Associations between Functional Mobility, Physical Functioning, and Dementia Caregiving Time

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Abstract

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To identify early mobility disability in people with cognitive impairment and to provide objective outcome measures of exercise and rehabilitation interventions, sensitive, valid, and reliable measures are needed. Portable inertial sensor systems have demonstrated sensitivity to mobility changes in Parkinson's disease, multiple sclerosis, and general populations of older adults. However, there has been no published information on whether inertial sensor-based measures are valid and reliable when administered with persons with dementia (PWDs). Additionally, even though the link between functional mobility and disability in activities of daily living (ADLs) has been supported in prior research, the association between (1) functional mobility in PWDs, (2) caregiver-reported PWD physical functioning, and (3) caregiver-reported dementia caregiving time spent in assisting ADLs remains unknown. To help bridge this gap, the purposes of this dissertation were (1) to examine the concurrent validity and test-retest reliability of a five-time sit-to-stand test (FTSTS) collected with an inertial sensor system in people with

mild cognitive impairment and dementia, and (2) to investigate the associations between PWD functional mobility (measured by the FTSTS and additional FTSTS subtask parameters obtained by the inertial sensor system), caregiver-reported PWD physical functioning, and caregiver-reported dementia caregiving time spent in assisting ADLs. The overall results suggest that (1) FTSTS subtask parameters (i.e. total time, mean sit-to-stand duration, mean stand-to-sit duration, mean sit-to-stand lean angle, mean stand-to-sit lean angle) collected by the portable sensor system (coined as "iFTSTS" parameters in this dissertation) have good to excellent concurrent validity when compared to FTSTS parameters simultaneously collected by a laboratory-based human motion capture system in people with mild cognitive impairment and mild dementia; (2) iFTSTS parameters have fair to good test-retest reliability over a 1-month period in PWDs; (3) higher PWD functional mobility (as measured by the ability to complete the FTSTS, FTSTS total duration, iFTSTS total duration, iFTSTS mean sit-to-stand duration, and iFTSTS mean stand-to-sit duration) is associated with better caregiver-reported PWD physical functioning; (4) higher caregiver-reported PWD physical functioning is associated with shorter caregiver-reported caregiver time spent in assisting PWDs with ADLs; and (5) higher functional mobility (as measured by the ability to complete the FTSTS) is associated with shorter caregiver-reported dementia caregiving time spent in assisting PWDs with ADLs.

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Chapter 1. INTRODUCTION

1.1 DEMENTIA, ALZHEIMER'S DISEASE, AND MILD COGNITIVE IMPAIRMENT

Dementia is a clinical syndrome of different etiologies, characterized by cognitive declines (e.g. memory, thinking, planning, etc.) severe enough to interfere with daily activities. The most common cause of dementia is Alzheimer's disease (AD; Barker et al., 2002). In 1983, the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) and the Alzheimer's Disease and Related Disorders Association (ADRDA; currently known as the Alzheimer's Association) convened a workgroup to establish diagnostic guidelines of AD. In 1984, the work group published a report with the NINCDS-ADRD criteria (McKhann, Drachman, Folstein, Katzman, Price, & Stadlan, 1984), which have been widely used in clinical trials (McKhann et al., 2011). In 2011, the National Institute on Aging and the Alzheimer's Association charged a workgroup to revise the NINCDS-ADRD criteria (Albert et al., 2011; McKhann et al., 2011; Sperling et al., 2011). One major difference in the revised guidelines is the incorporation of biomarker tests. Other major differences are the expansion of the definition of AD and the staging of AD. Under the 1984 guidelines, an individual with "AD" must have "symptoms of dementia" (i.e. memory loss and impaired ability to carry out daily tasks), while under the 2011 guidelines, the term "AD" is expanded to encompass the underlying pathophysiological disease process (e.g. asymptomatic individuals with biomarkers of AD). Additionally, the clinical stages of AD are divided into (1) mild cognitive impairment (MCI) due to AD and (2) dementia due to AD (or AD dementia). Individuals with MCI due to AD are characterized by (1) cognitive impairment greater than expected for their age and educational background and (2) preservation of independence in functional abilities (Albert et al., 2011). In

contrast, individuals with dementia due to AD have noticeable changes in memory, thinking and behaviors that impair their ability to function in daily life (McKhann et al., 2011).

It is important to note that "MCI due to AD" refers to the symptomatic pre-dementia phase of AD (i.e. AD is the primary underlying pathophysiology of an individual's MCI), whereas "MCI" is a broader term widely used to describe the intermediate stage from normal cognitive function to dementia, identifying a spectrum of disease that includes impairment in both memory and non-memory cognitive domains, such as language, executive function, and visuospatial skills (Petersen, 2004; Petersen et al., 2009; Roberts & Knopman, 2013; Winblad, et al., 2004). Individuals with MCI can be classified as the stage 2 or 3 of the Global Deterioration Scale (Reisberg, et al., 1988) and as having a Clinical Dementia Rating score (Morris, 1993) of 0 or 0.5 (Petersen, Smith, Waring, Ivnik, Tangalos, Kokmen, 1999; Petersen et al., 2009). Those with a memory impairment are labelled as amnestic MCI, whereas those without are labelled as non-amnestic MCI. Additionally, individuals with MCI may have impairment in a single cognitive domain or multiple cognitive domains (Petersen, 2004; Petersen et al., 2009).

According to Petersen et al. (2004, 2009), the amnestic MCI subtype likely presents a prodromal form of AD. Not surprisingly, the clinical syndrome of MCI due to AD in the 2011 guidelines is almost identical to the clinical syndrome of amnestic MCI described by Petersen (2004; See Table 1.1). After clinicians have determined that an individual meets the clinical and cognitive syndrome associated with AD, but does not have dementia (Step 1 in Table 1.1), the 2011 guidelines advise clinicians to further examine an individual's historical information and conduct ancillary testing (e.g. neuroimaging, laboratory studies, and neuropsychological assessment) to evaluate the likelihood that the underlying disease of MCI is a neurodegenerative disorder with characteristics consistent with AD (Step 2 in Table 1.1; Albert et al., 2011).

Table 1.1. Criteria for Amnestic MCI vs. Core Clinical Criteria for MCI due to AD

Criteria for amnestic MCI (Petersen, 2004)	**Clinical and cognitive evaluation for MCI due to AD** (Albert et al., 2011)
• Memory complaint usually corroborated by an informant • Objective memory impairment for age • Essentially preserved general cognitive function • Largely intact functional activities • Not demented	**Step 1: Establish clinical and cognitive criteria** (close to Petersen's criteria) • Cognitive concern reflecting a change in cognition reported by patient or informant or clinician • Objective evidence of impairment in one or more cognitive domains, typically including memory • Preservation of independence in functional abilities • Not demented **Step 2: Examine etiology of MCI consistent with AD pathophysiological process** • Rule out vascular, traumatic, medical causes of cognitive decline, where possible • Provide evidence of longitudinal decline in cognition, when feasible • Report history consistent with AD genetic factors, where relevant

1.2 Early Mobility Dysfunction

Increasing research evidence suggests that AD alters an individual's motor function even in the earlier stages of the disease. For example, Vidoni et al. (2012) reported that while performing a simple visuomotor task (i.e. hand squeezes on specific visual cues), older adults with early-stage AD had lesser cortical activation than those without AD in accessory motor regions, supplementary motor area, and the cerebellum. According to Vidoni et al., these AD-related differences in regional co-activation likely suggest inefficiency in the motor network as a consequence of the disease process, or represents compensatory activation. Kluger et al. (1997) found that relative to older people without cognitive impairment, those with MCI and mild AD performed worse on tasks involving fine and complex motor function. Manckoundia et al. (2006) analyzed shoulder displacement captured by human motion capture cameras during sit-to-stand and stand-to-sit motions to understand how AD affected motor preparation and control, and concluded that while lower-level motor features remain intact (e.g. peaks of velocity) in older adults with mild-to-moderate AD, higher level motor process of whole body motions (e.g.

shoulder displacement and shoulder path curvature during sit-to-stand) are affected by the disease. This prior research suggests that reliable, sensitive, and clinically meaningful measures are needed to identify subtle mobility dysfunction in people with earlier stages of AD, to identify potential areas of remediation, and to provide objective outcome measures for rehabilitation and exercise interventions.

1.3 Portable Body-Worn Inertial Sensor Systems

In the past, quantitative human motion analysis data could only be captured in specialized human motion analysis laboratories. With advancements in technology, portable, body-worn inertial sensors with built in accelerometers and gyroscopes have led to a new alternative for human motion performance assessment outside of the laboratory settings (Manicini et al., 2011; Spain, Mancini, Horak, & Bourdette, 2014). Gait and balance measures derived from body-worn inertial sensors have demonstrated validity, reliability, and sensitivity to mild mobility problems in patients with Parkinson's disease and multiple sclerosis (Godinho et al., 2016; Horak, Mancini, Carlson-Kuhta, Nutt, & Salarian, 2016; Ramsperger et al., 2016; Spain et al., 2012; Spain, et al., 2014; Zampieri et al., 2010). Sensor-based quantitative measurements have also been reported to have higher sensitivity to detect changes in mobility and fall risk in older adults than standard clinical measures (Regterschot, Folkersma, Zhang, Baldus, Stevens, & Zijlstra, 2014).

1.4 Aims

Sensor-based quantitative measures may be useful in detecting early mobility problems in people with AD and in tailoring and evaluating exercise and rehabilitation interventions. However, information on validity and reliability of sensor-based quantitative measures when applied to people with AD and related dementias is lacking. Therefore, the first aim of this dissertation is to

examine the concurrent validity and the test-retest reliability of an instrumented five-time sit-to-stand test, a widely used functional mobility test administered with an inertial sensor system, in older adults with MCI or dementia. The results of the first aim are reported in Chapter 2 of this dissertation.

Functional mobility refers to the manner in which people are able to move around in the environment to perform everyday activities and transfer from place to place. Typical functional mobility tasks include standing, bending, walking, and climbing (Forhan & Gill, 2013). Impairments in functional mobility are likely to negatively impact physical functioning in persons with dementia (PWDs) and to increase the time caregivers must spend assisting them with basic activities of daily living (ADLs). However, to the author's knowledge, no published studies have examined the relationship between PWD functional mobility, caregiver-reported PWD physical functioning, and caregiver-reported dementia caregiving time spent in assisting ADLs. To bridge this gap, the second aim of this dissertation is to examine the cross-sectional associations between (1) functional mobility in PWDs, (2) caregiver-rated physical functioning in PWDs, and (3) caregiver-reported caregiving time spent assisting in ADLs. The results of the second aim are reported in Chapter 3 of this dissertation.

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Chapter 2. CONCURRENT VALIDITY AND TEST-RETEST RELIABILITY OF AN INSTRUMENTED FIVE-TIME SIT-TO-STAND TEST IN OLDER ADULTS WITH MILD COGNITIVE IMPAIRMENT AND DEMENTIA

Purpose: In order to identify subtle mobility dysfunction in older adults with cognitive impairment, and to provide objective outcomes of rehabilitation and exercise interventions, reliable, sensitive, and clinically meaningful measures are needed. The purpose of this paper is to report two studies examining (1) concurrent validity of an inertial sensor instrumented five-time sit-to-stand test (iFTSTS) in older adults with mild cognitive impairment (MCI) to mild dementia, and (2) test-retest reliability of iFTSTS in older adults with mild to severe dementia. The iFTSTS included the following parameters: total time, mean sit-to-stand duration, mean stand-to-sit duration, mean sit-to-stand lean angle, and mean stand-to-sit lean angle. **Materials and methods:** Study 1 assessed concurrent validity of iFTSTS (collected by a portable inertial sensor system, APDM Mobility Lab^{TM}) in older adults with MCI and mild dementia (n=37) compared to the Qualisys Motion Capture System. Study 2 assessed test-retest reliability of the APDM iFTSTS administered approximately 1 month apart in people with mild to severe dementia (n = 46). Pearson's correlation coefficients (r's) were calculated to assess concurrent validity. Intraclass correlation coefficients (ICCs) were calculated to assess test-retest reliability. **Results:** Good to excellent concurrent validity between all APDM iFTSTS parameters administered in a human motion analysis lab and the laboratory-based Qualisys FTSTS parameters (r's = 0.644 to 0.996) was demonstrated. The test-retest reliability of APDM iFTSTS parameters over a 1-month period was fair to good (ICCs: 0.47 to 0.65) **Conclusions:** The APDM iFTSTS parameters demonstrated good concurrent validity with the Qualisys system.

However, future studies, specifically designed to examine test-retest reliability, within shorter lengths of time, are needed to provide more definite conclusions regarding the reliability of these measures in older adults with cognitive impairment.

2.1 INTRODUCTION

In 2017, an estimated 5.5 million Americans were living with Alzheimer's disease (AD; Alzheimer's Association, 2017). AD is a degenerative brain disease. An affected individual's cognitive and functional abilities both decline as the disease progresses. Increasing age is one of the greatest risk factors for AD. For example, among people age 65 to 74 years, 3 % have AD; among people age 75 to 84, 17 % have AD; while among people age 85 or older, 32 % have AD (Hebert, Weuve, Scherr, & Evans, 2013). As the world's population ages, more and more rehabilitation patients will be living with AD and other age-related cognitive impairment. For example, more individuals who are referred for hip fracture or other types of rehabilitation services will likely be experiencing AD or other age-related changes in their cognitive ability.

According to the 2011 revised guidelines for diagnosing AD proposed by the National Institute on Aging and the Alzheimer's Association (Albert et al., 2011; McKhann et al., 2011, Sperling et al., 2011), the clinical stage of AD should now be divided into (1) MCI due to AD and (2) dementia due to AD (or AD dementia). Individuals with MCI due to AD are characterized by (1) cognitive impairment greater than expected for their age and education level and (2) preserved independence in functional abilities. In contrast, individuals with dementia due to AD have memory, thinking and behavioral symptoms severe enough to interfere their ability to function in daily life. According to the revised guidelines, individuals meet the core clinical criteria for MCI (e.g. Petersen's criteria for amnestic MCI; see Chapter 1 of this dissertation) without biomarker confirmation still can be categorized as "consistent with the possibility that

the patient with MCI has underlying AD pathology" (Albert et al., 2011, p. 278). To align with the new terminologies proposed by the 2011 revised guidelines, in this paper, "AD" is used as an encompassing term to also include individuals with MCI and related dementias, and "PWDs" refers to persons with MCI or dementia, unless otherwise specified.

Increasing research evidence suggest that AD alters motor function even in the early stages of the disease (Kluger, Gianutsos, Golomb, & Ferris, 1997, Manckoundia, Mourey, Pfitzenmeyer, & Papaxanthis, 2006, Vidoni, Honea, Burns, Thomas, & Loskutova, 2012). To identify subtle mobility dysfunction in PWDs (early detection), as well as to provide objective outcomes of rehabilitation and exercise interventions, reliable, sensitive, and clinically meaningful measures are needed. Gait and balance measures derived from inertial sensors have demonstrated sensitivity to mild mobility problems in patients with Parkinson's disease and multiple sclerosis (Ramsperger et al., 2016; Spain et al., 2012; Spain, Mancini, Horak, & Bourdette, 2014; Zampieri et al., 2010). However, the validity and reliability of such measures when applied to PWDs is unknown. To help bridge this gap, this paper reports two studies assessing concurrent validity (Study 1) and test-retest reliability (Study 2) of a five-time sit-to-stand test (FTSTS) instrumented with a portable inertial sensor system, Mobility Lab™ (APDM Inc., Portland, Oregon, USA), in PWDs. "Instrumentation" in this context refers to the use of APDM Mobility Lab™ throughout the administration of the FTSTS to capture quantitative functional mobility parameters. Mobility Lab™ is a portable motion monitoring system designed for clinicians and clinical researchers to collect human motion data outside of the laboratory (Mancini, King, Salarian, Holmstrom, McNames, & Horak, 2011), including people's homes. The FTSTS is a common physical performance test for lower extremity strength and functional mobility (Csuka & McCarty, 1985; Guralnik, et al., 1994). The FTSTS measures the time taken

(seconds) for an individual to complete 5 sit-to-stand repetitions from a standard 18" high chair as quickly as possible. The test-retest reliability of the standard (or non-instrumented) FTSTS is good to excellent in various populations, including community-dwelling adults (Bohannon, Bubela, Magasi, & Gershon, 2011), community-dwelling older adults (Tiedemann, Shimada, Sherrington, Murray, & Lord, 2008), sedentary older adults with osteoarthritis (Lin, Davey, & Cochrane, 2001), adults with low back pain (Simmonds et al., 1998), and adult day center clients with dementia (Thomas & Hageman, 2002).

