human Services, June 2012.
17. Carande-Kulis V, Stevens JA, Florence CS, Beattie BL, Arias I. A cost-benefit analysis of three older adult fall prevention interventions. J Safety Res. 2015 Feb;52:65-70. doi: 10.1016/j.jsr.2014.12.007. Epub 2015 Jan 6. PMID: 25662884; PMCID: PMC6604798.
18. Ganz DA, Bao Y, Shekelle PG, Rubenstein LZ. Will my patient fall? JAMA. 2007 Jan 3;297(1):77-86. doi: 10.1001/jama.297.1.77. PMID: 17200478.
19. Schoene D, Wu SM, Mikolaizak AS, Menant JC, Smith ST, Delbaere K, Lord SR. 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 Feb;61(2):202-8. doi: 10.1111/jgs.12106. Epub 2013 Jan 25. PMID: 23350947.

20. Montesinos L, Castaldo R, Pecchia L. Wearable Inertial Sensors for Fall Risk Assessment and Prediction in Older Adults: A Systematic Review and Meta-Analysis. IEEE Trans Neural Syst Rehabil Eng 2018;26:573-82.

21. "Resource Algorithm for Fall Risk Screening, Assessment, and Prevention." National Center for Injury Prevention and Control, *United States Centers for Disease Control and Prevention*, 2019.

22. Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society. Summary of the Updated American Geriatrics Society/British Geriatrics Society clinical practice guideline for prevention of falls in older persons. J Am Geriatr Soc. 2011 Jan;59(1):148-57. doi: 10.1111/j.1532-5415.2010.03234.x. PMID: 21226685.

23. Benavent-Caballer, Vicent. "The effectiveness of exercise interventions and the factors associated with the physical performance in older adults." *University CEU Cardinal Herrera,* July 2016.

24. Mannini A, Sabatini AM. Machine learning methods for classifying human physical activity from on-body accelerometers. Sensors (Basel) 2010;10:1154-75.