Mobility Lab™ includes (1) a set of Opal™ inertial sensors with built in tri-axial accelerometers, gyroscopes, and magnetometers, (2) sensor docking stations, and (3) an access point for wireless data transmission, and a Mobility Lab™ data processing software. The FTSTS plug-in of the Mobility Lab™ software automatically analyzes and outputs quantitative measures of FTSTS subtasks, including total time, mean sit-to-stand duration, mean stand-to-sit duration, mean sit-to-stand lean angle, and mean stand-to-sit lean angle. To distinguish between the standard timed FTSTS and the FTSTS subtask parameters obtained by the Mobility Lab™, the author uses the term "iFTSTS" to refer to FTSTS parameters obtained by the Mobility Lab™ herein.

2.2 Materials and Methods

Study 1 was a sub-study of a 12-month cohort study that aimed to identify functional markers of mobility disability among older adults with MCI or mild dementia in the home environment. The baseline data of the cohort study were used to assess the concurrent validity of FTSTS parameters obtained by the Mobility Lab™ (i.e. iFTSTS) and obtained by a laboratory-based human motion analysis system, Qualisys Human Motion Capture System (Qualisys, Göteborg, Sweden). Participants' baseline iFTSTS were collected under two conditions: (1) at participants'

home (home-based assessment); and (2) in a human motion analysis lab, simultaneously collected with the Qualisys Human Motion Capture system (lab-based assessment). Currently, laboratory based human motion analysis systems using a multi-camera system and computer software to create 3-dimensional (3D) images, remains the industry "gold standard" for human-motion analysis (Beyea, McGibbon, Sexton, Noble, & O'Connell, 2017).

Study 2 was a secondary analysis of data from a large in-home exercise intervention study for older adults with dementia and their caregivers. The APDM iFTSTS measures were collected in a subset of the participants in the exercise study. Participants' iFTSTS measures taken at the baseline and pre-intervention data collection sessions, 1-month apart, were used to examine test-retest reliability. The University of Washington (UW) Institutional Review Board approved both studies.

2.2.1 *Participants*

Study 1 participants were older adults with MCI or mild dementia. Study 2 participants were older adults with mild to severe dementia. The inclusion and exclusion criteria of the 2 studies are summarized in Table 2.2. All participants in Study 1 and Study 2 provided written informed consent for their participation. All Study 2 participants had additional consent provided by a caregiver or a representative with power of attorney on their behalf, since most of them had more advanced cognitive impairment.

Table 2.2. Inclusion and Exclusion Criteria by Study

	Study 1	Study 2
Target Population	MCI or mild dementia	Mild to severe dementia
Inclusion Criteria	• Age: 70-95 years • Ability to walk 100+ meters (cane or walker allowed) • The Clinical Dementia Rating (CDR; Hughes, Berg, Danziger, Coben, & Martin, 1982; Morris, 1993) score: 0.5 - 1.0 (or an existing diagnosis of MCI or early dementia) • Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) score ≥ 18 • Self-reported memory problems	• Age: 60+ years • DSM-IV-TR criteria for dementia (confirmed in writing by their primary physician; American Psychiatric Association, 2000) • Exercise < 150 minutes/week • Approval from their primary physician to participant in the study • Having an informal (family or friend) caregiver living in the community
Exclusion Criteria	• MMSE score < 18 • Blessed Dementia Rating Scale phone screening score (Blessed, Tomlinson, & Roth, 1968) > 28 • Not fluent in English, blind, or deaf • Known terminal illness or uncontrolled medical conditions • Diagnosis of central nervous system condition (e.g. stroke, Parkinson's disease)	• The participant or the caregiver planned to move to long-term residential care or out of the study enrolment geographic area within the study period • Non-ambulatory, blind, or deaf • Hospitalized for psychiatric illness < 12 months • Known terminal illness

2.2.2 *Procedures and Instrumentation*

Study 1 participants were first assessed at home (home-based assessment) and then in the UW Rehabilitation Medicine human motion analysis lab (lab-based assessment). Study 2 participants had two home-based assessments scheduled approximately one month apart. Assessments of both studies were conducted by the research assistants who had received training on operating the Mobility Lab™, and/or the Qualisys Motion Capture System. To avoid confusion, in this paper, the author uses the term "home iFTSTS" to refer to iFTSTS measures collected at participants' home, the term "lab iFTSTS" to refer to iFTSTS measures collected in the human motion analysis lab, and the term "Qualisys FTSTS" to refer to FTSTS measures collected by the Qualisys Motion Capture system in the human motion analysis lab.

For the home-based assessment (Study 1 and Study 2), participants were instrumented with the APDM Mobility Lab™. Before the testing began, 6 Opal™ sensors were attached to the

participant with Velcro straps (2 on feet, 2 on wrists, sternum and lumbar). The participants' body motion data were recorded via wireless transmission from the 6 inertial sensors (sampling rate of 128 Hz) and then processed with the Mobility Lab™ software FTSTS plug-in (version 1) installed in a Dell laptop computer.

For the lab-based assessment, the participant was instrumented with both the Mobility Lab™ (same as the home-based assessment) and the Qualisys Motion Capture System. The Qualisys Motion Capture System included 8 cameras and 42 reflective markers. The reflective markers were placed on the participant's trunk (sternum, thorax), pelvis (anterior and posterior superior iliac spines, iliac crests), bilateral arms (acromion, deltoid insertion, lateral epicondyle, forearm, wrist) and bilateral legs (greater trochanter, thigh, patella, lateral knee joint, tibial tuberosity, lateral malleolus, posterior heel, second metatarsal-phalangeal joint). During testing, the participant's body movements were simultaneously recorded by the Mobility Lab™ and the Qualisys Motion Capture system (sampling rate at 120Hz). Qualisys Track Manager software was used to identify markers and interpolate gaps (< 0.25 seconds) in marker position data. Marker position data were then filtered in Visual 3D (C-Motion, Inc., Rockville, USA) using a fourth-order, zero-lag, Butterworth low-pass filter with a cut-off frequency of 6 Hz. Participant-specific anthropometric data (weight, height and limb circumference) were used to build a 12-sement whole-body model (trunk, pelvis, and bilateral upper arms, forearms, thighs, shanks, and feet) in Visual 3D.

2.2.3 *FTSTS Protocol*

After placement of the body-worn sensors (and reflective markers for the lab-based assessment), the participant was instructed to sit upright away from the back of a standard chair (18" seat to floor height), with feet flat on the floor and hands on either side of the knees. The participant was

not asked to fold arms across the chest, as per FTSTS typical instructions, because of the need to expose the upper extremity reflective makers to the cameras. When the participant was properly seated, a trained research assistant asked the participant to stand up from the chair once without using arms. If the participant could not rise without using arms, the test ended. If the participant rose successfully without using arms, the participant was then instructed to sit still for 3 seconds and then began standing up and sitting down five times quickly and safely when hearing the research assistant say, "Ready go." The research assistant counted each time when the participant's buttocks hit the seat. The research assistant timed the participant with a stopwatch from the participant's initiation of movement to when the participant was fully seated in the chair after the fifth stand-to-sit transition. If the participant did not perform the test correctly, the research assistant restarted the test.

2.2.4 *Qualisys FTSTS: Event Detection and Parameters*

One of the research team members (V. K.) developed the algorithm for Qualisys FTSTS. The right iliac crest marker vertical position was used to determine the initiation of sit-to-stand transitions and standing events. The trunk segment (shoulders/acromion to iliac crests relative to the lab) was used to calculate trunk lean angle as the rotation of the trunk in the sagittal plane relative to vertical. The initiation of sit-to-stand transitions was defined as the minimum vertical position for the second through fifth sit-to-stand transfers. The standing events for all five sit-to-stand movements were defined as the peak vertical position of the right iliac crest marker. The start of the task and the initiation of the first sit-to-stand transition was determined as the time point at which the right iliac marker vertical position rose above 5% of the average total excursion of the iliac crest marker during all other sit-to-stand transitions. The end of the trial was defined as the time point when the right iliac crest marker vertical position fell below 5% of

the average total excursion. See Table 2.3 for the definition of each of the Qualisys FTSTS parameters.

Table 2.3. Qualisys FTSTS Parameter Definitions

Parameter	Unit	Definition
Total duration	**Seconds**	The total duration is calculated as the time between the initiation of the 1st sit-to-stand transition and the time point when the right iliac crest marker vertical position falls below 5% of the average total excursion at the end of the 5th stand-to-sit transition.
Mean sit-to-stand duration	**Seconds**	The sit-to-stand duration, or the duration of the sit-to-stand transition, is defined as the time between the initiation of the sit-to-stand transition and the standing event (the peak vertical position of the right iliac crest marker). The mean sit-to-stand duration is the average of all 5 sit-to-stand transition durations.
Mean stand-to-sit duration	**Seconds**	The stand-to-sit duration, or the duration of the stand-to-sit transition is defined as the time between the standing event and the initiation of the subsequent sit-to-stand transition (for the 1st through 4th transfers) or the end of the trial (for the 5th transfer). The mean stand-to-sit duration was the average of all 5 stand-to-sit transition durations.
Mean sit-to-stand lean angle	**Degrees**	The sit-to-stand lean angle is calculated as the maximum forward trunk lean angle during each sit-to-stand transition. The mean sit-to-stand lean angle is the average of the 5 sit-to-stand trunk lean angles detected during the 5 sit-to-stand transitions.
Mean stand-to-sit lean angle	**Degrees**	The stand-to-sit lean angle is calculated as the maximum forward trunk lean angle during each stand-to-sit transition. The mean stand-to-sit lean angle is the average of the 5 peak trunk lean angles identified during the 5 stand-to-sit transitions.

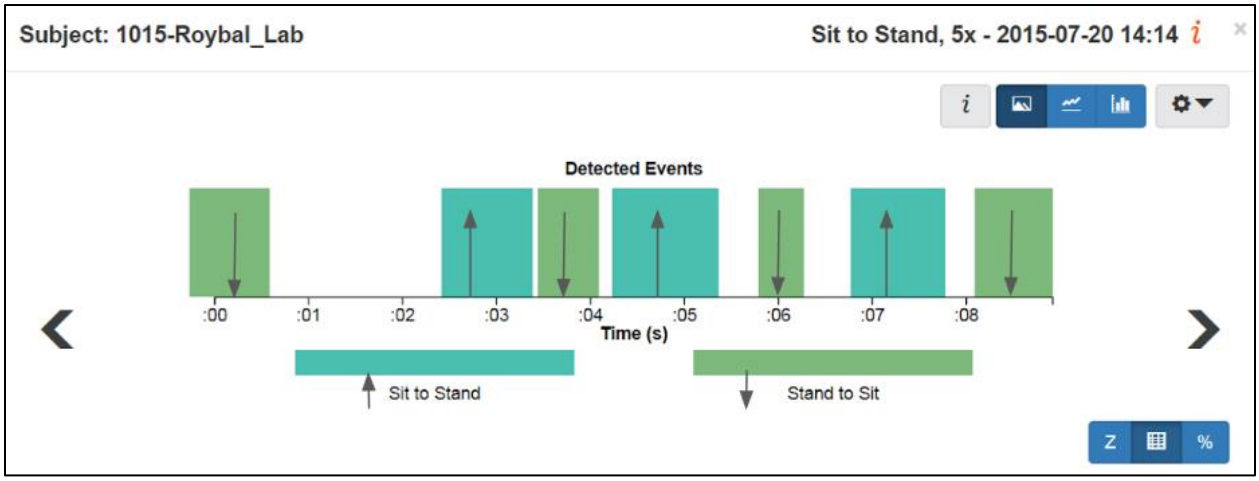
2.2.5 *iFTSTS: Event Detection and Parameters*

iFTSTS events were automatically detected by the Mobility Lab™ software FTSTS plug-in developed by the vendor. According to the vendor, the vertical displacement of the lumbar sensor was used to determine whether a sit-to-stand transition, or a stand-to-sit transition had occurred. The minimum displacement (upward) of a successful sit-to-stand event was defined as 0.24 m. The start of the sit-to-stand event was then the start of this vertical displacement. The end of the event was defined by the time when the vertical velocity went to 0 m/s^2. The minimum displacement of a successful stand-to-sit event was defined as 0.20 m (downward). The stand-to-sit events were segmented by either a period of zero velocity or a point of inflection in the vertical velocity indicating a change in direction. The signal was smoothed to better

estimate this time and to distinguish it from noise in the signal or irregular movement by the subject (e.g., tremor). The lean angle represents the amount that the subject's trunk leans forward (relative to vertical) during either a sit-to-stand transition, or a stand-to-sit transition. After the software automatically analyzed the sensor data and identified the sit-to-stand events and the stand-to-sit events that had occurred, it calculated and outputted the iFTSTS parameters as defined in Table 2.4. Since each sit-to-stand transition or each stand-to-sit transition was detected separately and treated as an independent event by the Mobility Lab™ software, it was possible that (1) the software detected fewer than 5 sit-to-stand events or fewer than 5 stand-to-sit events when the participant successfully performed all 5 chair stands, and that (2) there were unequal numbers of sit-to-stand events and stand-to-sit events detected by the software. For example, Figure 2.1 showed the Mobility Lab™ output of a participant who performed all 5 chair stands successfully, but who only had 3 sit-to-stand transitions detected and 4 stand-to-sit transitions detected by the software. Figure 2. 2 showed the Visual 3D output of the same participant's Qualisys FTSTS data. Being aware that the Mobility Lab™ software might not detect all sit-to-stand events and all stand-to-sit events, the author applied additional inclusion criteria for each of the iFTSTS parameter for data analysis. See Table 2.4 for details.

Table 2.4. iFTSTS Parameter Definitions and Inclusion Criteria for Data Analysis

Parameter	Unit	Definition	Inclusion Criteria for Data Analysis
Total duration	**Seconds**	If at least 1 sit-to-stand transition and at least 1 stand-to-sit transition are detected by the Mobility Lab™ algorithm, the total duration is calculated as the period between the initiation of the 1st sit-to-stand event detected and the termination of the last stand-to-sit event detected.	Based on the parameter definition, the total duration would only be calculated correctly by the Mobility Lab™ software if exactly five sit-to-stand transitions and exactly five stand-to-sit transitions were detected. Therefore, the inclusion criteria of iFTSTS total duration for data analysis was "exactly 5 sit-to-stand transitions and exactly 5 stand-to-sit transitions detected by the Mobility Lab™ software."
Mean sit-to-stand duration	**Seconds**	The sit-to-stand duration, or the duration of the sit-to-stand transition, is defined as the time between (1) the initiation of the sit-to-stand transition and (2) when the vertical velocity goes to zero. The mean sit-to-stand duration is the average of all sit-to-stand durations detected.	Since the Mobility Lab™ could only calculate the sit-to-stand duration for the sit-to-stand transitions that it successfully detected, the author decided to only include a participant's mean sit-to-stand duration for data analysis if the participant successfully completed the FTSTS and the Mobility Lab™ software successfully detected at least 50% of the sit-to-stand transitions performed by the participant.
Mean stand-to-sit duration	**Seconds**	The stand-to-sit duration, or the duration of the stand-to-sit transition, is defined as the time between (1) the initiation of the stand-to-sit event and (2) when the vertical velocity goes to zero m/s^2 or when the vertical velocity indicating a change of direction. The mean stand-to-sit duration is the average of all stand-to-sit durations detected.	Since the Mobility Lab™ could only calculate the stand-to-sit duration for the stand-to-sit transitions that it successfully detected, the author decided to only include a participant's mean stand-to-sit duration for data analysis if the participant successfully completed the FTSTS and the Mobility Lab™ software successfully detected at least 50% of the stand-to-sit transitions performed by the participant.
Mean sit-to-stand lean angle	**Degrees**	The sit-to-stand trunk lean angle is calculated as the maximum forward trunk lean angle during each sit-to-stand transition. The mean sit-to-stand trunk lean angle is the average of all sit-to-stand trunk lean angles detected.	Since the Mobility Lab™ software could only calculate the sit-to-stand trunk lean angle occurred during the sit-to-stand transitions that it successfully detected, the author decided to only include a participant's mean sit-to-stand lean angle if the participant had successfully performed the FTSTS and the Mobility Lab™ software successfully detected at least 50% of the sit-to-stand transitions performed by the participant.
Mean stand-to-sit lean angle	**Degrees**	The stand-to-sit trunk lean angle is calculated as the maximum forward lean angle during each stand-to-sit transition. The mean stand-to-sit trunk lean angle is the average of all stand-to-sit trunk lean angles detected.	Since the Mobility Lab™ software was only able to calculate the stand-to-sit trunk lean angle occurred during the sit-to-stand transitions that it successfully detected, the author decided to only include a participant's mean stand-to-sit lean angle if the participant had successfully performed the FTSTS and had at least 50% of the stand-to-sit transitions detected by the Mobility Lab™ software.



Note. The arrows were added by the author to show the direction of the movements. The 1st event detected by the system was a stand-to-sit transition.

Figure 2.1. Mobility Lab™ Output Example

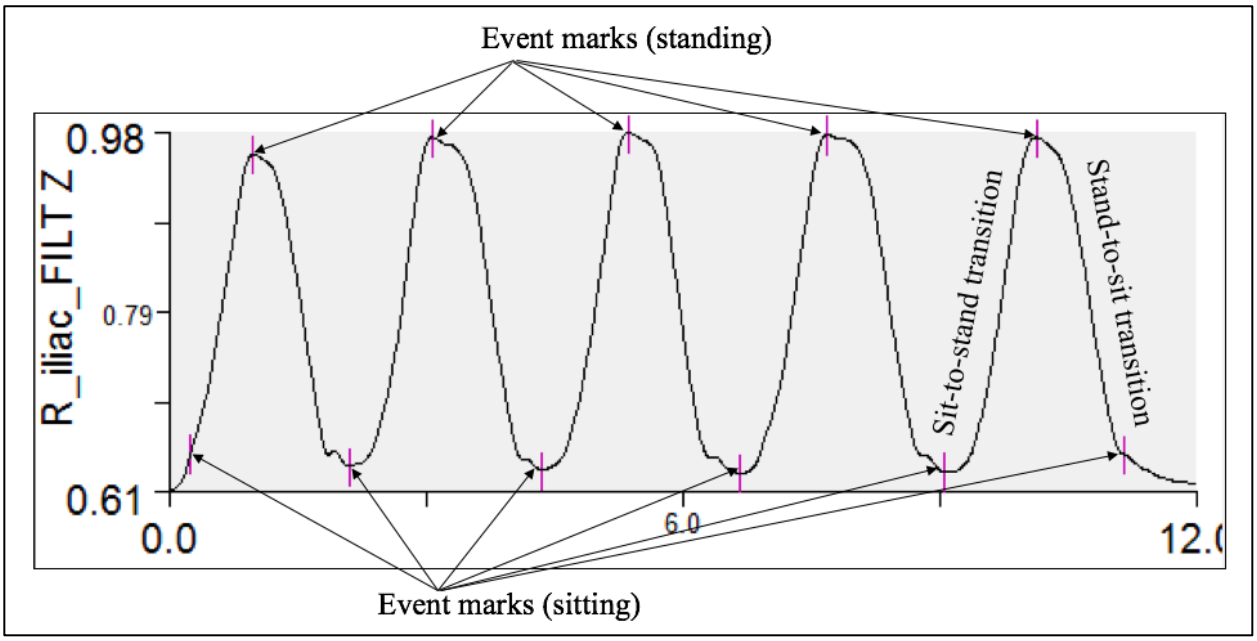


Figure 2.2. Visual 3D Output of Qualisys Data of the Same Participant in Figure 2.1.

2.2.6 *Other Measures*

Study 1 participants' cognition was measured by the Clinical Dementia Rating scale (CDR; Hughes, Berg, Danziger, Coben, & Martin, 1982; Morris, 1993) and the Mini Mental State

Examination (MMSE; Folstein, Folstein, & McHugh). Study 1 participants' cognition, range of motion, hearing, vision, sensation, as well as self-reported (or sometimes caregiver-reported) health conditions (comorbidities) were collected during the home-based assessment. Study 1 participants' age, sex, weight, and height were collected during the lab-based assessment. Study 2 participants' baseline MMSE was collected during the first home-based assessment. Study 2 participants' demographics (e.g. age, sex, date of birth) and health conditions were reported by their caregiver during the baseline and the pre-intervention caregiver phone interviews.

2.2.7 *Data Analysis*

Data analysis was conducted in Stata 12 (StataCorp, LLC, Texas, USA). Descriptive statistics were performed to assess central tendency (mean, median) and variability (standard deviation, range), as well as to check for missing data. To deal with missing values, the author applied the principle of pairwise deletion or "available case analysis" (Sangra & Codina, 2015). That is, a participant was deleted when data were missing in a variable required for a particular analysis, but included in analyses for which all required information were present. It is important to note that when pairwise deletion is applied, the total sample size for analysis does not remain the same across parameter estimations. After pairwise deletion, box plots, scatter plots and residual statistics (i.e. standardized residual, Cook's distance, leverage, dfbeta) were applied to identify outliers. For outliers, the author checked (1) whether the outlier values were humanly possible and (2) if they were due to data entry errors. (The author found 2 data entry errors and corrected the values.) The remaining outliers were included in the primary data analysis. Sensitivity analysis were conducted to evaluate the effect of outliers (See Appendices 2.6.1, 2.6.2, and 2.6.3 for details). In Study 1, (1) the concurrent validity between home iFTSTS parameters and Qualisys FTSTS parameters, as well as (2) the concurrent validity between lab iFTSTS

parameters and Qualisys FTSTS parameters were examined using Pearson's product-moment correlation coefficients (Pearson's r). In Study 2, intraclass correlation coefficients (ICCs) were calculated to assess iFTSTS test-retest reliability over a 1-month period.

2.3 RESULTS

2.3.1 *Study 1 Descriptive Statistics*

Thirty-seven participants with MCI or mild dementia (mean age: 86.4 years; female: 72.2%; mean MMSE: 26) were included in Study 1. See Figure 2.3 for the Study 1 flow chart and Table 2.5 for participant demographics. Descriptive statistics of their iFTSTS parameters and corresponding Qualisys FTSTS parameters were provided in Table 2.6 and Table 2.7. For each iFTSTS parameter, the inclusion criteria in Table 2.4 were applied before data analysis.

Table 2.5. Study 1 Participant Baseline Demographics

Variable	n	Mean (SD) or %	Median	Range
Age (years)	37	86.4 (5.7)	87	71 - 95
Sex	36			
Female	26	72.2	-	-
Male	10	27.8	-	-
MMSE	37	26.0 (3.1)	26	20 - 30
Number of comorbidity	36	2.8 (1.4)	3	0 - 5
Height, meter	36	1.61 (0.12)	1.60	1.27 - 1.83
Weight, kg	36	64.6 (14.4)	61.2	44.5 - 108.0
Body Mass Index	36	24.9 (3.9)	24.2	18.7 - 35.1

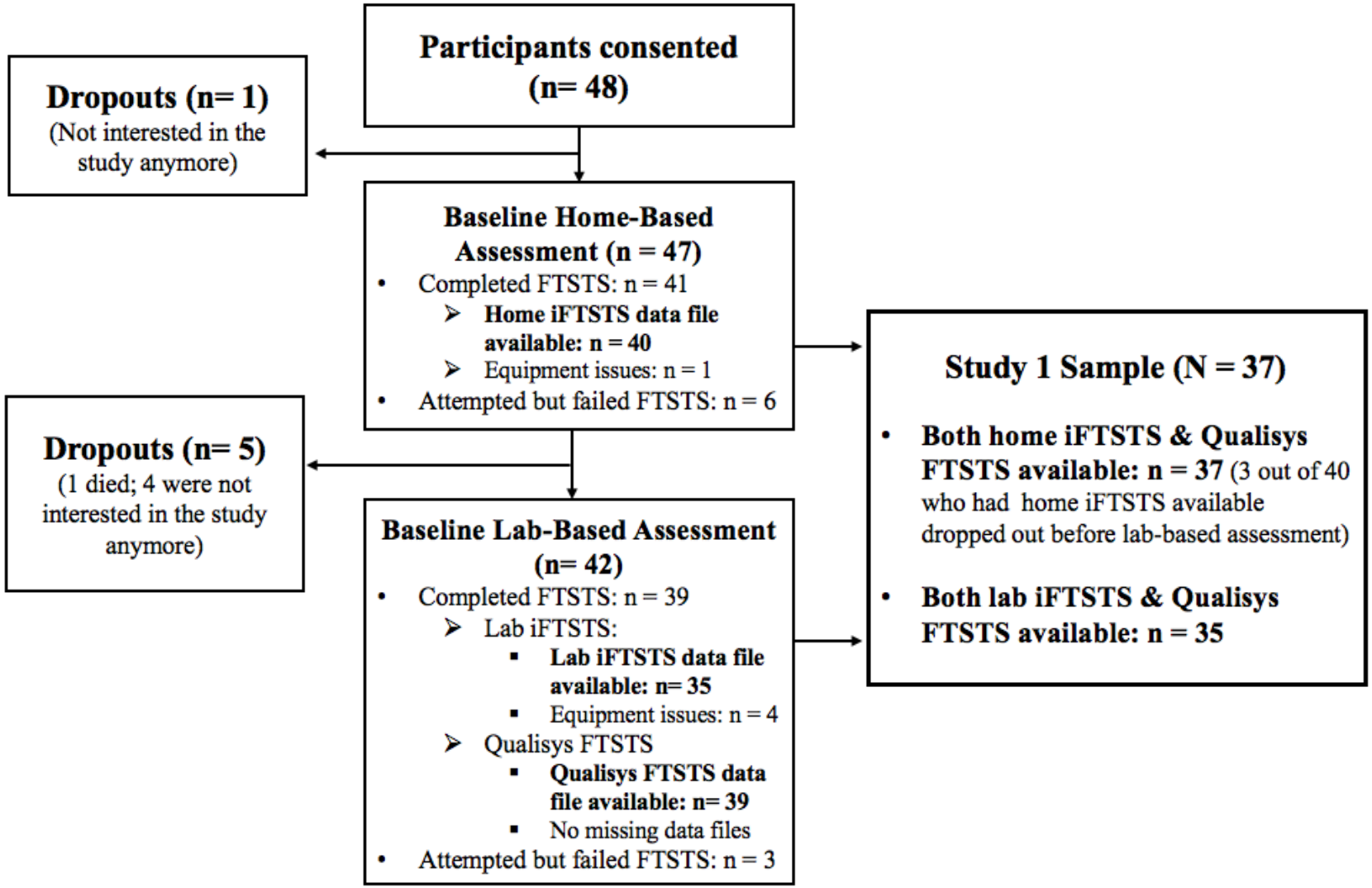


Figure 2.3. Study 1 Flow Chart

Table 2.6. Lab iFTSTS Parameters and Qualisys FTSTS Parameters

FTSTS[a] Parameter	n	Mean (SD)	Median	Range
Total duration, seconds				
Lab APDM iFTSTS[b]	20	12.67(2.63)	11.75	8.39 - 17.22
Lab Qualisys FTSTS[c]	20	12.42 (2.72)	11.64	7.94 - 16.97
Mean SitSt[d] duration, seconds				
Lab APDM iFTSTS	30	1.17 (0.22)	1.14	0.78 - 1.76
Lab Qualisys FTSTS	30	1.20 (0.38)	1.09	0.68 - 2.47
Mean StSit[e] duration, seconds				
Lab APDM iFTSTS	32	0.84 (0.22)	0.79	0.49 - 1.70
Lab Qualisys FTSTS	32	1.52 (0.56)	1.32	0.80 - 3.67
Mean SitSt lean angle, degrees				
Lab APDM iFTSTS	29	30.0 (14.5)	32.4	9.0 - 74.5
Lab Qualisys FTSTS	29	42.2 (7.9)	42.5	26.1 - 57.8
Mean StSit lean angle, degrees				
Lab APDM iFTSTS	30	28.9 (14.2)	30.6	9.3 - 77.7
Lab Qualisys FTSTS	30	42.4 (8.19)	43.3	27.8 - 64.3

Note. a. FTSTS = Five-time sit-to-stand test. b. iFTSTS = Instrumented five-time-sit-to-stand test (instrumented with Mobility Lab™) c. Qualisys FTSTS = FTSTS parameters obtained by the Qualisys Motion Capture System (Qualisys FTSTS descriptive statistics were calculated only in participants who had home iFTSTS parameters available after applying the inclusion criteria specified in Table 2.3.) d. SitSt = Sit-to-stand. e. StSit = Stand-to-sit.

Table 2.7. Home iFTSTS Parameters and Qualisys FTSTS Parameters

FTSTS[a] Parameter	n	Mean (SD)	Median	Range
Total duration, seconds				
Home APDM iFTSTS[b]	21	13.30 (2.51)	12.94	9.08 - 18.36
Lab Qualisys FTSTS[c]	21	13.17 (3.94)	12.46	7.94 - 25.46
Mean SitSt[d] duration, seconds				
Home APDM iFTSTS	36	1.10 (0.22)	1.08	0.73 - 1.62
Lab Qualisys FTSTS	36	1.23 (0.42)	1.11	0.68 - 2.54
Mean StSit[e] duration, seconds				
Home APDM iFTSTS	35	0.87 (0.24)	0.79	0.55 - 1.69
Lab Qualisys FTSTS	35	1.53 (0.57)	1.33	0.80 - 3.67
Mean SitSt lean angle, degrees				
Home APDM iFTSTS	35	28.5 (11.0)	27.8	12.5 - 51.3
Lab Qualisys FTSTS	35	42.3 (8.0)	42.5	26.1 - 57.8
Mean StSit lean angle, degrees				
Home APDM iFTSTS	33	25.6 (10.5)	23.4	10.2 - 47.2
Lab Qualisys FTSTS	33	42.2 (8.5)	42.8	25.5 - 64.3

Note. a. FTSTS = Five-time sit-to-stand test. b. iFTSTS = Instrumented five-time-sit-to-stand test (instrumented with Mobility Lab™) c. Qualisys FTSTS = FTSTS parameters obtained by the Qualisys Motion Capture System (Qualisys FTSTS descriptive statistics were calculated only in participants who had home iFTSTS parameters available after applying the inclusion criteria specified in Table 2.3.) d. SitSt = Sit-to-stand. e. StSit = Stand-to-sit.

2.3.2 *Pearson's Correlation Coefficient (r): Lab iFTSTS vs. Qualisys FTSTS*

The author appraised the strength of the correlation (Pearson's r) between each iFTSTS parameter and its corresponding Qualisys FTSTS parameter using cutoff values suggested by

Evans et al. (1996): The absolute value of r = 0.00 - 0.19 “very weak”; r = 0.20 - 0.39 “weak”; r = 0.40 - 0.59 “moderate”; r = 0.60 - 0.79 “strong”; and r = 0.70 - 1.00 “very strong”. All iFTSTS parameters demonstrated strong to very strong positive correlation (r = 0. 644 - 0.996) with the corresponding Qualisys FTSTS parameters. The parameter that showed the strongest correlation with the corresponding Qualisys FTSTS parameter was lab iFTSTS total duration (r = 0.996), followed by lab iFTSTS mean sit-to-stand duration (r = 0.877), lab iFTSTS mean stand-to-sit duration (r = 0.813), lab iFTSTS mean stand-to-sit lean angle (r = 0.762), and lab iFTSTS mean sit-to-stand lean angle (r = 0.644)

Table 2.8. Study 1 Concurrent Validity: Pearson’s r (Lab APDM iFTSTS vs. Lab Qualisys FTSTS)

Lab iFTSTS[a] Parameter	**Pearson’s r (n, p-value)**
Total duration, seconds	0.996 (n = 20, p < 0.0001)
Mean SitSt[b] duration, seconds	0.877 (n = 30, p < 0.0001)
Mean StSit[c] duration, seconds	0.813 (n = 32, p < 0.0001)
Mean SitSt lean angle, degrees	0.644 (n = 29, p = 0.0002)
Mean StSit lean angle, degrees	0.762 (n = 30, p < 0.0001)

Notes. a. iFTSTS = Instrumented five-time-sit-to-stand test. b. SitSt = Sit-to-stand. c. StSit = Stand-to-sit

2.3.3 *Pearson’s Correlation Coefficient (r): Home iFTSTS vs. Qualisys FTSTS*

Home iFTSTS total duration had a strong positive correlation with Qualisys FTSTS total duration (r = 0.604). Home iFTSTS mean stand-to-sit duration showed a moderate positive correlation with Qualisys FTSTS mean stand-to-sit duration (r = 0.418). Home iFTSTS mean sit-to-stand duration showed a weak positive correlation with Qualisys FTSTS mean sit-to-stand duration (r = .379), while Home iFTSTS mean sit-to-stand lean angle (r = 0.276) and home iFTSTS mean stand-to-sit lean angle (r = 0.243) showed nonsignificant weak positive correlations with their corresponding Qualisys FTSTS parameters.

Table 2.9. Study 1 Concurrent Validity: Pearson's r (Home APDM iFTSTS vs. Lab Qualisys FTSTS)

Home iFTSTS[a] Parameter	**Pearson's r (n, p-value)**
Total duration, seconds	0.604 (n = 21, p = 0.004)
Mean SitSt[b] duration, seconds	0.379 (n = 36, p = 0.023)
Mean StSit[c] duration, seconds	0.418 (n = 35, p = 0.013)
Mean SitSt lean angle, degrees	0.276 (n = 35, p = 0.108)
Mean StSit lean angle, degrees	0.243 (n = 33, p = 0.172)

Notes. a. iFTSTS = Instrumented five-time-sit-to-stand test. b. SitSt = Sit-to-stand. c. StSit = Stand-to-sit

2.3.4 *Sensitivity Analysis Results of Lab iFTSTS and Home iFTSTS*

The removal of outliers decreased the correlation strength between lab iFTSTS mean stand-to-sit duration and Qualisys mean stand-to-sit duration from "very strong" to "strong" (r = 0.813 to 0.674). Similarly, the removal of outliers decreased the correlation strength between lab iFTSTS mean stand-to-sit lean angle and Qualisys mean stand-to-sit lean angle from "strong" to "moderate" (r = 0.762 to 0. 584). In contrast, the removal of outliers had nearly no effect on the correlation strengths between the remaining lab iFTSTS parameters and their corresponding FTSTS parameters. See Appendix 2.6.1 for more details.

The removal of outliers increased the correlation strength between home iFTSTS mean sit-to-stand duration and Qualisys mean sit-to-stand duration from "weak" to "moderate" (r = 0.379 to 0.534). The removal of outliers did not have as much effect on the correlation strength between the remaining home iFTSTS parameters and their corresponding Qualisys FTSTS parameters. For example, even though the removal of outliers increased the correlation strength between home iFTSTS total duration and Qualisys total duration (r = 0.604 to 0.696), the correlation strength remained in the range of "strong" both before and after the outlier removal. See Appendix 2.6.2 for more details.

2.3.5 *Study 2 Descriptive Statistics*

A total of 46 participants with mild to severe dementia (mean age: 86.4 years; female: 72.2%; MMSE range: 2 - 29) were included in Study 2. See Figure 2.4 for the Study 2 flow chart and Table 2.10 for a summary of participant demographics. For each iFTSTS parameter at baseline and at pre-intervention, the inclusion criteria in Table 2.4 were applied before data analysis. To assess test-retest reliability of iFTSTS parameters, baseline data were treated as "test" while pre-intervention data were treated as "retest". See Table 2.11 for iFTSTS parameter descriptive statistics at test and retest.

Table 2.10. Study 2 Participant Baseline Demographics

Demographic Variables	**n**	**Mean (SD) or %**	**Median**	**Range**
Age (years)	46	79.0 (6.68)	80	66 - 91
Sex	46			
Male	26	56.5%	-	-
Female	20	43.5%	-	-
MMSE	46	17.6 (6.13)	18	2 - 29
Dementia	46			
Alzheimer's dementia	40	87.0%	-	-
Vascular dementia	2	4.3%	-	-
Mixed dementia	1	2.2%	-	-
Lewy Body disease	1	2.2%	-	-
Other dementia	2	4.3%	-	-
Number of comorbidity	46	.9 (1.15)	1	0 - 5

Table 2.11. Study 2 iFTSTS Parameter Descriptive Statistics

iFTSTS[a] Parameter	**Assessment**	**n**	**Mean (SD)**	**Median**	**Range**
Total duration, seconds	Test (T0)	33	17.58 (4.83)	17.21	9.59 - 28.40
	Retest (T1)	29	16.04 (4.54)	15.46	9.34 - 25.79
Mean SitSt[b] duration, seconds	Test (T0)	41	1.24 (0.28)	1.23	0.69 - 1.75
	Retest (T1)	42	1.28 (0.46)	1.20	0.70 - 3.29
Mean StSit[c] duration, seconds	Test (T0)	44	0.92 (0.26)	0.89	0.61 - 2.14
	Retest (T1)	44	0.90 (0.25)	0.85	0.51 - 1.66
Mean SitSt lean angle, degrees	Test (T0)	41	30.3 (10.2)	29.3	13.0 - 48.8
	Retest (T1)	42	28.8 (10.3)	27.5	9.45 - 52.3
Mean StSit lean angle, degrees	Test (T0)	44	26.1 (11.2)	24.0	7.2 - 54.1
	Retest (T1)	44	25.6 (10.7)	25.1	10.0 - 57.9

Notes. a. iFTSTS = Instrumented five-time-sit-to-stand test. b. SitSt = Sit-to-stand. c. StSit = Stand-to-sit

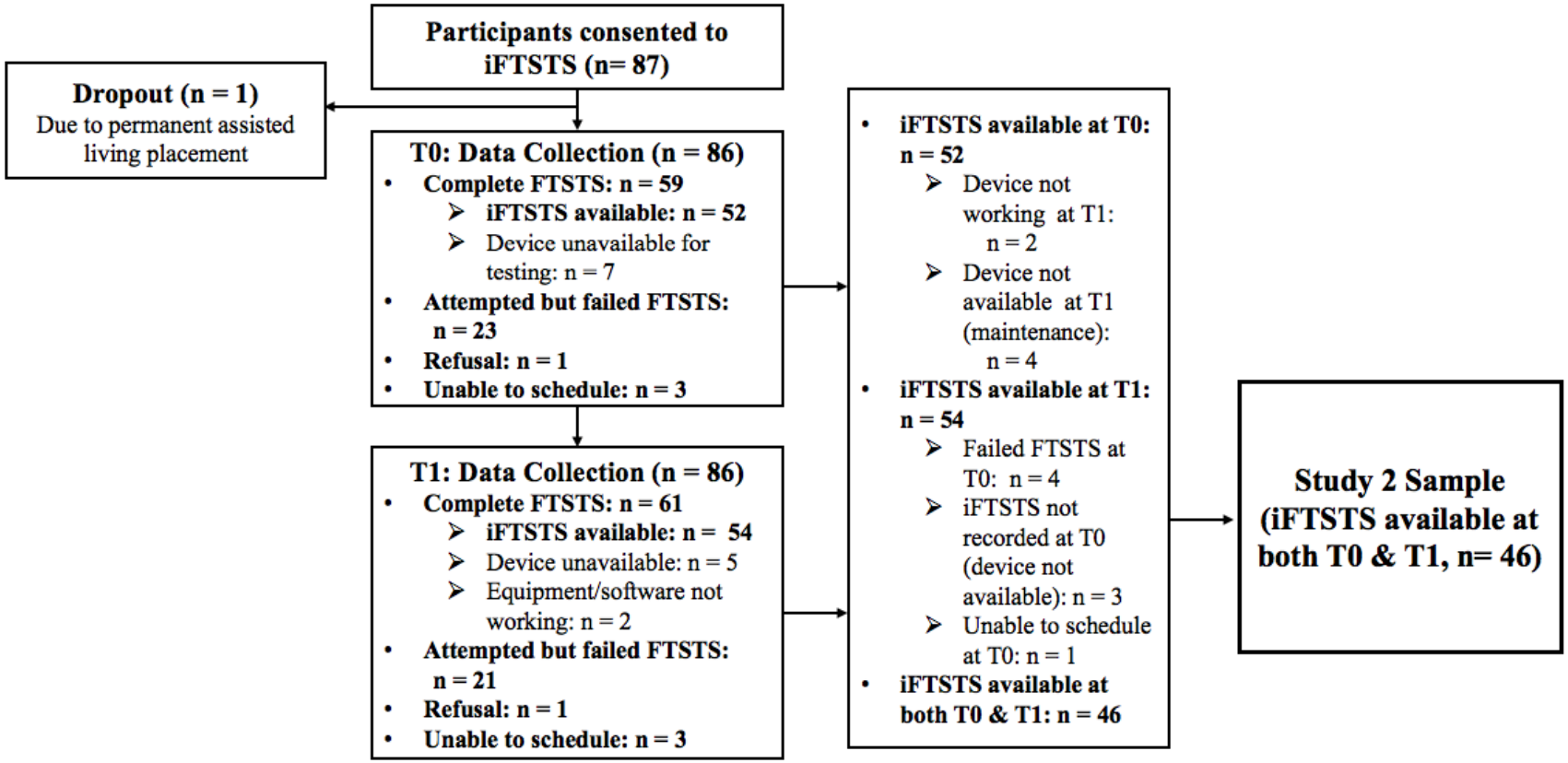


Figure 2.4. Study 2 Flow Chart

2.3.6 *Study 2 Test-Retest Reliability: Intraclass Correlation Coefficients (ICCs)*

The author appraised the ICC values based on Cicchetti et al.'s guidelines (Cicchetti 1994; Cicchetti & Sparrow, 1981): an ICC below 0.40, the level of clinical significance is "poor", between 0.40 and 0.59 is "fair", between 0.60 and .74 is "good", and between 0.75 and 1.00 is "excellent". iFTSTS mean stand-to-sit duration and iFTSTS mean sit-to-stand lean angle showed good test-retest reliability over a 1-month period (ICC = 0.65 and 0.60 respectively). The remaining iFTSTS parameters showed fair test-retest reliability over a 1-month period. Table 2.11 provides a summary of ICC results of all iFTSTS parameters.

The removal of outliers increased the test-retest reliability of all iFTSTS parameters except for iFTSTS mean stand-to-sit duration. Among all iFTSTS parameters, iFTSTS mean sit-to-stand duration's test-retest reliability improved the most, from "fair" to "excellent" (ICC = 0.55 to 0.77). See Appendix 2.6.3 for a summary of the sensitivity analysis results.

Table 2.12. Study 2 iFTSTS Parameter Intraclass Correlation Coefficients (ICCs)

iFTSTS[a] Parameter	**n**	**ICC[b]**	**95% CI[c]**	**p - value**
Total duration, seconds	24	0.55	0.2028 - 0.7793	0.002
Mean SitSt[d] duration, seconds	40	0.55	0.2932 - 0.7348	< 0.001
Mean StSit[e] duration, seconds	44	0.65	0.4367 - 0.7909	< 0.001
Mean SitSt lean angle, degrees	40	0.60	0.3617 - 0.7682	< 0.001
Mean StSit lean angle, degrees	44	0.47	0.2078 - 0.6732	0.001
ICC interpretation: < 0.40 "poor"; 0.40 - .59 "fair"; 0.60 - 0.74 "good"; 0.75 - 1.0 "excellent"				

Notes. a. iFTSTS = Instrumented five-time-sit-to-stand test. b. ICC = intraclass correlation coefficient. c. CI= Confidence interval. d. SitSt = Sit-to-stand. e. StSit = Stand-to-sit.

2.4 Discussion and Conclusions

This paper reported two studies that investigated concurrent validity and test-retest reliability of iFTSTS collected by the APDM Mobility Lab™ in PWDs.

2.4.1 *Concurrent Validity*

Pearson's correlation coefficients were used to assess concurrent validity between APDM iFTSTS and Qualisys FTSTS. All lab APDM iFTSTS parameters demonstrated strong to very strong positive correlations with the corresponding Qualisys FTSTS parameters, suggesting good to excellent concurrent validity between the two methods. In contrast, only three home iFTSTS parameters (home iFTSTS total duration, home iFTSTS mean sit-to-stand duration, and home iFTSTS mean stand-to-sit duration) showed a significant positive correlation with their corresponding Qualisys FTSTS parameters. The remaining two parameters, home iFTSTS mean sit-to-stand lean angle and home iFTSTS mean stand-to-sit lean angle were not significantly correlated with their corresponding Qualisys FTSTS parameters. It was not surprising that all lab APDM iFTSTS parameters had better concurrent validity than their home APDM iFTSTS counterparts because the lab iFTSTS parameters and the corresponding Qualisys parameters were recorded simultaneously, whereas the home iFTSTS parameters were collected between a couple of days to weeks before the lab parameters were collected (participants were scheduled based on their availability to travel to the laboratory after their home-based assessment, and the booking status of the laboratory at the time of the scheduling). Therefore, the non-significant correlation found (1) between home iFTSTS mean sit-to-stand lean angle and Qualisys mean sit-to-stand lean angle and (2) between home iFTSTS mean stand-to-sit lean angle and its corresponding Qualisys FTSTS parameter may be related to participants' functional declines overtime, or day-to-day variability, instead of low validity. Moreover, different time of the day when the two assessments were conducted (e.g. some people with dementia could be more confused and restless due to "sundowning") and the unfamiliar lab environment might have also

affected participants' test performance (e.g. if distracted by the unfamiliar smell, sounds, sights, or people in the lab environment).

2.4.2 *Test-Retest Reliability*

The ICCs of the APDM iFTSTS parameters in Study 2 ranged from 0.47 to 0.65, lower than the 0.80 to 0.94 ICC range that Schwenk et al. (2012) reported when they assessed the test-retest reliability of a FTSTS test instrumented with one body-worn inertial sensor (DynaPort® Hybrid, McRoberts, The Hague, the Netherlands) in an older adult sample. The lower ICCs in Study 2 reported in this paper may be due to several reasons. First, the retest in Schwenk et al.'s study was performed at approximately 5 minutes after the first test, while the retest in Study 2 was conducted approximately 1 month after the first test (secondary analysis of baseline and pre-test data collected 1 month apart for an exercise intervention study). Second, Schwenk et al. excluded older adults with more severe cognitive impairment (MMSE <17) while Study 2 included older adults with mild to severe cognitive impairment (MMSE range: 2 - 29). Third, Schwenk et al. implemented a stricter testing protocol, requiring participants' feet being 10 cm apart at the heels with the shanks positioned at a 10-degree angle relative to the vertical, while Study 2 only required participants to keep their feet flat. Finally, Study 2 required participants to perform at a fast speed, while Schwenk et al. asked participants to perform the test at a self-selected speed.

2.4.3 *Limitations*

There are several limitations in the two studies reported in this paper. First, the APDM Mobility Lab^{TM} FTSTS plugin had not been tested previously. Therefore, the detection rates of the sit-to-stand and stand-to-sit transitions led to missing data. Participant trials with at least 50% of the trials detected by the Mobility Lab^{TM} were included in the data analyses for mean sit-to-stand

duration, mean stand-to-sit duration, mean sit-to-stand lean angle, and mean stand-to-sit lean angle. In other words, the concurrent validity and test-retest reliability results for these parameters might not be generalizable to PWDs who have fewer than 50% of the trials detected by the system. Additionally, the author applied a stricter criterion for the inclusion of iFTSTS total duration for data analysis, requiring participants to have the perfect number of transitions (exactly 5 sit-to-stand transitions and exactly 5 stand-to-sit transitions) detected by the Mobility Lab^{TM} during the FTSTS. Therefore, APDM iFTSTS total duration concurrent validity and test-retest reliability results may not be applicable to PWDs who do not have the perfect number of transitions detected by the system. Moreover, since (1) the home-based assessment and the lab-based assessment for Study 1 (concurrent validity) were conducted between several days to several weeks apart and (2) Study 2's test and retest were secondary data collected approximately 1 month apart (the original study did not intend to examine reliability), these analyses might have been confounded by natural functional declines or acute illness occurred during the time apart between the two assessment sessions. Finally, each participant only performed one FTSTS trial for each of the assessment sessions in both studies unless the participant did not perform the test correctly. Taking the mean results of several trials might provide more reliable results for a more variable parameter. For example, Regterschot et al. (2014) found that in older adults, the smallest number of single sit-to-stand trials (participants were instructed to stand up in a fast speed and then hold still for 5 seconds before sitting down) required for excellent sit-to-stand duration test-retest reliability was 2 trials while the smallest number of excellent peak power test-retest reliability was 4 trials.

2.4.4 *Conclusion*

To the author's knowledge, the two studies reported in this paper are the first studies evaluating an instrumented FTSTS in MCI and dementia. Results of Study 1 demonstrated strong to very strong concurrent validity between all APDM iFTSTS parameters and the gold standard laboratory-based Qualisys Motion Capture system, that were collected concurrently in a laboratory setting in older adults with MCI and mild dementia. Results of Study 2, however, only showed good test-retest reliability in two APDM iFTSTS parameters (i.e. mean stand-to-sit duration, mean sit-to-stand lean angle) over a 1-month period in PWDs. It would be hard to appraise whether the lower ICCs of the remaining parameters were less reliability or if they were more sensitive to true functional declines or acute illnesses that had occurred over the 1-month period. Future research should consider evaluating test-retest reliability of APDM iFTSTS in PWDs over a shorter length of time (e.g. within a week), at the same time of both assessment days, when collecting the test and the retest data, and explore the number of iFTSTS trials needed to have the best test-retest reliability results.

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2.6 APPENDICES

2.6.1 *Study 1 Sensitivity Analysis Results (Lab APDM iFTSTS vs. Lab Qualisys FTSTS)*

Parameter	**Number of Outliers Identified (Participant ID)**	**Pearson's r with Outliers** (p-value, n)	**Pearson's r without Outliers (**p-value, n**)**
Total Duration, seconds	2 (1001, 1026)	0.996 (p < 0.0001, n = 20)	0.997 (p < 0.0001, n = 18)
Mean Sit-to-Stand Duration, seconds	2 (1022, 1039)	0.877 (p < 0.0001, n = 30)	0.896 (p < 0.0001, n = 28)
Mean Sit-to-Stand Lean Angle, degrees	3 (1013, 1026, 1042)	0.644 (p = 0.0002, n = 29)	0.633 (p = 0.0005, n = 26)
Mean Stand-to-Sit Duration, seconds	3 (1020, 1022, 1045)	0.813 (p < 0.0001, n = 32)	0.674 (p = 0.0001, n = 29)
Mean Stand-to-Sit Lean Angle, degrees	3 (1014, 1026, 1029)	0.762 (p < 0.0001, n= 30)	0.584 (p = 0.001, n = 27)
Notes. a. SitSt = Sit-to-stand. b. StSit = Stand-to-sit. c. Strength of the linear relationship: r = 0.00 - 0.19 "very weak"; r = 0.20 - 0.39 "weak"; r = 0.40 - 0.59 "moderate"; r = 0.60 - 0.79 "strong"; r = 0.80 -1.00 "very strong".			

Note. Outliers were identified using boxplots, scatterplots, and residual analyses.

2.6.2 *Study 1 Sensitivity Analysis Results (Home APDM iFTSTS vs. Lab Qualisys FTSTS)*

Parameter	**# of Outliers Identified (Participant ID)**	**Pearson's r with Outliers (p-value, n)**	**Pearson's r without Outliers (95% CI, p-value)**
Total Duration, seconds	2 (1018, 1022)	0.604 (p = 0.004, n = 21)	0.696 (p < 0.001, n = 19)
Mean Sit-to-Stand Duration, seconds	4 (1018, 1020, 1022, 1029)	0.379 (p = 0.023, n = 36)	0.534 (p = 0.002, n = 32)
Mean Sit-to-Stand Lean Angle, degrees	No outliers identified	0.276 (p = 0.108, n = 35)	NA
Mean Stand-to-Sit Duration, seconds	4 (1020, 1022, 1023, 1034)	0.418 (p = 0.013, n = 35)	0.496 (p = 0.005, n = 31)
Mean Stand-to-Sit Lean Angle, degrees	3 (1018, 1025, 1026)	0.243 (p = 0.172, n = 33)	0.205 (p = 0.277, n = 30)
Notes. a. SitSt = Sit-to-stand. b. StSit = Stand-to-sit. c. Strength of the linear relationship: r = 0.00 - 0.19 "very weak"; r = 0.20 - 0.39 "weak"; r = 0.40 - 0.59 "moderate"; r = 0.60 - 0.79 "strong"; r = 0.80 -1.00 "very strong".			

Note. Outliers were identified using boxplots, scatterplots, and residual analyses.

2.6.3 *Study 2 Test-Retest Reliability Sensitivity Analysis Results*

Parameter	**Number of Outliers Identified** (Participant ID)	**ICC** (95% CI, p-value, n)	**ICC without Outliers** (95% CI, p-value, n)
APDM Total Duration, seconds	3 (837, 862, 724)	0.55 (95% CI: 0.2028-0.7793, p = 0.002, n = 24)	0.67 (95% CI: 0.3437-0.8511, p < .001, n = 21)
APDM Mean Sit-to-Stand Duration, seconds	3 (836, 837, 977)	0.55 (95% CI: 0.2932-0.7347, p < 0.001, n = 40)	0.77 (95% CI: 0.6038-0.8770, p < 0.001, n = 37)
APDM Mean Stand-to-Sit Duration, seconds	4 (459, 836, 848, 984)	0.65 (95% CI: 0.4367-0.4909, p < 0.001, n = 44)	0.57 (95% CI: 0.3190-0.7476, p < 0.001, n = 40)
APDM Mean Sit-to-Stand Lean Angle, degrees	3 (728, 837, 838)	0.60 (95% CI: 0.3617-0.7682, p < 0.001, n = 40)	0.72 (95% CI: 0.5173-0.8444, p < 0.001, n = 37)
APDM Mean Stand-to-Sit Lean Angle, degrees	2 (837, 977)	0.47 (95% CI: 0.2078-0.6732, p = 0.001 n = 44)	0.54 (95% CI: 0.2899-0.7256, p < 0.001, n=42)
ICC interpretation: < 0.40 “poor”; 0.40 - 0.59 “fair”; 0.60 - 0.74 “good”; 0.75 - 1.0 “excellent”			

Note. Outliers were identified using boxplots, scatterplots, and residual analyses.

Chapter 3. ASSOCIATIONS BETWEEN FUNCTIONAL MOBILITY, PHYSICAL FUNCTIONING, AND DEMENTIA CAREGIVING TIME

Background and Objectives: The objective of this study was to examine the associations between functional mobility in persons with dementia (PWDs) using a five-time sit-to-stand test (FTSTS) and its instrumented version (iFTSTS), caregiver-reported PWD physical functioning, and caregiver-reported dementia caregiving time spent assisting in activities of daily living (ADLs). The iFTSTS included the following parameters: total time, mean sit-to-stand duration, mean stand-to-sit duration, mean sit-to-stand lean angle, and mean stand-to-sit lean angle. **Research Design and Methods**: The author conducted a cross-sectional analysis of baseline data from an exercise intervention study (n = 83). Robust regression was used to examine associations among PWD functional mobility, PWD physical functioning, and dementia caregiving time spent assisting in ADLs. **Results**: The findings suggested that PWDs who successfully completed the FTSTS had higher caregiver-reported PWD physical functioning ($p < 0.001$) and shorter caregiver-reported dementia caregiving time spent assisting in ADLs ($p = 0.001$), compared to those who could not complete the test. Among iFTSTS parameters, total duration ($p = 0.005$), mean sit-to-stand duration ($p = 0.017$), and mean stand-to-sit duration ($p = 0.036$) were associated with caregiver-reported PWD physical functioning. **Discussion and Implications**: Results of this study supports that there are significant associations between PWD functional mobility, caregiver-reported PWD physical functioning, and caregiver-reported dementia caregiving time spent in assisting ADLs. Longitudinal investigations are needed to confirm whether the associations between these variables found in this study are causal.

3.1 INTRODUCTION

In the United States, over 80% of hours of care received by older adults come from informal caregivers, primarily family members (Friedman, Shih, Langa, & Hurd, 2015). Caregiving tasks often involve assistance with activities of daily living (ADLs) and instrumental activities of daily living (IADLs). ADLs are everyday tasks, such as eating, bathing, dressing, toileting, and transferring (Wiener, Clark, Hanley, & Van Nostrand, 1990) while IADLs involve more complex activities, such as paying bills, preparing meals, and shopping (Lawton & Brody, 1969). In 2016, dementia caregivers provided an estimated 18.2 billion hours of unpaid assistance, the economic value of which was estimated at $ 230.1 billion (Alzheimer's Association, 2017). Among community-dwelling persons with dementia (PWDs), 53.1% receive assistance with ADLs, 39.8% receive help with 3 or more ADLs, and 29.5% have 3 or more caregivers (Kasper, Freedman, Spillman, & Wolff, 2015).

Dementia caregiving time is associated with care recipients' performance of everyday activities, which is affected by care recipients' functional mobility—i.e. the manner in which they are able to move around in the environment to participate in ADLs and to transfer from place to place (Forhan & Gill, 2013). Several performance-based tests exist to measure functional mobility in older adults (Tiedemann, Shimada, Sherrington, Murray, & Lord, 2008), of which one of the most widely used is the five-time sit-to-stand test (FTSTS; Csuka & McCarty; Guralnik et al., 1994). The FTSTS is a simple test that measures the time taken in seconds for an individual to complete standing up from a chair and then sitting down again for 5 times as quickly as possible using a stopwatch (the standard timed FTSTS). Even though (1) the association between functional mobility measured by the standard timed FTSTS and disability in ADLs has been established in large epidemiologic investigations (Guralnik et al., 1994) and (2)

recent research evidence suggests that objective subtask parameters (e.g. sit-to-stand duration, stand-to-sit duration, etc.) derived from body-worn sensors during the FTSTS administration are associated with older adults' self-reported functional status (Regterschot, Zhang, Baldus, Stevens, & Zijlstra, 2015; van Lummel, Walgaard, Maier, Ainsworth, Beek & van Dieen, 2016), the inter-relationships among (1) PWD functional mobility—measured by either the standard timed tests or sensor-based methods, (2) PWD physical functioning, and (3) dementia caregiving time spent assisting PWDs with ADLs have not been evaluated in published studies. Therefore, the purpose of this study is to examine the associations among (1) functional mobility measured by the timed FTSTS and an instrumented version of the test ("instrumentation" refers to participants wearing body-worn sensors throughout the administration of the FTSTS to obtain objective FTSTS subtask parameters), (2) caregiver-reported PWD physical functioning, and (3) caregiver-reported caregiving time spent assisting PWDs with ADLs (referred to as "ADLs caregiving time" from this point on). In this paper, the author uses the term "FTSTS" to refer to the standard timed test and the term "iFTSTS" to refer to the instrumented version. The body-worn sensor system used to "instrument" the study participants was the Mobility Lab™ (APDM, Inc., Portland, OR, USA). The APDM Mobility Lab™ includes a vendor-developed software that automatically analyses the sensor data and outputs the following quantitative FTSTS subtask parameters: total duration, mean sit-to-stand duration, mean stand-to-sit duration, mean sit-to-stand lean angle, and mean stand-to-sit lean angle.

The specific research questions were:

- Is functional mobility in PWDs associated with caregiver-reported PWD physical functioning?

- Is caregiver-reported PWD physical functioning associated with caregiver-reported ADLs caregiving time?
- Is functional mobility in PWDs associated with caregiver-reported ADLs caregiving time?

The author hypothesizes that (1) higher PWD functional mobility is associated with higher caregiver-reported PWD physical functioning (Hypothesis 1); (2) higher caregiver-reported PWD physical functioning is associated with shorter caregiver-reported ADLs caregiving time (Hypothesis 2); and (3) higher PWD functional mobility is associated with shorter caregiver-reported ADLs caregiving time (Hypothesis 3). Figure 3.1 provides an illustration of the hypothesized inter-relationships among functional mobility in PWDs, caregiver-reported PWD physical functioning, and caregiver-reported ADLs caregiving time.

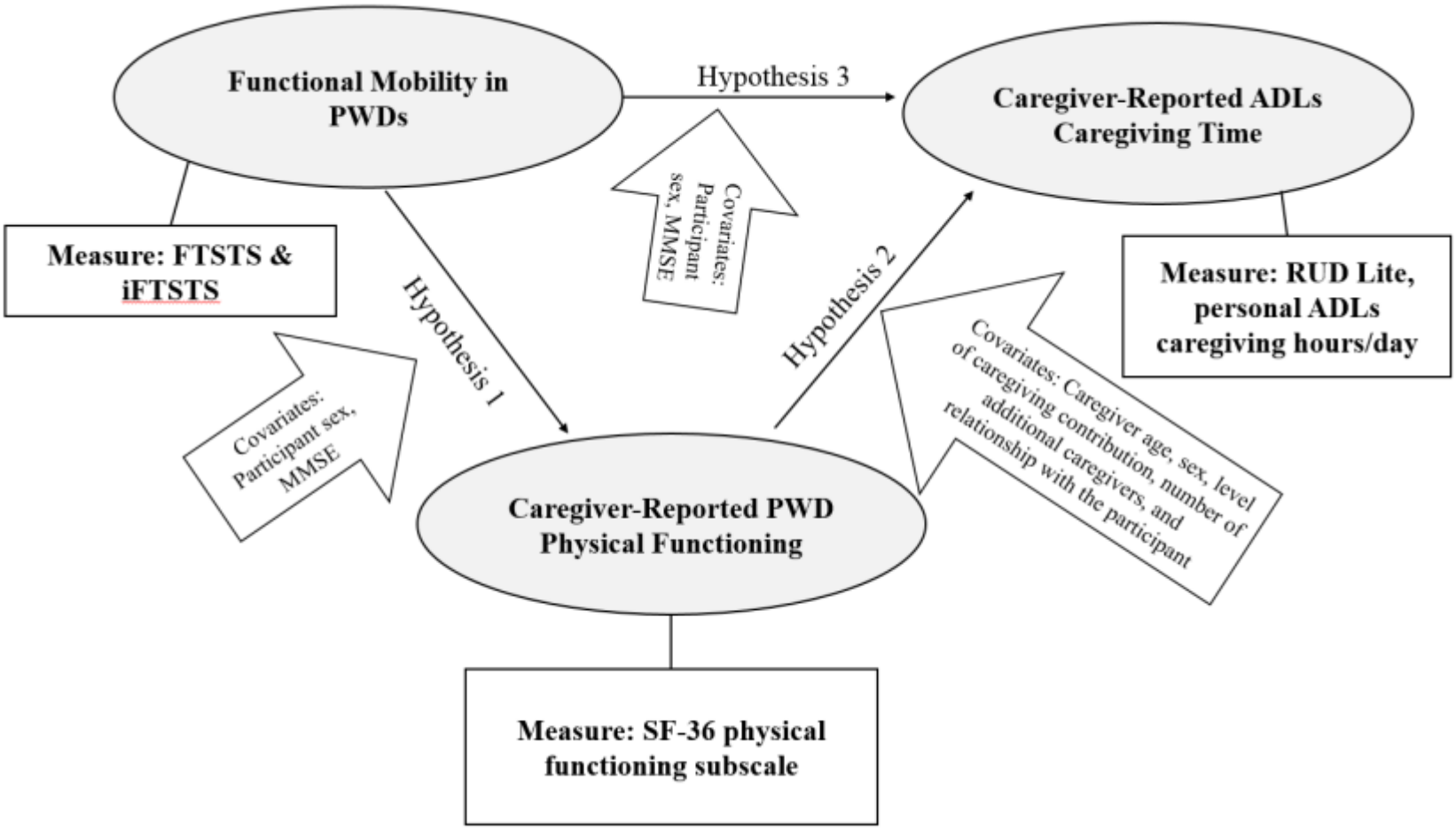

Figure 3.1. Conceptual Framework

3.2 METHODS

3.2.1 *Study Design and Subjects*

The current study is a cross-sectional analysis of baseline data from 83 community-dwelling PWDs who participated in a PWD-caregiver dyadic exercise intervention trial. Participants were recruited through urban and rural Aging and Disability Services (formerly known as Area Agencies on Aging) in Washington State and through community outreach. Study inclusion criteria included: (1) had to be 65 years of age or older; (2) met DSM-IV-TR criteria for dementia (confirmed in writing by their primary physician); (3) exercised less than 150 minutes per week; (4) obtained approval from their primary physician to participate in the study; and (5) had a primary caregiver living in the community. A potential participant was excluded if either the participant or the caregiver (1) had plans to move to long-term residential care within 6 months of enrolment; (2) expected to move from the study geographic area within the study period; (3) was non-ambulatory, blind, or deaf; (4) had been hospitalized for psychiatric illness within the past 12 months; or (5) had a known terminal illness. All participants (PWDs and caregivers) consented to the study. Moreover, a caregiver or a representative with power of attorney was required to consent on behalf of the PWD. The study was approved by the University of Washington Institutional Review Board.

3.2.2 *Measures*

Participants' baseline data were collected by phone (caregiver report) and in-person at participants' residence. Therefore, measures below are grouped as "caregiver phone survey" and "in-home testing" accordingly.

Caregiver phone survey

The study coordinator administered the measures of demographics, physical functioning, and caregiver resource utilization (including ADLs caregiving time) over the phone and entered the answer to each question into an online database as each answer was supplied by the caregiver. The paper form of these measures was mailed out to the caregivers before the phone survey so that they could see the question items.

Demographics.

The caregiver provided demographic information including date of birth, sex, race/ethnicity, education, marital status, and comorbidities of both the PWD and the caregiver, as well as the relationship between the dyad.

Caregiver-Reported PWD Physical Functioning

PWD physical functioning was assessed using caregiver ratings on the physical functioning subscale of the Medical Outcome Study 36-item Short Form Health Survey (SF-36; Ware & Sherbourne, 1992). The SF-36 is a reliable and valid measure for PWDs; the internal consistency of the physical functioning subscale is excellent (Cronbach's α= 0.918) in people with mild to severe dementia (Geschke, Fellgiebel, Laux, Schermuly, & Scheurich, 2013). In this study, the author used the transformed SF-36 physical functioning score. The possible transformed scores range from 0 to 100, with "0" indicating "limited a lot in performing all physical activities including bathing or dressing due to health" and "100" indicating the ability to "perform all types of physical activities including the most vigorous without limitations due to health."

ADLs caregiving time.

Caregiver-reported ADLs caregiving time was assessed using the following item in the Resource Utilization in Dementia short form (RUD Lite 2.2; Wimo & Winblad, 2003): "During the past month, on a typical day when you cared for your care recipient, how much time did you spend

helping with tasks like toilet visits, eating, dressing, grooming, walking, or bathing?" The RUD was developed to capture the use of resources by PWDs in clinical trial settings. The RUD is a valid and reliable measure of both informal and formal caregiving time (Wimo & Nordberg, 2007). It has also been validated for assessing informal caregiving time in community-dwelling PWDs (Wimo, Jonsson, & Lbrozek, 2010). Additional questions from the RUD Lite, such as "How many other caregivers are involved in the care of your care recipient?" were included as covariates in the statistical analysis.

In-home testing.

The trained research assistants administered the measures described below at participants' residence.

Cognitive function.

The participant's cognitive function was assessed using the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975). The MMSE is a 30-point questionnaire commonly used to screen for signs of dementia. The possible MMSE scores range from 0 to 30. An MMSE score between 19 and 24 indicates mild cognitive impairment, a score between 10 and 18 indicates moderate impairment, and a score of 9 and below indicates severe impairment. Since its creation in 1975, the MMSE has been validated and used extensively for both clinical and research purposes.

Functional mobility.

The PWD's functional mobility was assessed with the FTSTS (Csuka & McCarty, 1985; Guralnik, et al., 1994) and iFTSTS. The FTSTS requires the participant to stand up and sit down from a standard chair (18" seat to floor height) five times in a row as quickly as possible without using their arms. The total time for the FTSTS is measured with a stopwatch. The test-retest

reliability of FTSTS is good to excellent in in various populations, including community-dwelling adults (Bohannon, Bubela, Magasi, & Gershon, 2011), community-dwelling older adults (Tiedemann, et al., 2008), sedentary older adults with osteoarthritis (Lin, Davey, & Cochrane, 2001), adults with low back pain (Simmonds et al., 1998), and adult day center clients with dementia (Thomas & Hageman, 2002). The instrumented version provides objective quantitative measures of FTSTS subtasks, including total time, mean sit-to-stand duration, mean stand-to-sit duration, mean sit-to-stand lean angle, and mean stand-to-sit lean angle. Table 3.13 provides definitions of each iFTSTS parameter based on information provided by the vendor, as well as inclusion criteria for data analysis by parameter.

To obtain iFTSTS data, a trained research assistant instrumented the participant with the APDM Mobility Lab™ before testing began. APDM stands for Ambulatory Parkinson's Disease Monitoring. The Mobility Lab™ consists of (1) a set of small inertial sensors with built in tri-axial accelerometers, gyroscopes, and magnetometers; (2) sensor docking stations; (3) a wireless access control point; and (4) a Mobility Lab™ software for data processing. The trained research assistant first placed 6 inertial sensors on the participant (2 on feet, 2 on wrists, sternum and lumbar) and then instructed the participant to perform the FTSTS. Since the participant was wearing sensors, he/she was instructed to hold his/her hands at either side of the knees instead of folding them across the chest. The participant's body movement data were recorded via wireless transmission from the 6 inertial sensors and processed with the Mobility Lab™ software installed in a laptop computer.

Table 3.13. iFTSTS Parameter Definitions and Inclusion Criteria for Data Analysis

Parameter	Unit	Definition	Inclusion Criteria for Data Analysis
Total duration	**Seconds**	If at least 1 sit-to-stand transition and at least 1 stand-to-sit transition are detected by the Mobility Lab™ algorithm, the total duration is calculated as the period between the initiation of the 1st sit-to-stand event detected and the termination of the last stand-to-sit event detected.	Based on the parameter definition, the total duration would only be calculated correctly by the Mobility Lab™ software if exactly five sit-to-stand transitions and exactly five stand-to-sit transitions were detected. Therefore, the inclusion criteria of iFTSTS total duration for data analysis was "exactly 5 sit-to-stand transitions and exactly 5 stand-to-sit transitions detected by the Mobility Lab™ software."
Mean sit-to-stand duration	**Seconds**	The sit-to-stand duration, or the duration of the sit-to-stand transition, is defined as the time between (1) the initiation of the sit-to-stand transition and (2) when the vertical velocity goes to zero. The mean sit-to-stand duration is the average of all sit-to-stand durations detected.	Since the Mobility Lab™ could only calculate the sit-to-stand duration for the sit-to-stand transitions that it successfully detected, the author decided to only include a participant's mean sit-to-stand duration for data analysis if the participant successfully completed the FTSTS and the Mobility Lab™ software successfully detected at least 50% of the sit-to-stand transitions performed by the participant.
Mean stand-to-sit duration	**Seconds**	The stand-to-sit duration, or the duration of the stand-to-sit transition, is defined as the time between (1) the initiation of the stand-to-sit event and (2) when the vertical velocity goes to zero m/s^2 or when the vertical velocity indicating a change of direction. The mean stand-to-sit duration is the average of all stand-to-sit durations detected.	Since the Mobility Lab™ could only calculate the stand-to-sit duration for the stand-to-sit transitions that it successfully detected, the author decided to only include a participant's mean stand-to-sit duration for data analysis if the participant successfully completed the FTSTS and the Mobility Lab™ software successfully detected at least 50% of the stand-to-sit transitions performed by the participant.
Mean sit-to-stand lean angle	**Degrees**	The sit-to-stand trunk lean angle is calculated as the maximum forward trunk lean angle during each sit-to-stand transition. The mean sit-to-stand trunk lean angle is the average of all sit-to-stand trunk lean angles detected.	Since the Mobility Lab™ software could only calculate the sit-to-stand trunk lean angle occurred during the sit-to-stand transitions that it successfully detected, the author decided to only include a participant's mean sit-to-stand lean angle if the participant had successfully performed the FTSTS and the Mobility Lab™ software successfully detected at least 50% of the sit-to-stand transitions performed by the participant.
Mean stand-to-sit lean angle	**Degrees**	The stand-to-sit trunk lean angle is calculated as the maximum forward lean angle during each stand-to-sit transition. The mean stand-to-sit trunk lean angle is the average of all stand-to-sit trunk lean angles detected.	Since the Mobility Lab™ software was only able to calculate the stand-to-sit trunk lean angle occurred during the sit-to-stand transitions that it successfully detected, the author decided to only include a participant's mean stand-to-sit lean angle if the participant had successfully performed the FTSTS and had at least 50% of the stand-to-sit transitions detected by the Mobility Lab™ software.

3.2.3 *Data Analysis*

Data were analysed with Stata 12 (StataCorp, LLC, Texas, USA). Descriptive statistics were performed to summarize variable characteristics (central tendency, variability, spread) and to check for missing data. Histograms and boxplots were used to check for variable distribution and to identify outliers. Student t-tests with unequal variance and Pearson's Chi^2 were performed to determine (1) if baseline demographics were different between those who completed the FTSTS ("FTSTS completers") and those who were unable to complete the FTSTS ("FTSTS non-completers") and (2) among FTSTS completers, if any baseline demographics were different between those who had iFTSTS data available and those who did not. To downweigh influential outliers and to correct for potential heteroscedasticity (Sangra & Codina, 2015), robust regression instead of linear regression was conducted to assess associations between FTSTS performance, caregiver-reported PWD physical functioning, and caregiver-reported ADLs caregiving time. The detection rates of the sit-to-stand transitions and the stand-to-sit transitions of the Mobility Lab™ software were also calculated.

3.3 RESULTS

3.3.1 *Demographics*

A total of 83 community-dwelling PWDs (mean age: 80.1 years; 48.2% female; mean MMSE: 16.5) were included in the study. Among the 83 participants, 59 successfully completed the FTSTS ("FTSTS completers"), but 24 were unable to complete all 5 sit-to-stand repetitions required by the test ("FTSTS non-completers"). When compared to FTSTS completers, FTSTS non-completers (n = 24) had more comorbid conditions (p = 0.015), were older (p = 0.0045), and had more additional caregivers involved in their care (p = .022), as reported by their primary

caregiver during the caregiver phone survey. FTSTS completers versus non-completers did not differ in the rest of the demographic and caregiver variables listed in Table 3.14 and Table 3.15. No iFTSTS data were collected for FTSTS non-completers. Among the 59 participants who successfully completed the FTSTS, 7 had no iFTSTS files because the Mobility Lab™ was not yet available for data collection at the time when these 7 participants received their baseline assessment for the parent exercise intervention trial. Among FTSTS completers (n = 59), those who had their iFTSTS data collected (n = 52) and those who did not have their iFTSTS data collected (n = 7) did not differ in any demographic or caregiver variables listed in Table 3.14 and Table 3.15.

Table 3.14. Summary of Participant Demographics

Demographic Variable		**Whole Sample (n = 83)**	**FTSTS[a] completers (n = 59)**	**iFTSTS[b] subgroup (n = 52)**	**FTSTS non-completers (n = 24)**
Age (years)	Mean (SD) Range	80.1 (7.5) 62 - 95	78.6 (7.0) 62 - 93	79.0 (7.1) 65 - 93	83.8 (7.3) 67 - 95
Sex	Male, n (%) Female, n (%)	43 (51.8%) 40 (48.2%)	33 (56.0%) 26 (44.0%)	29 (55.8%) 23 (44.2%)	10 (41.7%) 14 (58.3%)
MMSE	Mean (SD) Range	16.5 (6.5) 1 - 29	16.6 (6.7) 1 - 29	16.6 (6.7) 1 - 29	16.3 (6.3) 3 - 25
Dementia	Alzheimer's dementia, n (%) Vascular dementia, n (%) Mixed dementia, n (%) Lewy Body disease, n (%) Other, n (%)	71 (85.5%) 3 (3.6%) 3 (3.6%) 2 (2.4%) 4 (4.8%)	53 (88.1%) 2 (3.4%) 1 (1.7%) 1 (1.7%) 2 (3.4%)	46 (88.5) 2 (3.9%) 1 (1.9%) 1 (1.9%) 2 (3.9%)	18 (75%) 1 (4.2%) 2 (8.3%) 1 (4.2%) 2 (8.3%)
Race/ ethnicity	Caucasian, n (%) African American, n (%) Asian, n (%) Other, n (%)	73 (88.0 %) 2 (2.4%) 6 (7.2%) 2 (2.4%)	52 (88.1%) 2 (3.4%) 4 (6.8%) 1 (1.7%)	45 (86.5%) 2 (3.9%) 4 (7.7%) 1 (1.9%)	21 (87.5%) 0 (0%) 2 (8.3%) 1 (4.2%)
Education	< High school or some high school, n (%) High school graduate, n (%) Some college, n (%) College degree to some graduate, n (%) Graduate degree, n (%) Vocational or technical certificate, n (%)	7 (8.4%) 17 (20.5%) 17 (20.5%) 22 (26.5%) 14 (16.9%) 6 (7.2%)	5 (8.5%) 13 (22.0%) 11 (18.6%) 17 (28.8) 10 (17.0%) 3 (5.0%)	5 (9.6%) 11 (21.2%) 9 (17.3%) 14 (26.9%) 10 (19.2%) 3 (5.8%)	2 (8.2%) 4 (16.7%) 6 (25.0%) 5 (20.8%) 4 (16.7%) 3 (12.5%)
Marital status	Married, n (%) Widowed, n (%) Separated, n (%) Divorced, n (%) Never married, n (%)	53 (63.9%) 21 (25.3%) 0 (0%) 7 (8.4%) 2 (2.4%)	40 (67.8%) 13 (22.0%) 0 (0%) 5 (8.5%) 1 (1.7%)	34 (65.4%) 12 (23.1%) 0 (0%) 5 (9.6%) 1 (1.9%)	13 (54.2%) 8 (33.3%) 0 (0%) 2 (8.3%) 1 (4.2%)
Number of comorbidity	Mean (SD) Range	1.2 (1.5) 0 - 9	.9 (1.1) 0 - 5	.9 (1.1) 0 - 5	2 (1.9) 0 - 9
Relationship to the caregiver	Spouse/romantic partner, n (%) Parent, n (%) Sibling, n (%) Other relative, n (%) Friend, n (%) Paid caregiver, n (%)	54 (65.1%) 22 (26.5%) 0 (0%) 3 (3.6%) 3 (3.6%) 1 (1.2%)	42 (71.2%) 14 (23.7%) 0 (0%) 2 (3.4%) 1 (1.7%) 0 (0%)	36 (69.2%) 13 (25.0%) 0 (0%) 2 (3.9%) 1 (1.9%) 0 (0%)	12 (50%) 8 (33.3%) 0 (0%) 1 (4.2%) 2 (8.3%) 1 (4.2%)

Notes. a. FTSTS = Five-time sit-to-stand test. B. iFTSTS = Instrumented five-time-sit-to-stand test.

Table 3.15. Summary of Caregiver Variables

Caregiver Demographic Variables		**Whole Sample (n= 83)**	**FTSTS[a] completers (n= 59)**	**iFTSTS[b] subgroup (n= 52)**	**FTSTS non-completers (n= 24)**
Age (years)	Mean (SD) Range	67.9 (12.0) 33 - 94	67.9 (11.6) 41 - 94	67.6 (11.9) 41 - 94	67.8 (13.1) 33 - 89
Sex	Male, n (%) Female, n (%)	63 (75.9%) 20 (24.1%)	45 (76.3%) 14 (23.7%)	40 (76.9%) 12 (23.1%)	18 (75%) 6 (25%)
Number of additional caregivers[c]	0, n (%) 1, n (%) 2, n (%) 3, n (%) 4, n (%)	43 (51.8%) 16 (19.3%) 15 (18.1%) 6 (7.2%) 3 (3.6%)	35 (59.3%) 11 (18.6%) 10 (17.0%) 1 (1.7%) 2 (3.4%)	29 (55.8%) 11 (21.2%) 9 (17.3%) 1 (1.9%) 2 (3.9%)	8 (33.3%) 5 (20.8%) 5 (20.8%) 5 (20.8%) 1 (4.17%)
Level of caregiving contribution[d]	1-20%, n (%) 21-40%, n (%) 41-60%, n (%) 61-80%, n (%) 81-100%, n (%) Refused, n (%)	0 (0%) 2 (2.4%) 4 (4.8%) 8 (9.6%) 68 (81.9%) 1 (1.2%)	0 (0%) 1 (1.7%) 2 (3.4%) 5 (8.5%) 50 (84.8%) 1 (1.7%)	0 (0%) 1 (1.9%) 2 (3.9%) 5 (9.6%) 44 (84.6%) 0 (0%)	0 (0%) 1 (4.2%) 2 (8.3%) 3 (12.5%) 18 (75%) 0 (0%)

Notes. a. FTSTS = Five-time sit-to-stand test. b. iFTSTS = Instrumented five-time-sit-to-stand test. c. Caregiver-reported number of other caregivers involved in the care of the participant. d. Caregiver-reported own level of contribution among all the caregivers involved in the care of the participant.

3.3.2 *Detection Rates of Sit-to-Stand and Stand-to-Sit Transitions*

Among the 52 iFTSTS completers (i.e. participants who successfully completed the FTSTS and had their iFTSTS data file available), the mean number of sit-to-stand transitions detected by the Mobility Lab™ software was 4.5 (SD: 1.24; range: 0 - 6); the mean number of stand-to-sit transitions detected by the Mobility Lab™ software was 4.8 (SD: 0.88; range: 0 - 6). Among the 52 iFTSTS completers, 40 (76.9%) had exactly 5 sit-to-stand transitions detected by the Mobility Lab™ software, 46 (88.5%) had exactly 5 stand-to-sit transitions detected, while 38 (73.1%) had not only exactly 5 sit-to-stand transitions detected but also exactly 5 stand-to-sit transitions detected. See Table 3.16 for details.

Table 3.16. Number of Sit-to-Stand and Stand-to-Sit Transitions Detected among iFTSTS Completers (n = 52)

Number of sit-to-stand transitions detected by Mobility Lab™ among iFTSTS completers	**Participants, n (%)**	**Number of stand-to-sit transitions detected by Mobility Lab™ among iFTSTS completers**	**Participants, n (%)**
0	1 (1.9%)	0	1 (1.9%)
1	3 (5.8%)	1	0 (0%)
2	1 (1.9%)	2	1 (1.9%)
3	1 (1.9%)	3	1 (1.9%)
4	5 (9.6%)	4	1 (1.9%)
5	**40 (76.9%)**	**5**	**46 (88.5%)**
6	1 (1.9%)	6	2 (3.9%)
iFTSTS completers who had exactly 5 sit-to-stand and exactly 5 stand-to-sit transitions detected: n = 38 (73.1%)			

Note. Participants in the grey area completed the FTSTS (all 5 required sit-to-stand repetitions), but had less than 50% of the sit-to-stand transitions or stand-to-sit transitions successfully detected by the Mobility Lab™.

3.3.3 *Descriptive Statistics*

Descriptive statistics of functional mobility, physical functioning, and caregiving time measures are summarized in Table 3.17 below.

Table 3.17. Descriptive Statistics of Functional Mobility, Physical Functioning, and Caregiving Time Measures

Variable Measure	**n**	**Mean (SD) or %**	**Median**	**Range**
Functional Mobility				
Timed FTSTS				
Total duration, seconds	59	17.43 (5.46)	16.56	8.5 - 34.05
iFTSTS				
Total duration, seconds	38	18.23 (5.6)	17.47	9.59 - 35.65
Mean SitSt duration, seconds	47	1.24 (0.28)	1.25	0.69 - 1.75
Mean StSit duration, seconds	50	0.91 (0.25)	0.87	0.61 - 2.14
Mean SitSt lean angle, seconds	46	30.26 (10.47)	29.18	12.23 - 48.79
Mean StSit lean angle, seconds	49	26.17 (11.07)	24.67	7.19 - 54.11
Physical Functioning				
SF-36 Physical functioning (transformed score)				
Whole sample	83	49.8 (29.3)	50	0 - 100
FTSTS completers	59	60.5 (26.8)	65	0 - 100
(iFTSTS completers)	52	57.9 (26.4)	62.5	0 - 100
FTSTS non-completers	24	23.5 (15.00)	20	0 - 50
Caregiving Time				
RUD-Lite: basic activity caregiving time, minutes/day				
Whole sample	83	43.6 (72.1)	9.6	0 - 360
FTSTS completers	59	25.8 (48.3)	9.6	0 - 300
(iFTSTS completers)	52	27.7 (51.1)	7.2	0 - 360
FTSTS non-completers	24	87.45 (99.2)	60.0	0 - 300

Notes. a. SitSt = Sit-to-stand. StSit = Stand-to-sit.

3.3.4 *Hypothesis 1: Association between PWD Functional Mobility and Caregiver-Reported Physical Functioning in PWDs*

As a group, FTSTS completers had significantly higher caregiver-reported PWD physical functioning when compared to FTSTS non-completers, both before ($p < 0.001$) and after adjusting for participant sex and MMSE ($p < 0.001$). Among FTSTS completers, total duration to complete the FTSTS (manually timed with a stopwatch) was significantly associated with caregiver-reported physical functioning both before ($p < 0.001$) and after adjusting for participant sex and MMSE ($p < 0.001$). Among iFTSTS completers, iFTSTS total duration, iFTSTS mean sit-to-stand duration, and iFTSTS mean stand-to-sit duration were all significantly associated with caregiver-reported physical functioning, both before and after adjusting for participant sex and MMSE (See Table 3.18). On the contrary, iFTSTS mean sit-to-stand lean angle and iFTSTS mean stand-to-sit lean angle showed no significant associations with caregiver-reported physical functioning both before and after adjusting for participant sex and MMSE.

Table 3.18. Association between PWD Functional Mobility and Caregiver-Reported Physical Functioning in PWDs.

	Original Model (Physical functioning = β_0 + β_1*functional mobility variable)				**After adjusting for covariates[a]**			
Functional Mobility Variable	Coefficient β_1	95% confidence interval	p-value	n	Coefficient β_1	95% confidence interval	p-value	n
FTSTS[b] (completers[c] vs. non-completers[d])	39.13	26.906 ~ 51.360	< 0.001	83	37.54	25.435 ~ 49.653	< 0.001	83
FTSTS total duration	-2.53	-3.729 ~ -1.332	< 0.001	59	-2.71	-3.973 ~ -1.463	< 0.001	59
iFTSTS[e] total duration	-2.15	-3.591 ~ -0.702	0.005	38	-2.70	-4.228 ~ -1.170	0.001	38
iFTSTS mean SitSt[f] duration	-35.62	-64.509 ~ -6.726	0.017	47	-35.69	-65.54 ~ -5.858	0.02	47
iFTSTS mean StSit[g] duration	-31.85	-61.607 ~ -2.093	0.036	50	-33.44	-65.965 ~ -0.912	0.044	50
iFTSTS mean SitSt lean angle	-0.51	-1.321 ~ 0.297	0.209	46	-0.60	-1.464 ~ 0.260	0.166	46
iFTSTS mean StSit lean angle	-0.035	-0.774 ~ 0.704	0.924	49	-0.143	-0.962 ~ 0.677	0.728	49

Note. a. Covariates = sex and the Mini Mental State Examination score. b. FTSTS = Standard timed five-time-sit-to-stand test. c. Completers = Those who successfully completed five sit-to-stand repetitions in a row without using arms. d. Non-completers = Those who were unable to complete five sit-to-stand repetitions in a row without using arms. e. iFTSTS = Instrumented five-time sit-to-stand test. f. SitSt = Sit-to-stand g. StSit = Stand-to-sit.

3.3.5 *Hypothesis 2: Association between Caregiver-Reported PWD Physical Functioning and Caregiver-Reported Caregiving Time Spent Assisting in ADLs*

Caregiver-reported PWD physical functioning was significantly associated with caregiver-reported caregiving time spent on assisting PWDs with ADLs, both before ($p < 0.001$) and after adjusting for caregivers' age, sex, level of caregiving contribution, number of additional caregivers, and relationship with the PWD (e.g. spouse, relative, etc.; $p = 0.002$). See Table 3.19 for details.

Table 3.19. Association between Caregiver-Reported PWD Physical Functioning and Caregiver-Reported Caregiving Time Spent Assisting in ADLs

	Original Model ($CT^a = \beta_0 + \beta_1$*physical functioning variable)				**After adjusting for covariates[b]**			
Physical Functioning Variable	Coefficient β_1	95% confidence interval	p-value	n	Coefficient β_1	95% confidence interval	p-value	n
SF-36 physical functioning	-0.49	-0.748 ~ -0.904	< 0.001	83	-0.47	-0.758 ~ - 0.190	0.001	83

Notes. a. CT = Caregiving time spent on helping participants with basic activities of daily living. Covariates = Caregiver age, sex, level of caregiving contribution, number of additional caregivers, and relationship with the participant (e.g. spouse, relative, etc.)

3.3.6 *Hypothesis 3: Association between PWD Functional Mobility and Caregiver-Reported Caregiving Time Spent Assisting in ADLs*

On average, caregivers of FTSTS completers reported less caregiving time spent on assisting their care recipient with ADLs when compared to caregivers of FTSTS non-completers, both before ($p = 0.001$) and after adjusting for participant sex and MMSE ($p = 0.001$). No significant associations were found between caregiver-reported caregiving time spent on assisting PWDs with ADLs and the remaining parameters, both before and after adjusting for participant sex and MMSE, except for the iFTSTS mean stand-to-sit duration. iFTSTS mean stand-to-sit duration showed no significant association with caregiver-reported caregiving time spent in assisting ADLs before adjusting for participant sex and MMSE, but the association became highly significant after adjusting for these covariates ($p < 0.001$).

Table 3.20. Association between Functional Mobility and Caregiving Time Spent on Assisting PWDs with ADLs

	Original Model ($CT^a = \beta_0 + \beta_1$*functional mobility variable)				**After adjusting for covariates[b]**			
Functional Mobility Variable	Coefficient β_1	95% confidence interval	p-value	n	Coefficient β_1	95% confidence interval	p-value	n
FTSTS[c] (completers[d] vs. non-completers[e])	-14.65	-23.411 ~ -5.889	0.001	83	-24.77	-39.551 ~ -9.990	0.001	83
FTSTS total duration	0.20	-0.336 ~ 0.740	0.456	59	0.13	-0.327 ~ 0.578	0.580	59
iFTSTS[f] total duration	0.33	-0.252 ~ 0.904	0.260	38	0.17	-0.426 ~ 0.774	0.560	38
iFTSTS mean SitSt[g] duration	4.00	-4.951 ~ 12.945	0.373	47	5.13	-4.753 ~ 15.009	0.301	47
iFTSTS mean StSit[h] duration	0.54	-8.507 ~ 9.587	0.905	50	28.66	16.079 ~ 41.234	< 0.001	50
iFTSTS mean SitSt lean angle	-0.05	-0.341 ~ 2.333	0.705	46	0.08	-0.211 ~ 0.381	0.565	46
iFTSTS mean StSit lean angle	-0.04	-0.252 ~ 0.179	0.736	49	0.208	-0.052 ~ 0.469	0.114	49

Notes. a. CT = Caregiving time spent on helping participants with basic activities of daily living tasks. b. Covariates = sex and the Mini Mental State Examination score. c. FTSTS = The five-time-sit-to-stand test. d. Completers = Those who successfully completed five sit-to-stand repetitions in a row without using arms. e. Non-completers = Those who were unable to complete five sit-to-stand repetitions in a row without using arms. f. iFTSTS = Instrumented five-time sit-to-stand test. g. SitSt = Sit-to-stand. h. StSit = Stand-to-sit.

3.4 Discussion and Implications

This study examined the associations between PWDs' functional mobility as measured by the FTSTS and the iFTSTS, caregiver-reported PWD physical functioning, and caregiver-reported caregiving time spent on assisting PWDs with ADLs. The FTSTS refers to the standard timed physical performance test that measures the total time taken (seconds) to complete five sit-to-stand repetitions without using arms as quickly as possible from an 18" high standard chair (a human assessor times the total duration with a stopwatch). The iFTSTS refers to the additional objective, quantitative FTSTS subtask parameters obtained by a portable, inertial sensor-based

human motion monitoring system (APDM Mobility Lab™) during the administration of the standard timed FTSTS. The subtask parameters are iFTSTS total duration, iFTSTS mean sit-to-stand duration, iFTSTS mean stand-to-sit duration, iFTSTS mean sit-to-stand lean angle, and iFTSTS mean stand-to-sit lean angle. In what follows, the author will first discuss the three hypotheses specified in the introduction of this paper, with functional mobility measured by the standard timed FTSTS, and then proceed to discuss each of the iFTSTS parameters. The author will close with implications for policy, practice, and research.

3.4.1 *Hypothesis 1: Higher PWD Functional Mobility is Associated with Higher Caregiver-Reported PWD Physical Functioning*

In this study, caregiver-reported PWD physical functioning was measured with the SF-36 physical functioning subscale transformed score (a higher score indicates better physical functioning). As expected, PWDs who were able to complete the FTSTS (higher functional mobility) had significantly higher caregiver-reported physical functioning scores than those who were unable to complete the test. Also, among FTSTS completers, a shorter FTSTS total time (higher functional mobility) was significantly associated with higher caregiver-reported PWD physical functioning score. These associations remained significant both before and after adjusting for participants' sex and MMSE score. These findings confirmed the first hypothesis—higher PWD functional mobility is associated with higher caregiver-reported PWD physical functioning.

In this study, the mean SF-36 physical functioning transformed score is 49.8, which is lower than the mean score of 64.8 reported by Geschke et al. (2013), derived from a sample of 60 older adults with dementia (mean age: 78.7 years; MMSE mean: 20.2; MMSE range: 5 - 27). Possible explanations for the lower mean SF-36 physical functioning transformed score in this

study include: (1) this study used the caregiver-reported score while Gescheke et al. used PWDs' self-reported score (caregivers might perceive PWDs' physical functioning differently from how PWDs perceive their own physical functioning); and (2) participants in this study are older (mean age: 80.1 years) and have more advanced cognitive impairment (MMSE mean: 16.5; range: 1 -29) than the sample of older adults with dementia in Geschke et al.'s study.

3.4.2 *Hypothesis 2: Higher Caregiver-Reported PWD Physical Functioning is Associated with Shorter Caregiver-Reported ADLs Caregiving Time*

The results of this study confirmed the hypothesis that higher caregiver-reported PWD physical functioning is associated with shorter caregiver-reported ADLs caregiving time, with and without taking into consideration caregivers' age, sex, level of caregiving contribution, number of additional caregivers, and relationship with the PWD (e.g. spouse, friend, etc.). On average, the ADLs caregiving time reported by caregivers in this study was 43.6 minutes per day, which was much lower than what was reported in the RUD instrument validation study (Wimo et al., 2010) in community-living PWDs. In the validation study, the mean ADLs caregiving time was 70.6 minutes per day. The shorter mean caregiver-reported ADLs caregiving time in this study may be explained by the differences in PWD and caregiver characteristics between this study and the validation study. For example, in this study (1) the ratio of male and female PWDs was nearly equal and (2) the caregivers were on average 12 years younger than their care recipient, while in the validation study, (1) more than 85% of PWDs were male and (2) the caregivers were on average only 3 years younger than their care recipient. Additionally, in the validation study, all caregivers (100%) reported that their caregiving contribution was 81-100% of the total caregiving time received by their care recipient, whereas in our study, about 4 out of every 5 caregivers (81.9%) stated that their contribution was at the 81-100% level.

3.4.3 *Hypothesis 3: Higher PWD Functional Mobility is Associated with Shorter Caregiver-Reported ADLs Caregiving Time*

As hypothesized, results of this study showed that caregivers of FTSTS completers (higher functional mobility) reported shorter ADLs caregiving time compared to caregivers of FTSTS non-completers, both before and after adjusting for participants' sex and MMSE score. On the other hand, the hypothesis was not supported among the FTSTS completers (the higher functional mobility subgroup). Among the FTSTS completers, the FTSTS total time (higher functional mobility) was not significantly associated with ADLs caregiving time, both with and without adjusting for participants' sex and MMSE score, except for mean stand-to-sit duration. These results indicate that (1) a PWD's inability to complete the FTSTS may be a good indicator of the PWD's needs for additional ADLs caregiving time; and (2) the FTSTS total time may not be sensitive enough to distinguish the subtler difference in ADLs caregiving time needs among PWDs with higher functional mobility, or alternatively, PWDs with higher functional mobility may have minimum needs for ADLs assistance (ceiling effect).

3.4.4 *iFTSTS Parameters*

iFTSTS total duration.

A recent study conducted by van Lummel et al. (2016) suggested that in an older adult sample (age> 64 years; MMSE >18), the FTSTS total duration recorded manually using a stopwatch was not associated with functional status measured by the physical function index of the RAND-36 ($p = 0.055$), whereas the FTSTS total duration recorded by an inertial sensor system (DynaPort Hybrid, McRoberts, The Hague, The Netherlands) was ($p = 0.009$). In the current study, on the contrary, all relationship patterns among iFTSTS total time, caregiver-reported PWD physical functioning (measured by the SF-36 physical functioning subscale), and caregiver-reported

ADLs caregiving time mirrored the relationship patterns among FTSTS total time, caregiver-reported PWD physical functioning, and caregiver-reported ADLs caregiving time (i.e. when FTSTS total duration had a significant association with a variable, iFTSTS total duration also had a significant association with the same variable; vice versa), suggesting that FTSTS total duration and iFTSTS total duration likely measure the same functional mobility concept in the current study (construct validity). The discrepancy in results between the current study and van Lummel et al.'s study may result from differences in (1) the participant population, (2) the scoring method of the functional status measure, (3) the FTSTS protocol used, and (4) the inertial sensor systems. The current study's participants were older adults with mild to severe dementia (MMSE range 1 – 29), whereas van Lummel et al.'s participants were older adults with mild to no cognitive impairment (MMSE score > 18). Even though the SF-36 physical functioning subscale and RAND-36 physical function index share exactly the same survey items, the scoring methods are different. Lastly, the current study instructed participants to end the test on a sitting position after the 5th sit-to-stand repetition (5 full sit-to-stand cycles) and used 5 full sit-to-stand cycles to calculate the total duration for both the standard timed test and the iFTSTS, whereas van Lummel et al. (1) instructed the participants to end the test on a standing position after standing up for the 5th time (4.5 sit-to-stand cycles) and (2) used the 4.5 cycles completed to calculate the stopwatch-based FTSTS total duration while used only the first 4 completed cycles to calculate the sensor-based FTSTS total duration. According to van Lummel et al., they used only the first 4 completed cycles to calculate the sensor-based total duration because "draft correction of the raw signals is easier when the sensors end in the same position as they started". The different number of sit-to-stand cycles van Lummel et al. used to calculate the total duration of the standard timed test and the sensor-based version may result in the difference in the

statistical significance they found, especially the non-significant p-value they found for the standard timed test was approaching significance at 0.055. Finally, the inertial sensor system used in this current study was Mobility Lab™ (APDM, Inc., Portland, OR, USA), whereas the inertial sensor system used by van Lummel et al. was DynaPort® Hybrid (McRoberts, The Hague, The Netherlands).

Mean sit-to-stand duration and mean stand-to-sit duration.

Results of the current study showed that among iFTSTS completers, PWDs who had either a longer mean sit-to-stand duration, or a longer mean stand-to-sit duration, had lower caregiver-reported PWD physical functioning, both before and after adjusting for participant sex and MMSE. Similarly, van Lummel et al.'s (2016) also found that in an older adult sample, (1) those in the "fast" sit-to-stand duration group (dichotomised using a median split) had significantly higher self-reported physical functioning, compare to those in the "slow" sit-to-stand duration group; and (2) those in the "fast" stand-to-sit duration group also had significantly higher self-reported physical functioning, compare to those in the "slow" stand-to-sit duration group.

On the contrary, results of the current study showed that neither the mean sit-to-stand duration or the mean stand-to-sit duration were associated with caregiver-reported ADLs caregiving time among iFTSTS completers. A possible explanation is that since this group of people was able to complete the FTSTS (higher functional mobility), they had minimum needs for ADLs assistance. Therefore, their mean sit-to-stand duration or mean stand-to-sit duration would not have much effect on their needs for ADLs assistance (ceiling effect). After adjusting for participant sex and MMSE, however, the association between mean stand-to-sit duration and ADLs caregiving time became highly significant ($p < 0.001$), whereas the association between mean sit-to-stand duration and ADLs caregiving time remained non-significant ($p = 0.301$).

Future research is needed to understand how and why participant sex and MMSE affect the association between mean stand-to-sit duration and their caregiver reported ADLs caregiving time, but not the association between mean sit-to-stand duration and their caregiver-reported ADLs caregiving time.

Mean sit-to-stand lean angle and mean stand-to-sit lean angle.

Results of this study showed no significant associations between mean sit-to-stand lean angle and (1) caregiver-reported PWD physical functioning and (2) caregiver-reported ADLs caregiving time, before and after adjusting for participant sex and MMSE. Similarly, no significant associations between mean stand-to-sit lean angle and (1) caregiver-reported PWD physical functioning and (2) caregiver-reported ADLs caregiving time were found, before and after adjusting for participant sex and MMSE. This suggests that lean angle parameters may not be independent predictors of caregiver-reported PWD physical functioning and caregiver-reported ADLs caregiving time. However, future research should examine if there is a synergic effect on predicting caregiver-reported PWD physical functioning and caregiver-reported ADLs caregiving time if lean angle parameters and mean sub-duration parameters (e.g. sit-to-stand duration) are combined.

3.4.5 *Limitations and Strengths*

There are several limitations of this study. First, the relatively small sample size did not provide statistical power to control for all potential confounders (e.g. whether participants had paid caregivers to take care of their ADLs, whether their primary caregiver worked, etc.). Second, iFTSTS only provided meaningful data for iFTSTS completers. Therefore, it was not possible to examine iFTSTS parameters in non-completers. Finally, due to the cross-sectional nature of this study, the associations found among variables should be interpreted with caution. Future

longitudinal investigations of these associations are needed to determine whether these relationships are causal.

Despite these limitations, there are unique strengths of this study. First, the data source was a rigorously designed intervention trial. The rigorous research protocol ensured minimum missing data. The pragmatic nature of the trial required fewer inclusion/exclusion criteria, which increased the generalizability of findings of this current study. For example, since PWDs with mild to severe dementia (MMSE range: 1-29) were included, the results of this study would be generalizable to people with mild to severe cognitive impairment instead of just mild dementia or moderate dementia. Second, all measures utilized to test the three main hypotheses of this study, FTSTS, SF-36, and RUD Lite, have been validated with PWDs. Finally, to the author's knowledge, this is the first study that (1) examined the interrelationships among PWDs' functional mobility, caregiver-reported physical functioning, and caregiver-reported caregiving time spent on assisting PWDs with ADLs, and (2) the first to explore associations between FTSTS subtasks measured by inertial sensors in PWDs with these caregiver-reported variables.

3.4.6 *Conclusion and Implications*

In this study, the following was confirmed. First, higher functional mobility in PWDs is associated with higher caregiver-reported PWD physical functioning. Second, higher caregiver-reported PWD physical functioning is associated with shorter caregiver-reported ADLs caregiving time. Third, higher PWD functional mobility is associated with shorter caregiver-reported ADLs caregiving time. Finally, iFTSTS duration parameters—total duration, mean sit-to-stand duration and mean stand-to-sit duration—are all associated with caregiver-reported PWD physical functioning (for each of these parameters, longer durations are associated with lower caregiver reported physical functioning).

Implications for policy makers are that (1) since higher PWD functional mobility is associated with shorter caregiver-reported caregiving time spent on assisting PWDs with ADLs, improving PWD functional mobility may reduce dementia caregiving time spent assisting in ADLs and consequently reduce dementia caregiving costs; and (2) it may be possible to estimate the potential "savings" from preserving/improving PWDs' functional mobility through assessing PWDs' functional mobility using a simple chair stand test. For example, based on findings of this study, PWDs who completed FTSTS required approximately 15 minutes less ADLs caregiving time on a typical day compared to those who were unable to complete the test. If we apply the same rate of $12.65/hour used to calculate informal caregiving costs in *2017 Alzheimer's Disease Facts and Figures* (Alzheimer's Association, 2017), then preserving a PWD's ability to perform FTSTS for a year will lead to a "saving" of $1,154/year (i.e. 15 minutes/60 minutes * $12.65/hour * 365 days= $ 1,154.3). However, the actual "cost-savings" will depend on the "cost" of the method(s) used to improve or preserve the PWD's functional mobility (i.e. cost-savings = savings minus the cost). Additionally, the association between PWD functional mobility and caregiver-reported ADLs caregiving time found in this study needs to be confirmed in larger, longitudinal studies with representative dementia samples (to determine whether the relationship is causal).

An important implication for practitioners is that since iFTSTS subtask durations (e.g. mean sit-to-stand duration) in PWDs are associated with caregiver-reported PWD physical functioning, incorporating these objective, quantitative subtask parameters in clinical practice may help practitioners more precisely evaluate not only the effect of exercise and rehabilitation interventions on PWDs functional mobility, but also the effect of changes in these subtask parameters on caregiver-reported PWD physical functioning. The implications for future

research include: (1) larger, well-designed longitudinal studies are needed to confirm whether the associations identified in this study are causal (e.g. When PWDs' functional mobility improves after an exercise intervention, do their caregiver also report higher PWD physical functioning and shorter ADLs caregiving time after the intervention?); (2) participant sex and dementia severity seem to affect the association between PWD mean stand-to-sit duration and caregiver-reported ADLs caregiving time (the association became significant after adjusting for participant sex and MMSE), the mechanism under which needs to be explored further; (3) even though sensor-based lean angle parameters in PWDs seem not be associated with caregiver-reported PWD physical functioning and caregiver-reported dementia caregiving time spent assisting in ADLs, future research should evaluate whether these parameters produce synergic effects when combined with the mean duration subtask parameters; and (4) since the iFTSTS protocol used in the current study only provided meaningful iFTSTS parameters for those who were able to complete the FTSTS, future studies intended to investigate the subcomponents of body movement during a repeated chair stand test should consider other alternative chair stand tests, such as the 30-second chair stand test, to allow inclusion of PWDs with lower functional mobility (e.g. someone who could only perform 1 or 2 chair stands).

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Chapter 4. CONCLUSION

In this dissertation, the author evaluated (1) the concurrent validity of an instrumented five-time sit-to-stand test in older adults with mild cognitive impairment (MCI) and mild dementia, (2) the test-retest reliability of the instrumented five-time sit-to-stand test in people with mild to severe dementia, and (3) associations between functional mobility (measured by both the standard five-time sit-to-stand test and the instrumented version) in persons with dementia (PWDs), caregiver-reported physical functioning in PWDs, and caregiver-reported dementia caregiving time spent on assisting PWDs with activities of daily living (ADLs). "Instrumentation" refers to participants wearing a portable inertial sensor system, APDM Mobility Lab™, throughout the administration of the five-time sit-to-stand test. In this dissertation, the standard timed five-time sit-to-stand test is referred to as "FTSTS" and the instrumented version of the test is referred to as "iFTSTS". The Mobility Lab™ software automatically processes and outputs the following iFTSTS parameters: iFTSTS total duration, iFTSTS mean sit-to-stand duration, iFTSTS mean stand-to-sit duration, iFTSTS mean sit-to-stand lean angle, and iFTSTS mean stand-to-sit lean angle.

To evaluate the concurrent validity of iFTSTS parameters, the author analyzed the baseline data of a cohort study with older adults with MCI and mild dementia (primary analysis). The baseline data included two assessment sessions scheduled between several days to several weeks apart. The first assessment session occurred at participants' home, with the Mobility Lab™ only. The second assessment session occurred at the University of Washington Rehabilitation Medicine human motion analysis lab. During the lab-based assessment, participants' data were collected simultaneously with the Mobility Lab™ and with a laboratory-based human motion analysis system, Qualisys Motion Capture System. The author uses the term "home iFTSTS" to refer to iFTSTS measures collected at participants' home, the term "lab

iFTSTS" to refer to iFTSTS measures collected in the human motion analysis lab, and the term "Qualisys FTSTS" to refer to FTSTS measures collected by the Qualisys Motion Capture system in the human motion analysis lab. The analysis results showed significant, high to very high correlations between all lab iFTSTS parameters and corresponding Qualisys FTSTS parameters. In contrast, only three out of the five iFTSTS parameters (total time, mean sit-to-stand duration, mean stand-to-sit duration) had a significant correlation with their corresponding Qualisys FTSTS parameters. Based on these findings, the author concludes that iFTSTS parameters' concurrent validity between lab iFTSTS parameters and Qualisys FTSTS parameters collected simultaneously is supported, whereas the concurrent validity between home iFTSTS parameters and Qualisys FTSTS is not fully supported. Future research should consider schedule the two assessments within shorter lengths of time apart (e.g. the next day at the same time).

To evaluate test-retest reliability of iFTSTS parameters, the author analyzed the baseline and pre-intervention assessments in a sample of older adults with mild to severe dementia who participated in a home-based exercise intervention study (secondary analysis). The baseline and the pre-intervention assessments were administered 1 month apart. The test-retest reliability was in the fair to good range across iFTSTS parameters. Future studies should schedule the test and the retest closer in time to rule out the possibility that natural functional declines had occurred.

To examine the associations between functional mobility in PWDs, caregiver-reported PWD physical functioning, and caregiver-reported caregiving time spent on assisting PWDs with ADLs, the author analyzed the baseline data of a home-based exercise intervention study with people with mild to severe dementia (secondary analysis). The associations between PWD functional mobility, caregiver-reported PWD physical functioning, and caregiver-reported dementia caregiving time spent in assisting ADLs were confirmed when functional mobility was

measured by participants' ability to complete the FTSTS (FTSTS completers vs. FTSTS non-completers). In contrast, even though some of the iFTSTS parameters (i.e. total duration, mean sit-to-stand duration, mean stand-to-sit duration) were significantly associated with the participants' physical functioning reported by their caregivers, no iFTSTS parameters were associated with dementia caregiving time spent in assisting ADLs. A possible explanation is the ceiling effect since iFTSTS parameters were only collected for participants who were able to complete the FTSTS (the ability to complete the FTSTS indicates higher functional mobility; participants with higher functional mobility might not need help with ADLs).

In summary, concurrent validity of lab iFTSTS is supported by the analysis results reported in this dissertation. The test-retest reliability may be improved if the test and retest were scheduled close in time. Lastly, analysis results in this dissertation confirmed that (1) higher functional mobility (measured by the ability to complete FTSTS, FTSTS total time, iFTSTS total time, iFTSTS sit-to-stand duration, and iFTSTS stand-to-sit duration) is associated with better caregiver-reported PWD physical functioning; (2) higher physical functioning is associated with shorter caregiver-reported dementia caregiving time spent in assisting ADLs; and (3) higher functional mobility (measured by the ability to complete FTSTS) is associated with shorter caregiver-reported caregiving time spent in assisting ADLs.

VITA

The author of this dissertation, Shih-Yin Lin, was originally from Taiwan. She moved to the United States to study Music Therapy in 2005. She graduated from the Michigan State University with her Master's degree in Music Therapy in December 2008. Between 2009 and 2013, she worked as a music therapist and clinical supervisor in Denver, CO, mainly providing music therapy services to older adults with dementia in private homes, adult day centers, assisted living facilities, and nursing homes. Over the years working with seniors with dementia, she developed a strong desire to make a difference in their lives on a larger scale and began searching for means to fulfill this calling. She was introduced to her dissertation chair, Basia Belza, PhD, RN, FAAN, at UW School of Nursing through a colleague in 2012. With Dr. Belza's encouragement, she decided that becoming a nursing scientist would bring her a step closer to fulfill her calling. She applied and was accepted into the PhD in Nursing Science program at UW in 2013 and began her concurrent Master of Public Health degree program at UW in 2015.